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Toledo, Ohio

The American Scientific Glassblowers Society
1507 Hagley Road
Toledo, Ohio 43612
Phone: (419) 476-5478

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CONTENTS

The Manufacture of the 40 x 50 mm Micro Channel Plates 1
Daniel J. Baker

Technical Posters for the A.S.G.S. 11
Edwin A. Powell

Grinding Techniques for Optical Applications 13
William H. Shoup

Ultraviolet (U. V.) Curing Adhesive 27
Joel M. Babbit

"The ASTM-NBS Standard Reference Material Programs for Glass" 29
Henry E. Hagy

The Design of the Small – Medium Glassblowing Workshop 34
John C. Penno

Apparatus: for Chemical Processing: Absorption, Distillation (Rectification) and Extraction 42
Karl Heinz Liedel

Multiple Windowed Quartz Cell 50
Robert J. Ponton

"Glassing and Assembly of a Five Watt Continuous Wave Magnetron" 53
Raymond F. Steiner

"Surface Sealing of Sintered Discs in Flat Flanges" 59
A. Stuart

You Can Host a Section Meeting 63
A. Ben Seal

A Survey of Asbestos Substitutes 66
Michael Olsen

How to Make Notched and Beveled Thin Layer Chromotography Plates on a Cut Off Machine 70
Allan B. Brown

The Revival of the Glass Harmonica: From a Scientific Glassblower's Perspective 71
Gerhard Finkenbeiner *Vera Meyer*

Members in Attendance 79

Non-Members in Attendance 87

Day Card 88

Exhibits Only 88

THE MANUFACTURE OF THE 40 x 50 mm MICRO CHANNEL PLATES

As presented by **Daniel J. Baker**
Varian Associates
Palo Alto, California

INTRODUCTION

As an employee of Varian Associates in Palo Alto, California, I am gratified at this occasion to present the manufacture of the 40 x 50 (millimeter) rectangular micro channel plates.

Since 1967 Varian has been in the field of channel multiplier devices and image tubes.

In 1979 at the Detroit symposium a technical paper was presented by John T. Balkwill, also of Varian Associates in Palo Alto, on the fabrication, operation, and applications of circular micro channel plates.

The rectangular configuration of the micro channel plates in this presentation, in contrast to the circular micro channel plates, requires the efforts of a glassblower to a greater degree, particularly in the preparation of the boule.

Micro channel plates are utilized in vacuum tubes; primarily in image intensifier tubes. A photo cathode is at the input end of the tube. The micro channel plate is in the center with an electrical contact. A phosphor screen is at the output end of the tube. As light enters through the photo cathode, electrons are given off and enter the input side of the micro channel plate. As the electrons progress through the array of channels, a cascade effect takes place. This effect produces secondary electrons resulting in multiplier gain. The electrons from the multiplier MCP strike the phosphor screen and their energy is converted into amplified light. This multiplier gain can be controlled by varying the voltage across the plate.

The features of MCP are:

- Self saturating
- Low noise
- High speed
- Low power consumption
- High electron gain
- High resolution
- Ruggedness
- Small size

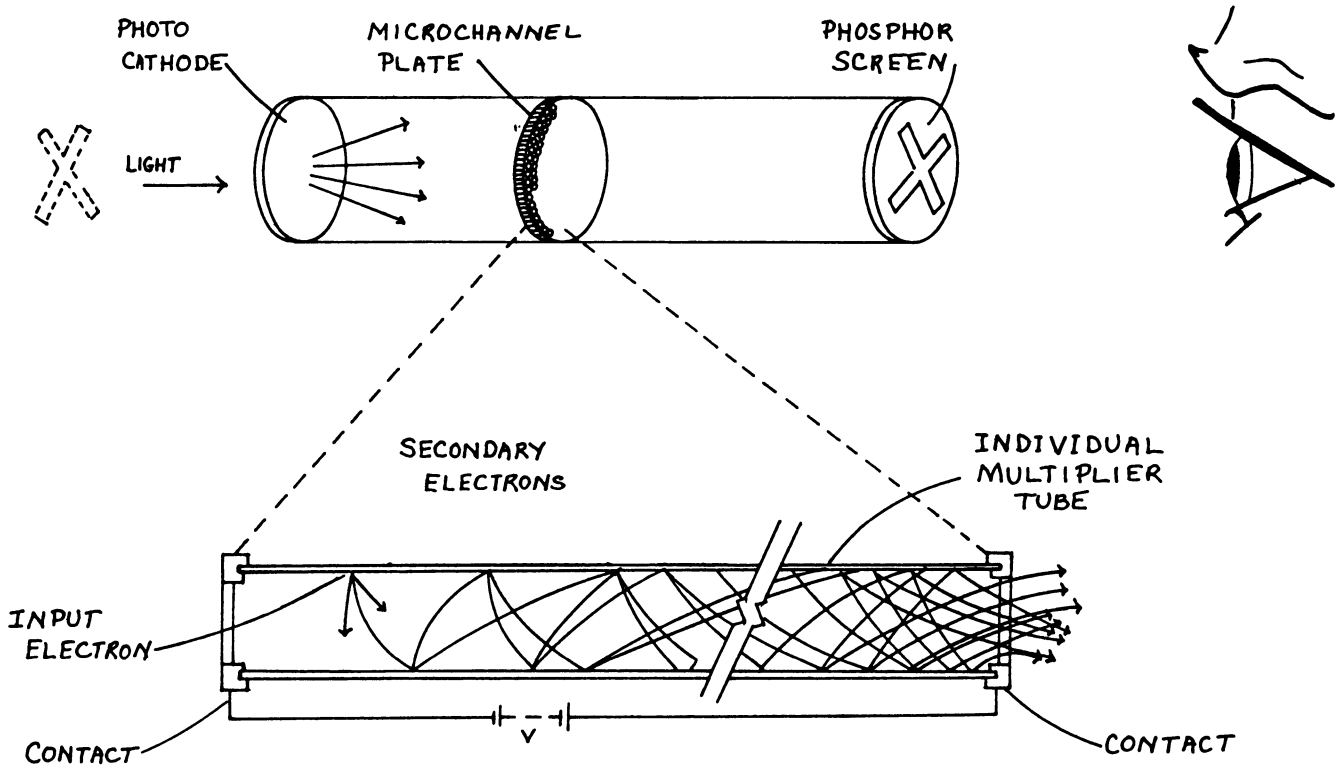
Some applications of micro channel plates are:

- Night surveillance
- Night warfare image intensifiers
- Low light television
- Low light photography
- Astronomy
- Electron microscopes
- Quantuum detectors
- Electron spectrometers for chemical analysis
- High speed oscilloscopes

The 40 x 50 mm MCP is used primarily in high speed oscilloscopes where the MCP provides the electron gain necessary to excite the phosphor screen; the faster the sweep, the highter electron gain required.

Single Fiber Draw

In the construction of the single draw fiber, a solid rod of lead glass is cleaned and polished. This polished rod is cut and notched so that a second identical rod will interlock from a vertical hanging position. When both rods are properly prepared, they will be lowered into a length of heavy wall lead glass tubing four feet long. This assembly will be loaded into a draw tower and the single fiber draw will take place. These single fibers will be drawn down, keeping in mind that the center of



PRINCIPLE OF OPERATION

the fiber will contain the core glass, surrounded by a cladding (See figure on page 4).

When a sufficient number of these single fibers have been drawn, they will be gauged for size and checked for flaws and cut to length.

Preparation for Multi-draws

A six sided carbon mold is now ready to receive the single draw fibers. The fibers are layered in perfect order, so many to each row, until the carbon mold is filled. A carbon top is carefully slid into position and the entire unit is placed into a tacking furnace.

This heating process will tack all the single fibers together without losing their configuration. This assembly is known as a tacked single.

Upon removal from the furnace, the tacked single, now a hex shaped single length of glass, is measured for thickness and uniformity. With this completed, the tacked single is then stored in a dry nitrogen cabinet and identified.

The tacked single is now ready for the multi draw tower. Each end of the tacked single is secured with a wrap of Nichrome wire. After loading the tacked single into the furnace the drawing process begins; hex shaped fibers will be drawn down. Keep in mind now that there are over two thousand channels in each fiber. These drawn fibers are now called multis. These multis will be gauged, checked for flaws and cut to length (See figure on page 4).

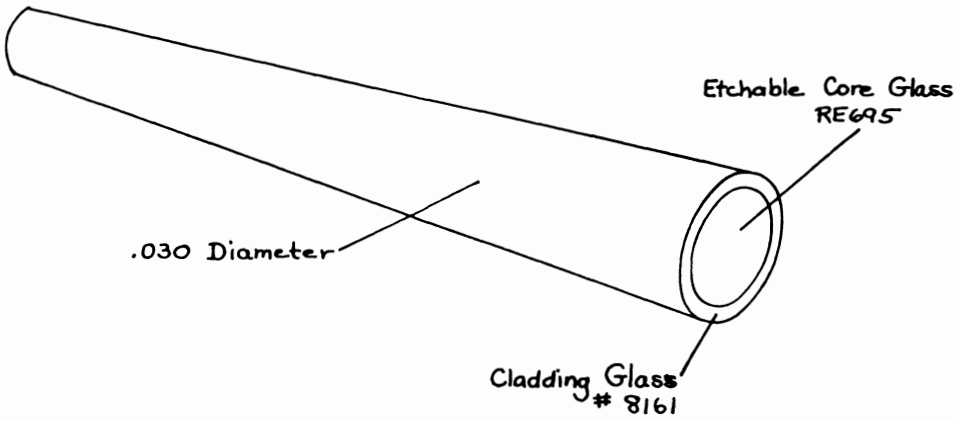
Boule Fabrication

The multi fibers must be arranged in a glass rectangular box. To construct the glass box, four sections of heavy wall tubing are selected. A cut-off saw with a diamond wheel is utilized to make a cut down one side of the entire length of the tubing. After cleaning, the glass tubes are then arranged in an oven. When the oven is turned on it is programmed to ramp up in segments. Upon reaching maximum temperature, the oven holds at that temperature, allowing the glass to lay out flat as possible. After the soak is completed, the temperature begins to decline until eventually falling to near room temperature. By heating up these glass tubes in temperature stages, the heat has time to permeate the thick wall of the tubing so that when it reaches the transformation point, the radiant heat from the bottom heating coils will flatten the glass from the bottom and allow the sides and top of the tubing to follow suit.

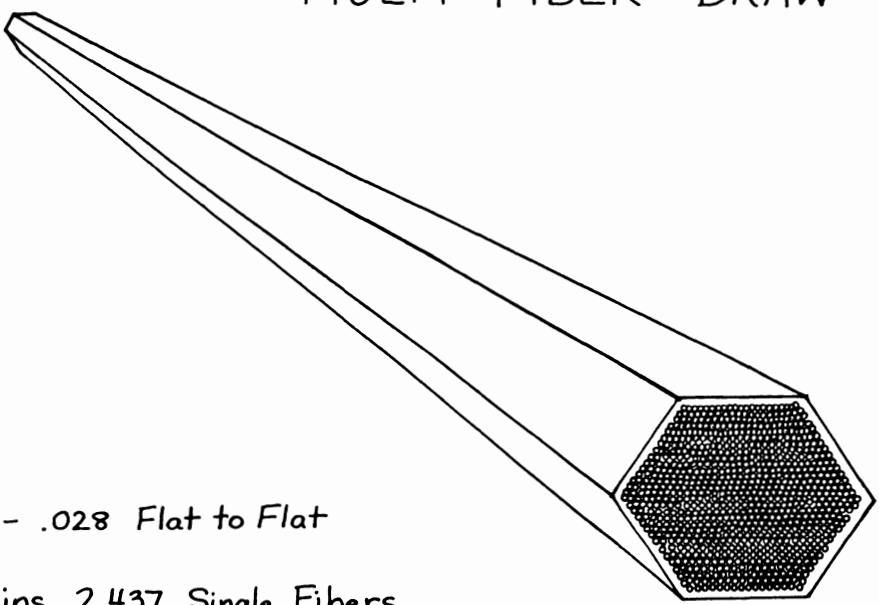
After flattening and cooling, the plates are cut on a diamond saw to just slightly more than the desired length and width. Two plates cut in half will yield the four sides necessary to make the glass box. Following the saw cutting, the four plates are lapped flat on both sides. The plates are then ground down to the proper length and width. The plates are then separated, cleaned and ready to fabricate into a rectangular box. Using binder and an artist paint brush, the edges are painted and fitted together, blocked and allowed to set. Only three sides of the box are constructed. The fourth side which is the top, is fitted into place after the proper number of multi fibers and solid border fibers have been placed in their proper positions. The fiber size will determine the inside dimensions of the box. These dimensions are regulated by the width of the top and bottom plates. The solid glass border is drawn down to the same size as the multi fibers, and is also hexagonal in order to maintain the geometry of the boule as it is being pressed.

The loading of the glass box will begin with a specified number of solid border fibers on the bottom. The multi-fibers are arranged to form the active area with solid border fibers on each side and on the top (see packing diagram on page 6).

SINGLE FIBER DRAW



MULTI-FIBER DRAW



Size - .028 Flat to Flat

Contains 2,437 Single Fibers

With the glass box loaded with the proper number of fibers, it is ready to be fitted into a glass tube. Since lead glass does not come readily in all diameter sizes, we make our own glass jacket. Care is taken to make glass tubing as parallel as possible. The rectangular box in the round tube will leave arch spaces on the sides which will be packed with scrap fibers, making the entire unit solid without any internal movement.

This assembly will now be encased in a slightly larger tube which will make up the outer jacket. This tube is made in the same manner as the tube housing the rectangular box. This outer jacket is then sealed to a metal boule stem. The composition of the metal boule stem allows us to seal directly to the glass because the co-efficient of expansion of the glass and the metal are quite similar. With the boule stem sealed to the outer jacket, and the prescribed cleaning completed, the inner jacket loaded with the glass box and packed fibers is placed carefully into the boule stem. The boule assembly will rest on two circular stainless steel screens on the bottom. On the top of this assembly two more screens are added and on top of the screens a glass cup is set into place ready for sealing.

A Dewar seal is performed. The boule assembly is chucked into place in the headstock where the blowing will be done. A carbon rod secured by the tailstock and lowered into position will hold the glass cup in place for sealing. The sealing operation then commences with care taken while warming into the assembly. The Dewar seal is sealed in the usual way of flaring out the inner tube to meet the diameter of the outer tube. Heat is applied to the joined area and the seal is worked out smooth.

A brief flame annealing follows the seal fabrication. The carbon rod in the tailstock is replaced by a 4 litre beaker which will serve as an oven for the sealed boule. As the beaker is being lowered into position over the sealed boule, it is simultaneously being warmed by a hand torch. When in place it is left to cool down slowly.

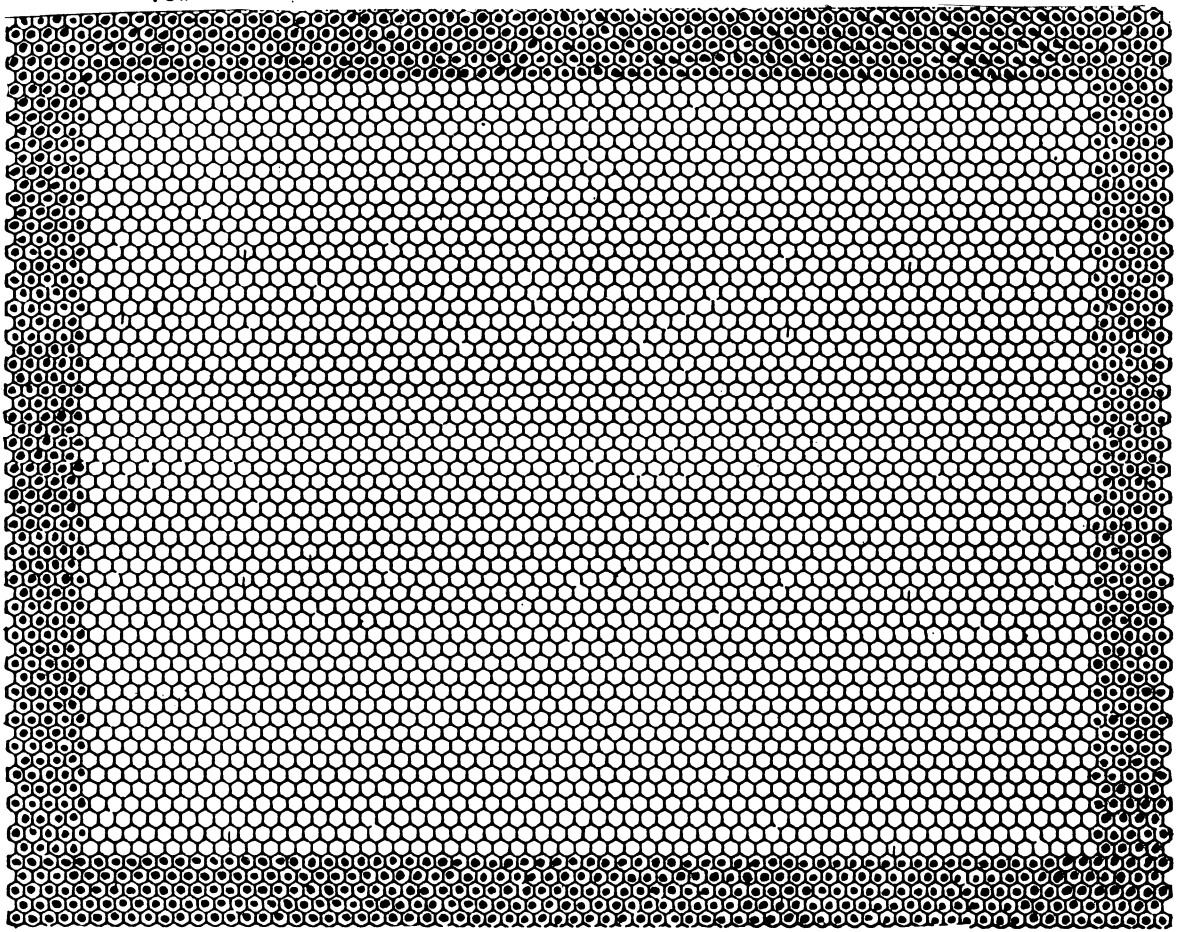
Pressing the Boule

This boule will be iso-statically pressed which means that heat, vacuum and pressure are applied to the boule during the pressing temperature period. When the boule has cooled, it is ready to be placed into a thick walled container known as a boule can. The boule can and contents are then set into a boule press. The boule can rests on three pancake heaters and is secured at the top of the stem. Thermocouples are contained in the boule can for recording internal temperature. With the boule secured into place, the thermocouples connected, the boule press door is secured and the top is packed with fiber frax to prevent heat loss. The pressing proceeds with an air bake to remove excess gas and impurities. Vacuum is applied and the temperature is graduated in stages. Accompanying the heat and vacuum is nitrogen pressure of one hundred fifty pounds which helps in pressing the entire boule assembly into a solid mass. The pressing stage completed, the temperature slowly lowers. The boule can is unloaded from the oven and boule is removed from the can. The boule is identified, tagged and set aside.

Acquiring the Rectangular Configuration

The pressed boule is circular. The first cutting operation is to saw off a quarter inch from each end using a diamond cut-off saw. For easier handling and better accuracy, the remaining length is cut in half and both ends of each half are lapped flat. After lapping, the outline of the regular box is easily identified with a light shining at one end of the boule. Using a straight edge and a pencil, the four outer edges of the glass box are marked off at each end. Also, linear lines are drawn the length of each half boule. These lines will mark the guides for cutting.

VUW 8951 (40x50) .0284"±.0001" MULTIS 15μ C.C 12 C.D



SOLID BORDER 8161

ACTIVE AREA CHANNEL DIA

ACTIVE AREA BEFORE PRESS
Includes some S.B

Tremendous care must be taken at this cutting stage. With the backstop on the saw aligned 90° to the diamond wheel and the ends lapped flat, the first cut is made along the previously marked lines. Any misalignment, mismarking, shifting or saw whip can drift the saw blade into the solid border area, thus creating instant scrap. Upon completion of the first cut, that particular surface is lapped level. With two level surfaces working for you, the second cut is made and that surface leveled. This is continued with the next two cuts resulting in a rectangular boule which is then lapped to size.

Boule Mount For Slicing

In preparation for slicing the boule, a notched graphite beam is required. A cutting spacer made of graphite is mounted on an aluminum mounting spacer. This assembly is then attached to the bias mounting fixture. This entire assembly is then loaded into the feeding table for slicing. An I.D. saw of the type which is commonly used to slice silicon chips is used to slice the boule. The boule is sliced at a bias angle.

Re-assemble and Final Lap

Since the slicing is done at a bias angle, the length or the long dimension of the boule will increase. As was previously mentioned, both boule halves had special lined markings on three sides. After the removal from the annealing oven, the plates are re-stacked by waxing together in the order in which they were sliced.

When the boule halves are re-stacked the assembly is placed on a hot plate. Care is taken to make sure the boule assembly is squared off as to corner alignments. The unit is blocked up securely with a small weight placed on top. A tent made of aluminum foil is placed over the unit to retain heat. The assembly is then removed from the hot plate and allowed to cool in the blocked up position.

With the boule set up and the blocks removed, the final lapping may commence. A final touch up with aluminum oxide and the boule is ready for heating on the hot plate for separation, cleaning with trichloroethane in an ultrasonic, placed in racks, identified and ready for beveling.

Bevel

Our bevel operation is normally accomplished on machines that can bevel various diameters of round micro channel plates. However, with a very limited number of rectangular plates in production, we are currently beveling by hand. This is achieved by mounting a specially designed aluminum fixture over a lapping wheel. This is a time consuming process due to the fact only one edge of one side can be beveled at a time. The beveling is accomplished by applying a slurry to the wheel and placing the plate up against the machined angle of the fixture, and sliding the plate horizontally back and forth as the wheel is turning. As one edge is beveled, the plate is turned over to bevel the other side of the same edge. This operation is repeated on each side of the other three ends as well as the corners. A microscope is utilized to check the uniformity of the bevel and the width of center track. Beveling is necessary in protecting the plates in subsequent operations, reducing cracking and chipping. Also, beveling is helpful, if not necessary, in the electroding process.

Polish

The polish process utilizes a planetary machine with polish pads on the upper and lower surfaces. The plates are mounted into carriers, top surface lowered into position, timer set and the unit turned on. When the plates are polished down to the desired thickness, they are rinsed and inspected under the microscope for slurry cracks and scratches. Following this, the plates are thoroughly washed in an

ultrasonic cleaner, rinsed, placed in racks and blown dry.

Chem-etch

The chemical etch operation is designed to etch out the core glass of all the fibers in the active area of the micro channel plate. This procedure involves a complex operation of which I will not go into detail. However, I will explain the goal and purpose of this process.

The goal is to remove the core glass from the active area leaving hexagonal cladding glass behind to form an even lattice pattern. Other achievements in the etch process are to leave no blocked channels which would inhibit viewing or to have no breakdown of the lattice-work walls.

The etch process itself is a function of time, temperature, acids, alkalines and rotating action as well as thorough rinsing. The rotating action which takes place in etch tanks produces uniform etch results. This is especially important since the plates were sliced at a bias angle.

The plates are removed from a cleaning rack and placed in a U-rack in a vertical attitude separated by spacers. The U-racks can be loaded into the lid assembly of the etch tank designed to hold the U-racks as well as a stir motor.

Wall erosion can occur to the core glass if any one of the etching procedure variables are out of order. The plates are then unloaded from the cleaning racks and moved to hydrogen firing.

Hydrogen Firing

The purpose of hydrogen firing is to reduce the lead in the micro channel plates. The firing of the plates transforms the clear micro channel plates to black. The reduction of the lead oxide produces a strip current across the plate, as well as a gain factor.

The function of time, temperature and rate of increase in temperature are essential. The rate of penetration of the hydrogen upon the plates is important in order to remove the water from the surface of the plates and not create any blistering from trapped moisture.

The firing fixtures are circular metal plates. With the 40 x 50 mm plates in place, rectangular frame weights are placed on top of the micro channel plates. These weights come in contact with the solid border area only and not in the active area. Each firing fixture with its ten plates can be stacked one upon the other in the firing furnace. After the firing a fast clean process is performed by placing the plates into the cleaning racks, ultrasonic rinsing and drying in a vacuum box where the plates will move on to the electroding process.

Electroding

Since micro channel plates are mounted into tubes with a phosphor screen, contain a photo cathode, are under vacuum and operate electrically, the electroding process is therefore a necessity.

By deposition of an alloy across the surface of both sides of the plate, an electrical conductivity is produced. The two surfaces of the micro channel plates are referred to as the input side and the output side. The input side is designated by a bias marker on the solid border area. The deposition of the alloy not only takes place across the two surfaces of the plate, but also gets into the channels. On the input side, deposition will occur one half a channel diameter in depth and on the output side, the depth of deposition will be one and a half to two channel diameters.

The electroding process is accomplished in a electroder involving time, temperature and vacuum. Electroding fixtures are mounted in a carousel in the top of the electroder. The fixtures are mounted at a specified angle for proper deposition of the alloy as the carousel rotates. When the proper vacuum and temperature are acquired, the deposition commences. With the desired thickness achieved, the electroder is allowed to cool down and the vacuum released. This process is repeated again in order to electrode the other side of the plates. After both sides have been electroded, the fixtures are removed. The plates are carfully removed from the fixture, visually inspected for over-electroding or peeling. The plates are placed into transfer racks and placed in a nitrogen cabinet ready for electrical test.

Electrical Test

With the electroding process accomplished, it is now possible to test the micro channel plates for several electrical characteristics. The testing is carried out in vacuum chambers known as test heads. The test heads have several windows enabling the operator to carry out visual testing as well as electronic testing from a console of equipment.

One of the traits which is checked for is "dark current". Dark current is that current which flows across the micro channel plate without any light input.

Another feature in electrical testing is the measure for gain. This is completed by measuring the intensity for the light-in versus the intensity of the light-out. Likewise, for the current-in versus the current-out. The photo cathode in the test head, when in operation, changes the light to electrons in measuring for the gain.

One other characteristic which is electrically tested for is "strip current". Strip current can be primarily defined as voltage across the micro channel plate. To determine the strip current a visual test for self-glow is executed with non-illumination and voltage across the tested plate. This can result in spots and other electronic noise patterns.

When a micro channel plate satisfies the measurements for strip current, and meets the criteria for dark current and for gain it is now ready for the final inspection.

Final Inspection

The final inspection is carried out under high powered microscopes. These microscopes are powerful enough to indicate if there is one blocked channel within the active area. The final inspection checks also for scuffs, scratches, blemishes and other physical damage due to handling.

As a micro channel plate passes the final inspection it is placed into a shipping container and transferred to shipping.

Conclusion

You have heard the various processes in the manufacture of the 40 x 50 mm micro channel plates. However, this article does not reveal the problems, pitfalls, and perplexities that can and do develop when producing a product such as this. A separate presentation alone could be given dealing with these difficulties.

Many variations exist in micro channel plates with regard to the size and configuration, as well as the size of the active area and solid border. Plate thickness, channel pitch, channel diameter and open area ratio are some of the capabilities performed to customer specifications. This demand for various designs along with new applications create an outlook for continued growth in the near and intermediate future.

ACKNOWLEDGEMENTS

Very little or no written material was specifically available in preparing this particular presentation. The information garnered for this article came from five years of exposure to a number of areas in the manufacturing process, the various people in specific operations, and engineers with a variety of backgrounds. I would like to list the names of the people who enlightened me in a number of processes in the manufacture of the 40 x 50 mm micro channel plate.

The names are as follows: John Balkwill, Maurice Smith,. *John Doherty, Hal Sowers, *Richard Wilcox, Po Ping Lin, Chuck Watkins, The Operators of MCP and Varian Publication "Application for Micro Channel Plates".

*deceased

TECHNICAL POSTERS FOR THE A.S.G.S.

Edwin A. Powell
ICI Americas Inc.
Wilmington, DE 19897

Within the American Scientific Glassblowers Society abounds an abundance of diverse knowledge, creativity, and techniques of which is often never disseminated to their peers and the scientific community.

Numerous reasons or excuses are hastily conjured up when a member or individual is confronted with the possibility of presenting a technical paper or workshop. A technical poster presentation will alleviate these apprehensions. For the first time, a technical posters program will be implemented at the 33rd Symposium in Atlantic City.

Technical posters provide an exciting addition to our technical program, especially for the scientific glassblower, where visual materials need to be before the viewer for more than a fleeting glimpse. Because the presenter is also there, technical posters offer the best of both worlds.

The concept is simple. Bulletin boards or pin boards. Approximately 4' x 6' or 4' x 8' in size, are used by the presenter to display photographs, drawings, or other graphics, and a small amount of well edited text to illustrate the main points of the presentation. The technical poster will be displayed for a prescribed period of time, with a scheduled period of time when the presenter is required to be with his or her poster to discuss the material presented.

Technical posters offer presenters a more relaxed atmosphere than the formal technical paper program, complete with an often intimidating combination of "podium, microphone, and audience." With the technical poster the presenter is able to relax and communicate. The result generally is a better presentation of material and an improved exchange of ideas.

Technical posters consist of a title with the author's name, employer, and his address, Three main elements follow: the introduction, the main content, and the conclusion. A brief introduction should include the objective of the poster. The main content of main body element is composed of a series of photographs, drawings, or other graphics conveying the main idea of the poster. The conclusion summarizes the technique's uses and alternatives. A list of acknowledgements may be added if necessary.

In organizing your poster, write a simple list of events that will convey the message of the poster. The poster must be well organized. Viewers should be able to recognize a starting point. Then follow the written text and graphics easily without any help. If there is too much to look at, or it is not well organized, the viewer will be confused and may not get your message. Keep it simple, keep it to the point, and design the display so it guides the viewer.

Label elements A, B, C or 1, 2, 3 to make it easier for a viewer to follow and give him points of reference for discussion.

Size is important too. Photographs, drawings, or other graphics should be at least 8" x 10" in size so they can be easily viewed at a reasonable distance.

Mount your graphics and other elements on paper or poster board of contrasting colors. Captions may be mounted with your graphics or mounted separately. By mounting your graphics, they will be easier to transport and display. Poster board and spray adhesives can be purchased from art supply stores and are ideal for this

purpose. Plan to leave an inch or so of mounting board around your element to frame them. The mounting board can be trimmed with an X-Acto knife or matte cutter. Remember, all elements should be mounted. Mounting your elements helps frame them, giving your poster presentation a professional look that attracts attention.

Lettering in your poster should be of sufficient size to enable the viewer to read the written text at a distance of approximately 4' to 6'. The title should be 1" to 2" high. Subheadings should be ¼" to ½" high and text and captions ¼" high. Lettering of your elements in proper proportions will help the viewer find his way through your material and again give it that professional look. Neat hand letterings or stenciling will do, but the use of dry-transfers, rub-on letters, or adhesive-back letters are best. They are sold under the brand names: Letraset, Chartpak, Format, Presto, Artype, and Normatype: and can be obtained from art supply stores. For the perfectionist, contact the art department at your place of employment or a commercial artist.

Type styles for titles, headings, and captions should be bold and semibold weight. Avoid stylish scripts.

Place your lettering on white paper, then mount on the poster board of contrasting color for the most impact.

These are only guidelines. Use your own creativity, make your poster personal. Develop your own style.

When the thought of presenting a technical paper or workshop intimidates you, technical posters can be your alternative. A poster can be developed in the familiar environment of your glassblowing facility and then presented at a future symposium's relaxed technical poster program. Future symposium posters may be presented at a section meeting, thus easing an individual into the presentation process, encouraging others to participate, and enhancing the section meeting.

When you have decided to present a technical poster, a brief abstract should be written and sent to the present symposium's technical posters chairman. The brief abstract should include the title, author's name, employer, mailing address, and telephone number.

Whether it is technical posters, technical papers, or workshops, or a combination of one or more, plan to participate at a future symposium.

ACKNOWLEDGMENTS

I would like to thank the following for their support and assistance in the preparation of this paper: Kenneth Everingham, David Edson, and Jerry Cloninger.

REFERENCES

Portions of this endeavor taken from the Archaeological Institute of America's *"Poster Sessions"* and *"How To Assemble A Good Presentation"*.

GRINDING TECHNIQUES FOR OPTICAL APPLICATIONS

William H. Shoup
University of Virginia

Prior to optical polishing it is necessary to prepare glass surfaces so that they will have the correct dimensions and surface quality. It is the purpose of this paper to explain the equipment and operations necessary to achieve flat ground surfaces which are prepared for optical polishing.

FORCES OF GRINDING

The tensile strength of glass is dependent upon composition, surface condition, and surface hydration. It is the tensile strength which must be overcome to grind glass.

The nature of the fractures associated with grinding glass is illustrated in Figure 1. A slurry made up of grinding compound and fluid lapping vehicle is ground between two counter-moving surfaces, one is the tool and the other is the glass workpiece. As the two are ground against each other the points of the grinding compound pieces exert stresses on the glass, deforming it via compression. The resultant tension from the immediate vicinity exceeds the strength of the hydrated glass and small concoidal fractures or pits result, beginning and ending at the surface of the glass.

GRINDING COMPOUNDS

To optimize grinding, the loose grit of the grinding compound should be sharply fractured as well as significantly harder than glass. Two of the many available grinding compounds will be considered: silicon carbide and alumina. Silicon carbide is used for coarse grinding because its sharply fractured points are harder than alumina and thus it grinds many times faster. Because silicon carbide breaks down quickly it is not usually recycled. At the finer grinding sizes the pits produced by silicon carbide are deeper than those produced by alumina. As a result silicon carbide is used at the coarser grinding processes while alumina is more desirable for the finer work. Alumina works better if its slurry is slightly alkaline. This alkalization happens automatically if these compounds are recycled because the ground glass which is included in the recycling process has this effect. The pH may also be adjusted directly with lye to a value of 8 to 9.

RECYCLING ALUMINA GRINDING COMPOUND

To recycle grinding compounds create a sedimentation tower (Fig. 2). Make the tube large, 100 mm or larger diameter, by 4 feet or longer. The sidearm tubulation should be located 75% of the way down from the top and should be large, 22 mm or larger.

Run standards of new grit sizes down the water filled column to establish the fall times for the various grit sizes. Then introduce the mixture of used grits as a water slurry laid gently on the surface of the column of water. After the correct fall time has passed, remove the sidearm stopper. Allow a small amount of the first eluent to fall into the first catch basin to rinse off any large grit particles which may have strayed into the sidearm. Recover the remainder in the second catch basin. Recover the grit in filter paper, dry it and store it in a zipper type plastic bag. Repeat the process for larger size grits by shortening the fall times.

FLAT GRINDING EQUIPMENT

Any two surfaces ground together will tend to become mating surfaces. Thus generating a convex surface requires a concave tool, and generating a flat surface requires a flat tool.

For flat lapping it is imperative to first generate and then continuously maintain the flatness of the lap or grinding tool. If the tool is a rotating flatbed grinder then this is a straightforward process. The flatbed (Fig. 3A) should be made of cast iron and must have an indentation in the center. The diameter of this indentation should be one-sixth to one-fourth of the diameter of the grinder. The flatbed grinder may be smooth or have a variety of groove patterns.

A conditioning ring (Fig. 3B) made of mild steel is used to generate and maintain the flat surface of the grinder. The ring must be larger in diameter than the distance from the edge of the central depression to the edge of the grinder. The conditioning ring needs to be made so that the weight distribution is perfectly even: that is, it should be machined so that the internal diameter and the external diameter are concentric and the ends are parallel and at right angles to the sides of the ring. One edge of the conditioning ring should be numerously slotted to allow for the even distribution of the grinding slurry over the lap.

Inside the conditioning ring is a plastic plate (Fig. 3C) which should fit loosely. Into this plate holes are bored to accommodate test plates or workpieces in a "floating" configuration. The test plates are made of mild steel and are about one inch thick and four inches in diameter.

One pair (Fig. 4) of sealed bearing rollers which are mounted in an adjustable fashion should be attached to the frame of the grinding machine. These rollers should be positioned so as to allow for the free rotation of the conditioning ring as it is driven by the rotating lap. The roller support must be adjustable to allow for the positioning of the ring towards the center or periphery of the grinder.

Figure 5 shows the relative positions of all the elements in the assembly.

GETTING THE GRINDER FLAT

With the grinder, conditioning ring, and test plates in position apply a slurry of grinding compound and lapping vehicle and start the grinder. The use of a commercial lapping vehicle is recommended rather than plain water for use with silicon carbide to increase its cutting speed and efficiency, and improve the ease of cleaning.

Once the lap has achieved a uniform grey surface it can be checked for flatness. Four methods are described: two straightedge methods, a spherometer method and a two test plate method.

STRAIGHTEDGE METHOD NO. 1 (Static) – Both straightedge methods require a good quality machinist's straightedge which is at least as long as the diameter of the lap. With the lap clean and dry darken the room. Set a lamp behind the lap with the bulb about level with the lap (Fig. 6). Place the straightedge across the diameter of the flatbed grinder in front of the lamp. Look at the margin of the lap and the straightedge. The shape and location of the light which comes through will reveal the convexity or concavity of the lap. This method can reveal curvatures of less than 0.0001"/foot.

STRAIGHTEDGE METHOD NO. 2 (Dynamic) – With the lap clean and dry hold the straightedge at either end across the diameter of the lap (Fig. 7). By moving one end of the straightedge it is easy to determine if the straightedge is dragging the edge of a concave lap or the center of a convex one. This method is not recommended since it wears out the machinist's edge.

SPHEROMETER METHOD – Making a spherometer requires a ring of metal, three ball bearings, and a last-word type dial indicator capable of measuring extremely fine distances of 0.00005 inches or two microns. Assemble the

spherometer as indicated (Fig. 8). Glue the ball-bearing feet into place with epoxy so they can be easily remounted if they start to flatten.

The spherometer establishes a plane by the three point contacts of the ball feet. Variations from that plane are measured by the dial indicator. Zero the dial indicator on a known flat surface such as a machinists flat or preferably an optical flat. Then carefully place the spherometer on various locations on the clean and dry lap. The dial indicator will determine if the center of the spherometer is higher or lower than the reference. This method allows for quantification of out-of-flatness and the measuring of spherically curved surfaces.

TWO TEST PLATE METHOD – This method is probably the best and is also the least expensive. Place the test plates in the plastic holder in the conditioning ring (Fig. 5 above). After the lap has run for a while check the plates. If they have "greyed" uniformly they are ready to use. First clean and dry them. Then burnish or rub them together using a few short strokes. Note the figures created (Fig. 9). If the figures are in the centers of the disks they are convex. If they are at the peripheries they are concave. Notice that since each test plate is mated to the flatbed lap, when they are used on one another the variation from the lap is effectively doubled. If the test plates burnish evenly over their entire surfaces they and the lap are extremely flat. The advantages of this method are the fact that only the plates have to be cleaned and dried not the entire lap. The lap does not even have to be stopped to check the plates.

MAKING CORRECTIONS

When it has been determined that the lap is concave or convex corrective measures should be taken. If the lap is convex the conditioning ring is positioned too close to the periphery of the lap (Fig. 10). If the lap is concave the conditioning ring is positioned too close to the center of the lap (Fig. 11).

Make the corrections by altering the position of the conditioning ring rollers. Continue to grind. Avoid radical corrections of the ring position. It is better to move the conditioning ring gradually so that it can alter the lap evenly. When near flatness is achieved the corrections of the ring position should be quite small, one quarter of an inch or less. Be sure that the ring is always positioned so that it overlaps both the inner depression and the periphery of the lap.

FLAT GRINDING OPERATIONS

In order to prepare a glass surface for polishing it is necessary to establish the procession of finer and finer grinding compounds so that when the polishing process is commenced the surface of the workpiece is both ground finely enough and has the correct dimensions. Refer to the table to determine the appropriate size of abrasive to achieve the surface and the removal rate required. The grits which are listed represent a minimum of different sizes. There are many intervening sizes which may be added to the list if needed.

Grit No.	Approximate Size (Microns)	Maximum Thickness for Removal (Inches)	Thickness Remaining for Removal (Inches)
Silicon Carbide			
60	250	⟩ .175	.175
120	125	.100	.075
220	70	.040	.035
440*	40	.020	.020

600	20	.010	.010
1000	10	.005	.005
Alumina			
No. 30**	20	.005	
No. 10	9	.002	
No. 7	4.5	.0005	
No. 1	1	.0002	
Cerium Oxide (for polishing with pitch lap)			
N/A		< .0001	

*Alumina series may start after 400 grit silicon carbide
** Cerium oxide polishing may start after No. 15 alumina

In the table above the approximate removal rates for each size grit is given. Notice that when the changeover from silicon carbide to alumina is made there is an overlap in particle size. This is because the pits produced by silicon carbide are deeper than those produced by alumina.

There are many important factors to remember when grinding a glass surface in preparation for surface polishing: complete grinding, cleanliness and correct change of grit size.

The surface must be ground completely by the abrasive size being used. This means that adequate time must be spent on each grit size before moving to a smaller size. If this is not done there will be pits in the surface of the glass which will appear only when the surface is polished. The amount of time required to achieve this degree of completion varies with surface area, loading, glass type and lap speed. The following are intended as convenient starting points from which to make adjustments to optimize grinding processes: loading 100 g/cm^2 of surface area, lap speed 350 ft./min at periphery. Further, the amount of grinding time for each glass type should increase directly with hardness. Generally, this order of increasing hardness is optical glasses, soft glasses, borosilicates, and fused silica.

The removal of material from the workpiece can be monitored by measurement. The minimum thickness of material which is to be removed from the workpiece should be at least three times the abrasive particle size. Example: # 220 grit: size 70 microns (0.07mm) x 3 = 0.2mm = .008 in. minimum removal. Also, monitoring removal rates when larger grits are being used will allow for the establishment of grinding times. These grinding times can be applied to the smaller grit sizes where dimensional monitoring is more difficult.

The second point to remember is that when changing grit sizes every possible surface must be scrupulously cleaned. The one factor of contamination is the cause of most of the failures encountered in doing optical work. Also, avoid stirring up dust or using contaminant-producing equipment such as abrasive saws or belt grinders. Workpieces must be cleaned before each measurement. All components and workpieces must be cleaned at each change (reduction) of grit size. Residue from grinding must be easily rinsed without rubbing if previously polished surfaces are to be protected from scratches. Commercial lapping vehicles are available which allow for the rinsing of silicon carbide residues off of the workpiece without scrubbing using only gently running water.

The final point to remember is that when changing grit sizes it is important to go through a complete schedule of grit sizes for the grinding times which have been

established. A good starting point from which to make adjustments is to approximately double the grit number or halve the micron size for each change of abrasive size. Refer to the grinding table for a typical schedule. More intervening sizes than those listed may be used if necessary. When moving from silicon carbide to alumina it is a good idea to use alumina which is larger than the last silicon carbide size used. This is because the silicon carbide plucks deeper pits than alumina for equivalent grit sizes.

PROBLEMS OF GRINDING

Among the myriad problems encountered in grinding, the most common are edge rounding, surface contamination and seizing.

Edge rounding (Fig. 12) is caused when grinding slurry builds up as a wave in front of the leading edge of the workpiece. This forces more slurry under the edge grinding the edge more before the slurry can even out to a uniform film. This is caused by too light loading, a grinding slurry which is too thick or a lap speed which is too fast. The loading should be adjusted so that it is not too light, but not so heavy that seizing occurs. Using a conditioning ring creates an even, thin coat of grinding slurry. The speed of the lap may be adjusted on lapping machines with a constant speed motor by changing the pulley sizes of the drive belts.

Surface contamination is the most common problem encountered in optical surface generation. This occurs when a larger grit gets onto the surface of the workpiece and gouges it. Frequently this does not show up until the polishing stage has been reached. I must re-emphasize that the only solution to surface contamination is cleanliness. Each part must be scrupulously cleaned before proceeding to the next smaller grit size. The use of appropriate lapping vehicles, lots of paper towels and copious quantities of soap and water is recommended. Keeping a separate scrub brush for the cleaning of each grit size limits the range of cross contamination.

Seizing is caused when the workpiece and lap are very closely mated and the slurry is excluded. This can be caused by excessive loading, inadequate slurry, or cavitation. The use of adequate slurry and a conditioning ring will insure the elimination of the first two of these problems. The low interface pressures which cause cavitiation must be interrupted by grooves in the lap.

For each of the surfaces illustrated (Fig. 13) there are advantages and disadvantages.

The flat ungrooved surface (Fig. 13A) is easiest to clean and is good for small pieces and small cross-section pieces like cylinder ends. But edge rounding and seizing are worst on this surface.

The radially grooved lap (Fig. 13B) reduces both seizing and edge rounding. The grooves are a small cleaning problem and can catch the edges of small workpieces.

Concentric grooves (Fig. 13C) on a lap reduce seizing, edge rounding end edge catching of small workpieces. Although these grooves are the easiest to machine they are the most difficult to clean.

Spiral grooves (Fig. 13D) are similar to concentric grooves but while more difficult to machine are easier to clean. The spiral should be machined so that it will be self flushing when in use and while being cleaned. That is, it should appear to unscrew while the lap is running.

A reticulated or cross-hatch groove pattern (Fig. 13E) is the best for large area pieces and worst for small. It is the most difficult to machine and is also difficult to clean.

QUICK TRIGONOMETRY LESSON

Trigonometry is an extremely handy method whereby angles and sides of right triangles may be calculated. This is useful in the production of optical devices such as prisms, Brewster windows, parallel ends of cylinders and right angles. In a right triangle (Fig. 14) the identities listed can be used to calculate angles. Use a scientific calculator or a book of tables to find the angles once their trigonometric value is calculated.

BRESTER'S ANGLE

Brewster windows are frequently affixed to the ends of gas laser discharge tubes. A Brewster's window (Fig. 15) is a parallel sided plate of glass set at such an angle that the reflected light and the refracted light are at right angles. This makes the reflected light polarized and the refracted light partially polarized. Lasers which have Brester's windows produce light which is highest in energy in the refracted plane. This increases the useful energy for many applications.

Brewster's angle θ = arctran [n_D(higher)/n_D(lower)]
Example: for air (n_D= 1.00) to borosilicate (n_D = 1.47)
Brewster's angle = Arctan 1.47/1.0 = 55° 46' 25"

Remember that these angles are always calculated from the normal (the ray going directly into the surface at right angles to it). So, if you wish to calculate Brewster's angle on the end of a cylinder when using the side of the cylinder as reference, ninety degrees must be added to the calculated value.

GRINDING RIGHT ANGLES ON CYLINDER ENDS

To make a right angle on a cylinder of glass first cut the tube as squarely as possible. Commence grinding using a moderate grit size (200 - 400 grit) remembering to keep the conditioning ring and the test plates on the grinder. When the surface of the cylinder is flat remove, clean, and dry it. Place the cylinder in a machinist's "V" (Fig. 16) which has been clamped into position. On one end of the cylinder (which is extending out of the "V") hold a primary surface mirror in place. Train the beam of a HeNe Laser on the mirror and note the position of the beam spot on the wall at some distance (10 feet is good). Carefully, holding the mirror snug to the surface of the cylinder, rotate the cylinder (but not the mirror in case it is a wedge) in the "V". Note the deflection of the laser beam spot. This movement is caused by out-of-squareness of the cylinder end. Mark the cylinder and grind the end of it applying additional pressure to the high side of the cylinder. Repeat the test process. It is possible to get a total beam deflection of .1 inches at a distance of 10 feet in a relatively short time. If you consider the laser beam to describe a very long, thin right triangle, then the opposite side would be equal to .1 in. The hypotenuse would be equal to 120 in. (10 ft.). Sin θ = opposite/hypotenuse = .1 in./120 in. Then θ = 0.04775° or 0°2' 52". This results in a cylinder end which is 90 degrees $\pm$ 1 minute 26 seconds to the side. Notice that the total deflection represents twice the variation from 90 degrees. Even if a total beam deflection at 10 feet is one inch, the variation from 90 degrees is still less than a quarter of a degree.

PARALLEL ENDS

If right angles and parallel ends are required first generate one right-angled end. Then when grinding the other end use that right-angled end as a reference.

To test for parallelism (Fig. 17) place cylinder on a flat reference surface such as a machinist's granite flat or a piece of thick float glass. Place the primary surface mirror on the end of the cylinder and train the HeNe laser beam onto it so that the reflected beam spot is about 10 feet distant. Note the deflection of the beam as the

cylinder (but not the mirror) is rotated. Mark the high side and apply a slight extra pressure when grinding. Using the same trigonometric techniques, a .1 in. deflection at 10 ft. represents a variation from parallel of ± 0°1i 26".

PRODUCING AN ANGLE

To produce a certain angle set the mirror position with an angle block or a good protractor against a fixed stop (Fig. 18). (A prism whose angles need to be reproduced it is ideal for set-up.) With the HeNe laser firmly fixed and the beam on the mirror mark the reflected spot at an appropriate distance (10 feet). When testing the angle of a workpiece position it against the same stop and using the same mirror compare the current spot position to the original one. Make appropriate corrections and retest until a satisfactory angle is produced.

SPHERES

Glass spheres, hollow or solid, are useful in poppet valves and float valves. Solid spheres are also used in some fiber optic couplers and other optical devices. After glassblowing and annealing the best sphere possible (Fig. 19), select a metal cylinder (copper or brass is best) which is smaller in diameter than the glass sphere. After applying a slurry of grinding compound and lapping vehicle grind the ball in random motions against the cylinder using the palm of your hand. In this manner a sphere will be generated.

CONCLUSION

It has been shown that extreme accuracy can be achieved in the grinding of optical parts with only a modest investment in supplies and measuring devices. These measuring devices such as a HeNe laser and steel test plates make advantageous use of geometry to amplify dimensional variations to easily perceived values.

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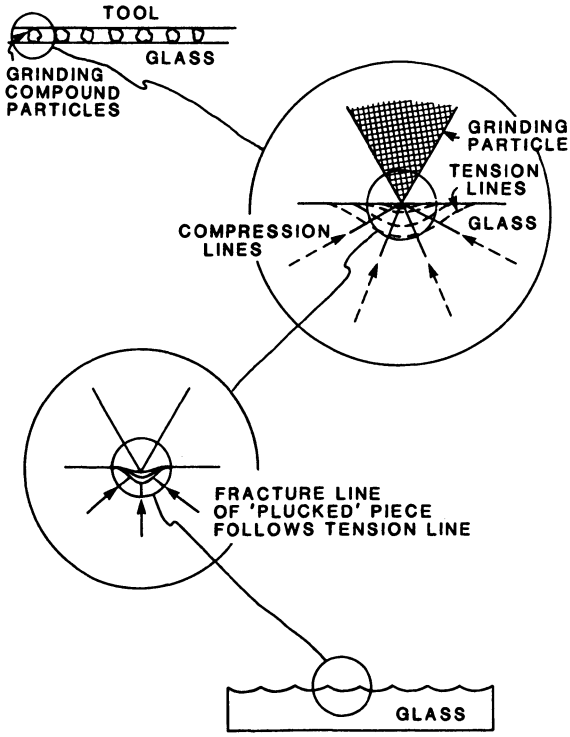


Figure 1. Grinding processes

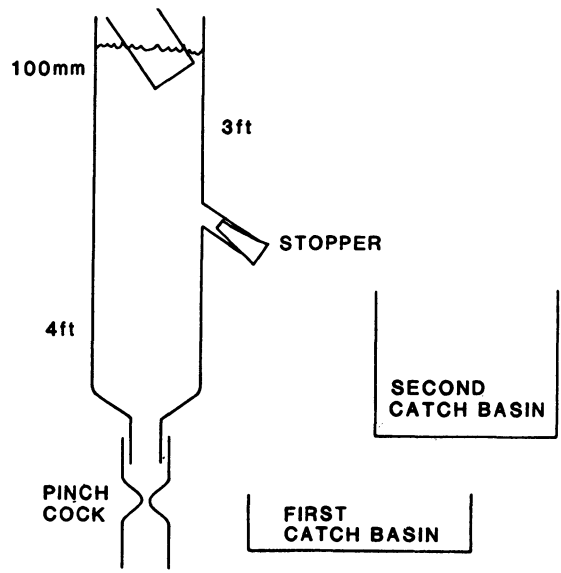


Figure 2. Recycling Grinding Compound

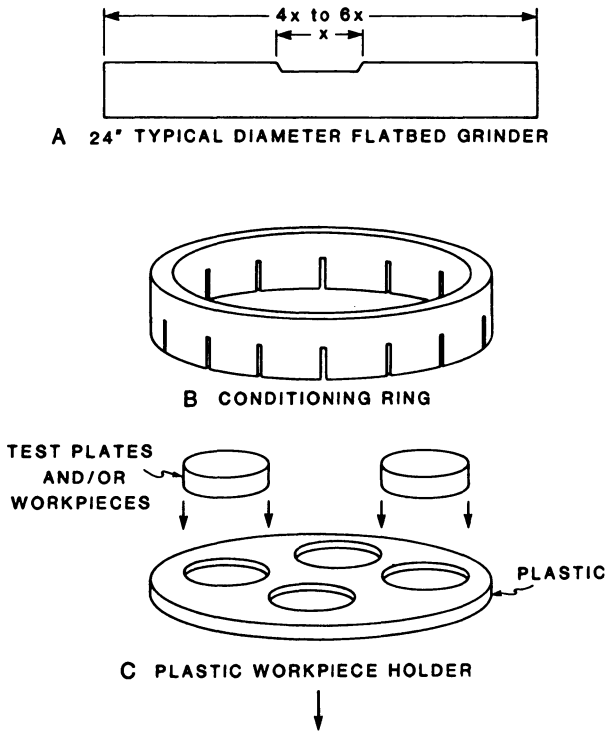


Figure 3. Flatbed grinding and conditioning ring assembly

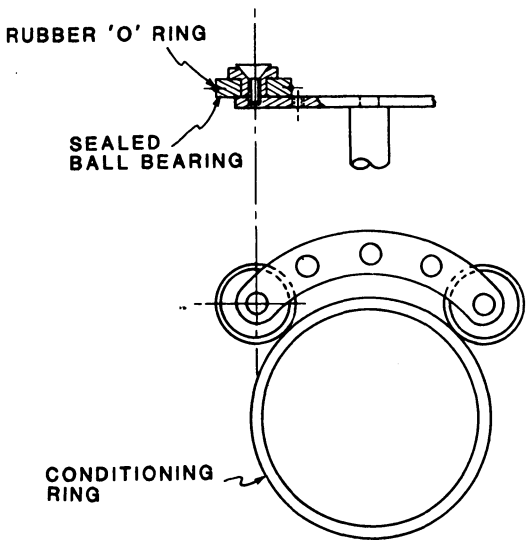


Figure 4. Roller Assembly

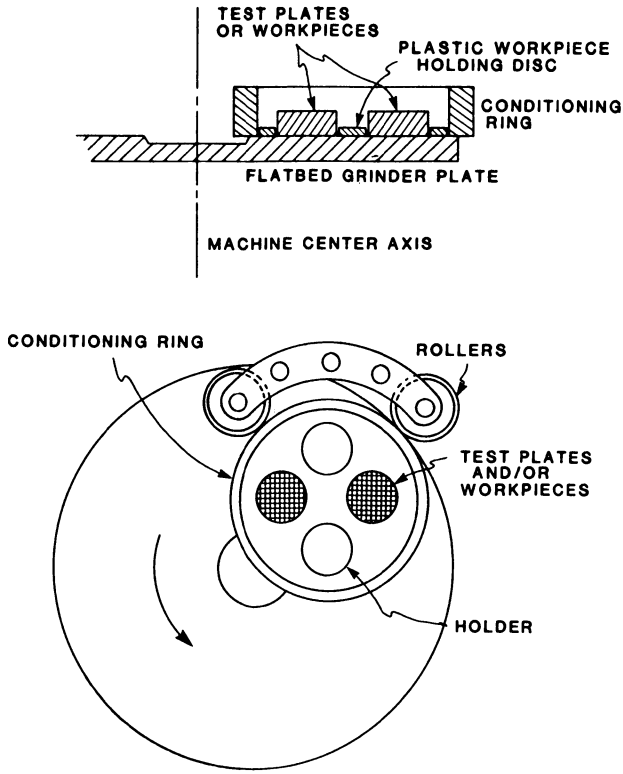


Figure 5. Position of grinder, rollers, conditioning ring, and holder with workpieces and testplates

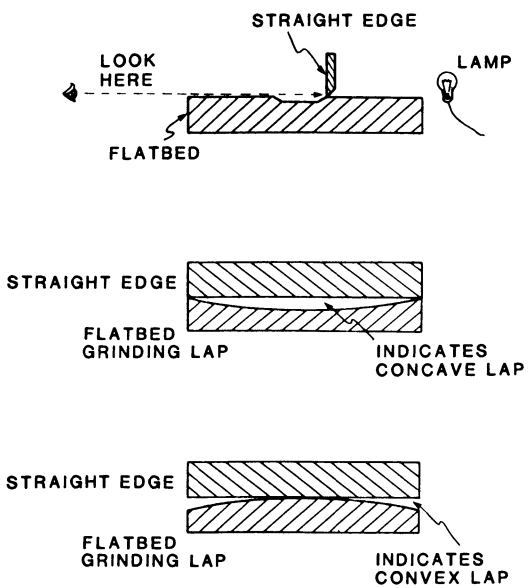


Figure 6. Testing with a straight edge (static)

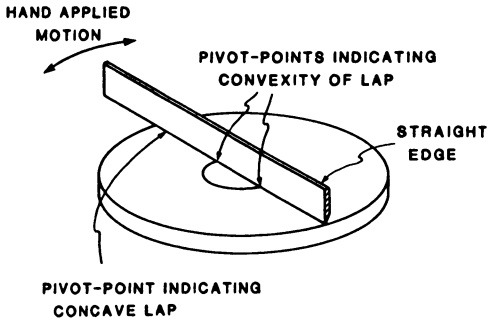
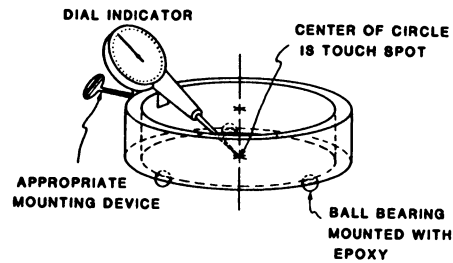


Figure 7. Testing a flatoed lap with a straight edge (dynamic)



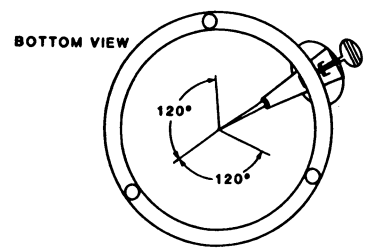
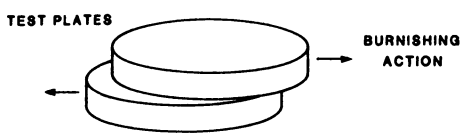


Figure 8. Spherometer construction



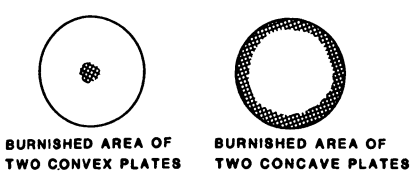


Figure 9. Testing plates by burnishing

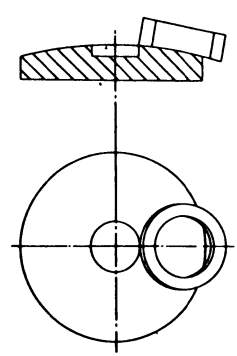


Figure 10. Ring position to generate convex grinder surface (curvature exaggerated for illustration)

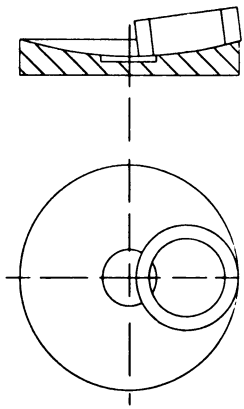


Figure 11. Ring position to generate concave grinder surface (curvature exaggerated for illustration)

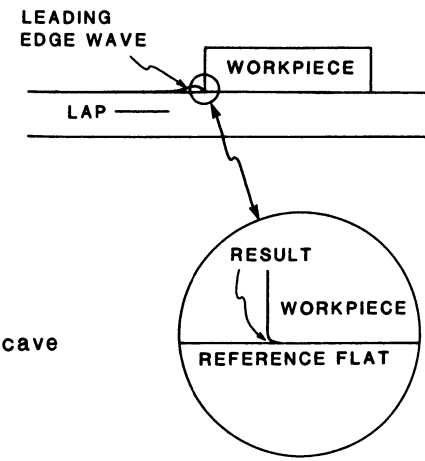


Figure 12. Corner rounding caused by excesss grinding slurry

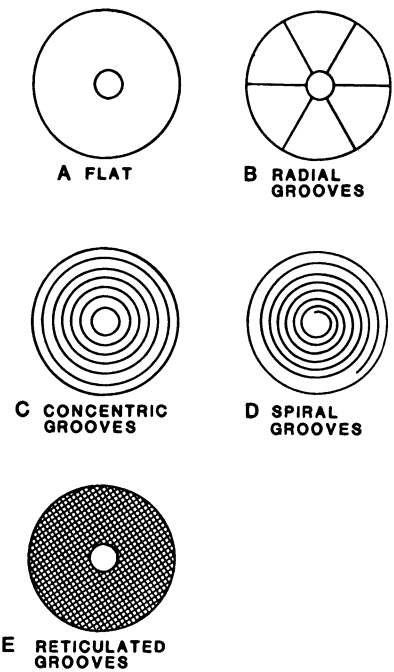
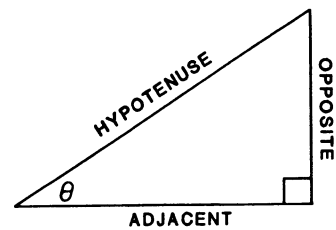


Figure 13. Flatbed grinding laps with various surfaces

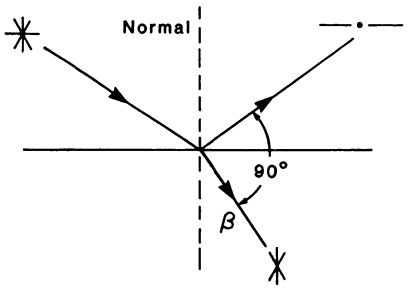


$$\sin\theta = \frac{OPP}{HYP}$$

$$\cos\theta = \frac{ADJ}{HYP}$$

$$\tan\theta = \frac{OPP}{ADJ}$$

Figure 14. Trigonometry



$$\beta = \text{Arctan} \frac{(n_2)}{(n_1)}$$

$$\text{Arctan} \frac{1.47(\text{Borosilicate})}{1.00(\text{Air})} = 55°46'25''$$

Figure 15. Brewster's Angle

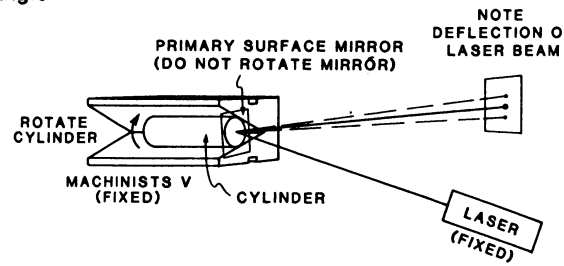


Figure 16. Test for right angle to axis

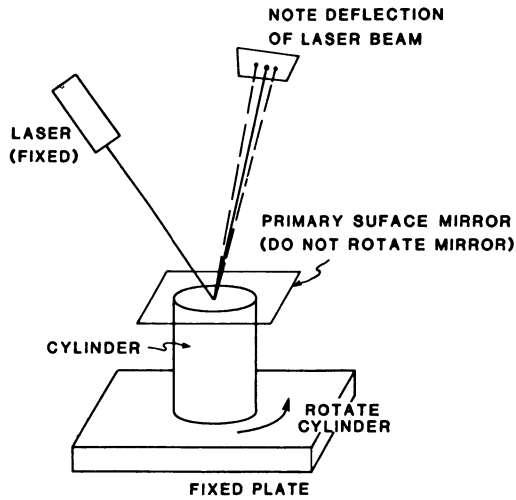


Figure 17. Test for parallel ends

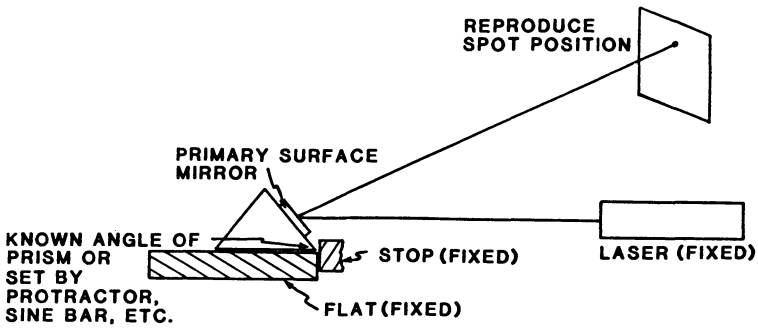


Figure 18. Test for reproduction of an angle

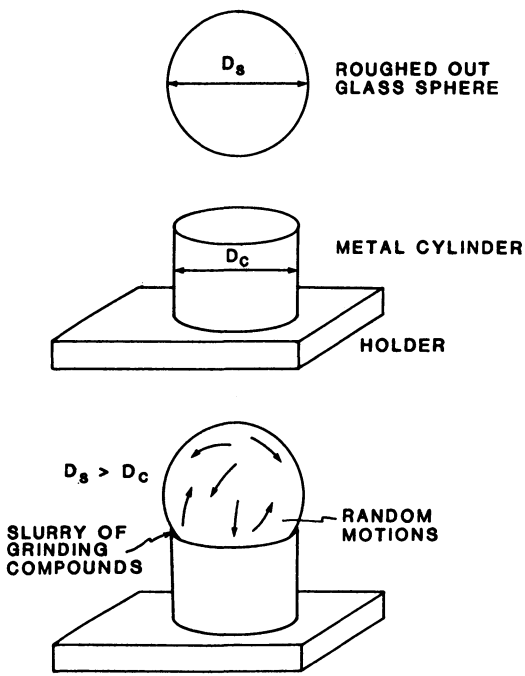


Figure 19. Sphere generator

ULTRAVIOLET (U.V.) CURING ADHESIVE

by

Joel M. Babbit

Department of Chemistry
University of South Carolina
Columbia, SC 29208

Norland Optical Adhesive 61 (NOA 61) is a crystal clear, one part adhesive that contains no solvents. When exposed to ultraviolet light, it gels in seconds and fully cures in minutes to give a tough, resilient adhesive bond. This adhesive is designed for fast, precision bonding applications. NOA 61 eliminates premixing, drying, or heat curing operations common to other adhesive systems. Shelf life of the liquid is at least 4 months at room temperature; longer if refrigerated. To prevent accidental curing, gold fluorescent lights or yellow u.v. filters are recommended for overhead lighting. This adhesive simplifies any process that requires critical alignment or exact positioning. With NOA 61 you are in complete control. Just apply the adhesive, take as much time as needed to position your parts; then set it in seconds with ultraviolet light. NOA 61 is designed to give the best possible bond to glass surfaces. This adhesive also has excellent adhesion to metals, fiberglass, fiberoptics and glass filled plastics. As with any organic chemical, care should be taken in handling NOA 61. Skin contact should be avoided and affected areas should be washed well with soap and water. Avoid prolonged vapor inhalation and use in well ventilated areas.

PREPARING SURFACES

Surfaces to be bonded must be free of any dirt, grease or oil. Standard cleaning procedures for glass and metal should be used. Before applying the adhesive, the glass, metal and/or plastic parts should be wiped with reagent grade solvent such as alcohol or acetone to remove all traces of dust and oil residue.

APPLYING ADHESIVE

For bonding of flat pieces, the adhesive should be applied dropwise to the center of one surface. The second surface is then placed on the adhesive laden first surface. Light pressure is applied and the top element is moved in a rotary motion to spread the adhesive evenly to the edges and remove any air bubbles. This adhesive can also be applied as a drop or bead along the edge of a component to mount or encapsulate it. This procedure is used when sealing windows on ends of tubes.

CURING THE ADHESIVE

NOA 61 is cured by longwave ultraviolet light with maximum absorption within the range of 350-380 nanometers. The cure is not inhibited by oxygen, and hence any areas in contact with air will cure to a non-tacky state when exposed to ultraviolet light.

In most optical applications, curing is done in two steps. A short precure with ultraviolet light of sufficient duration to set is followed by a longer cure under u.v. light to obtain full crosslinking and solvent resistance in the adhesive. The precure can be had as quickly as 10 seconds using a 100 watt mercury lamp at 8". Where longer time is required for alignment it can be extended to a few minutes using a very low intensity light source. The final cure can be accomplished in 5 to 10 minutes using the 100 watt mercury lamp.

The precure allows the user to align and set his precision parts quickly without long holding times and minimizes the number of holding fixtures required. After the precure, excess adhesive can be wiped up with an acetone moistened cloth.

Assemblies should be inspected at this time and rejects can be separated in methlylene chloride. The bonded area must be soaked in the solvent and normally will separate overnight. Time required to break the bond depends upon the extent of cure and area of bond. The addition of 10% methanol and 2% concentrated ammonia to this solvent improves the penetrating action.

When finally cured NOA 61 has very good adhesion and solvent resistance, but it has not reached its optimum adhesion. This will come with aging over a period of about 3 weeks in which a chemical bond will form between the glass and adhesive. This optimum adhesion will also occur in 12 hours at 50°C.

Doublets bonded with NOA 61 can withstand temperature thermoshocks before aging from -15° to 60°C. After aging, they will withstand temperature conditions from -80° to 90°C.

NOA 61 is unique because in addition to its outstanding adhesion, it has stress relieving characteristics that make it superior to all other materials for optical bonding. These characteristics are a combination of low shrinkage and flexibility that minimize stress and strain on the optical bond. This is important not only for high optical quality, but also assures stability on long term performance under changing environments.

CHEMICALS THAT WILL ATTACK NOA 61

Hexafluoroisopropyl alcohol – this chemical will also attack TorrSeal. Deuterated dimethyl chloroamine also will attack NOA 61; undeuterated dimethyl chloroamine has no effect.

"THE ASTM-NBS STANDARD REFERENCE MATERIAL PROGRAM FOR GLASS"

Henry E. Hagy
Consultant
Chairman, ASTM Subcommittee C14.91 on SRM Development

The American Society for Testing and Materials and the National Bureau of Standards have joined forces to develop standard reference materials (SRM's) used for calibrating and certifying analytical and testing procedures. SRM's are developed under the jurisdiction of ASTM Subcommittee C14.91 and direction of a Research Associate working closely with the National Bureau of Standards. A historical background is traced, the activities and procedures described, and specific SRM's are discussed.

A success story is easy to tell, especially if one is part of it. The experience of working with enthusiastic and dedicated people enriches one's life and, because of my personal association with Subcommittee C14.91, it is appropriate that this be told in the first person.

Before going further, it is advisable to define a standard reference material (SRM) to those unfamiliar with the term. An SRM is a material whose chemical and/or physical characteristics have been meticulously defined by qualified scientists and used for calibrating or verifying a measurement system. The National Bureau of Standards generates and maintains a large inventory of SRM's which they sell as a service to the technical community. Hundreds of SRM's covering a wide range of materials and physical and chemical properties are available.(1) (2)

On September 30, 1977, the National Bureau of Standards and the American Society for Testing and Materials under joint sponsorship held a workshop on SRM's. Three areas of known industrial need were chosen for discussion: (1) rubber, (2) glass and (3) fine particles. I was chosen to chair the session on glass.

Before the workshops convened, we were told about the problem of lagging SRM development due to increased demand from industry and simultaneous funding and manpower restrictions at NBS. The solution to the problem was found in the Research Associate (RA) Program already in operation at NBS. This program provides for an industrially sponsored scientist to work at NBS on a research project that benefits a wide community of interest. The idea to use this program to bolster SRM development was not only smart, but had already been proven by a successful program with metals through the efforts of research associate James Schultz and the newly-formed ASTM Committee S17.

The workshop on glass was well attended and productive. The consensus of the group as reported to ASTM Committee C14 on Glass and Glass Products was:

1. Since SRM's have played an important role in glass, they will continue as such. Thus a RA program will be advisable and probably get support.
2. Chemical analysis SRM's will probably be easier to decide upon than physical property SRM's by the pool of industrial supporters (this did not prove to be true).
3. The recommended process for planning and administering an RA program is through a new and separate C14 subcommittee.

Based upon this response, an ad hoc committee within Committee C14 was formed for further study. I was asked to chair the group. Specifically, the ad hoc committee was charged with developing recommendations on the following:

1. Rationale for the Glass Research Associate Program.
2. Estimated budget for the RA program.
3. Appropriate C14 committee structure.
4. Duties of the RA.
5. Guidelines for developing SRM priorities.
6. Interface with C14 subcommittees.

This ad hoc committee moved swiftly and decisively. By May 1978, at the annual meeting of the American Ceramic Society in Detroit, much of this groundwork was in place, and we were ready to go. The C14 meeting in Detroit brought about a couple of milestones: (1) as recommended by the ad hoc committee, a new subcommittee on SRM development was formed and designated C14.91 and (2) the decision was made to approach ASTM with a formal request for a RA program on glass SRM's. I was made chairman of C14.91, and given the task of approaching ASTM on the RA program.

With the help of a very energetic and cooperative ASTM representative, Mr. George Stevenson, Assistant Manager, Standards Development Division, we were able to put our package proposal together and make our pitch to the Committee on Technical Committee Activities (TCA), the ASTM body with the authority to approve such action. George and I made our case before the TCA on September 18, 1978. A few questions from TCA members followed our presentation and then they unanimously and quickly approved. George told me later that their swift action was most unusual and that such meetings characteristically are marked by lengthy, probing deliberations. But we had a lot of support! I quote from a letter to William Cavanaugh, ASTM Executive Director, from Paul Cali, Chief, Office of Standard Reference Materials, "I strongly endorse the establishment of a glass SRM research associate program. I hope that ASTM management and the ASTM Board of Directors will also lend their support to the establishment of the proposed program.

In my opinion, the establishment of a second ASTM sponsored SRM program at NBS will further enhance the voluntary standards system and the objectives of both ASTM and NBS. It will help to assure that glass SRM's developed in the future will be based on the most important needs and the highest priorities of industry as determined through a formal national consensus process. The new SRM's will also help American industry become more competitive, help to stimulate innovation, and expand the use of glass in advancing technologies, and help increase productivity through better quality control."

Another letter of support came to Mr. Cavanaugh from Ernest Ambler, Director of the National Bureau of Standards, "I strongly support the current efforts of the American Society for Testing and Materials to establish a second Research Associate Program at NBS to develop Standard Reference Materials (SRM's). The proposed Research Associate Program to be sponsored by ASTM C-14 on Glass and Glass Products should benefit both producers and users of glass products. This program will provide an effective mechanism for the timely development and production of SRM's used for measurement and quality control applications and will assure that glass SRM production priorities are established with the direct input of board segments of the glass industry.

The first ASTM SRM Research Associate Program, which is for the production of metal SRM's, has now been underway for nearly three years. The metals program has resulted in many significant accomplishments including the certification of over 40 SRM's with an additional 70 currently planned or in production. Over 100 companies have cooperated with ASTM and NBS to produce and certify these SRM's."

We were on our way and the next order of business was the solicitation of funds from industry. Letters of solicitation were sent to not only industries associated with glass but to known users of glass SRM's. The NBS office of Standard Reference Materials was helpful in supplying the glass SRM user list. What surprised many of us was the widespread use of glass SRM's by many organizations not directly involved with glass or glass products.

Financial solicitation was also successful. We asked for a maximum of $7,500 but made it clear that any contribution was certainly acceptable. This took some time as we sent out three separate mailings. By the end of 1979 with the final drive behind us, organization of C14.91 could now proceed, and on March 19, 1980 at ASTM headquarters in Philadelphia the subcommittee was formed. Membership in 14.91 has no strings attached, and in no way is limited to those who made financial contributions. We want people who can **contribute** technically and/or administratively to our programs. Our by-laws define the membership make-up as follows:

a. The Chairman.
b. One official and one alternate representative from each organization interested in **supporting** a Research Associate Program.
c. An official representative of NBS.
d. The Chairman of each of the interested C-14 subcommittees.
e. An official representative of ASTM, who shall also be the secretary.
f. The Research Associate.

Present membership numbers thirty. We meet twice a year along with all the other C14 subcommittees.

Everything was now in place except that we needed to fill the position of the Research Associate. The metals program preceding ours was fortunate in finding Jim Schultz, a retired NBS researcher with technical know-how and familiarization of NBS. We wanted to do as well and we did! In 1980 we hired Dr. August Siefert, retired former Director of Research of Owens-Corning Fiberglass Corporation. Gus is a delightful and talented individual who has brought to us a variety of technical and administrative skills. Subcommittee C14.91 members are energetic, friendly, and enthusiastic and Gus fits right in! This is a key position for the success of the program and fortune smiled upon us again.

The RA's duties are:

a. The RA shall plan and implement a schedule of work based upon the priorities established. This schedule will take into consideration the availability of materials and facilities to maximize the production of SRM's. Coordination of these tasks must be in accordance with the established NBS-OSRM policy and guidelines if these materials are to become documented NBS-SRM's. The RA's responsibility shall be to perform the task (or to coordinate the services of others in the performance of the tasks) required to achieve the ultimate goal of providing the maximum number of SRM's on the Committee's priority listing to be accepted on the NBS priority listing.
b. The RA shall maintain all records required to implement the program. The RA shall be responsible for complete coordination with NBS including transmitting to NBS all information required for certification of a candidate SRM as the work is being done and for a final report upon completion.
c. The RA will prepare a progress report and distribute it to the committee members three weeks prior to each regular meeting. He will also prepare an

annual summary of the accomplishments of the program for use by the chairman in preparing the committee annual report.

d. The RA will attend all committee meetings and be prepared to discuss all facets of the program in detail, when required.

It's really a lot of work! Unlike Jim Schultz, Gus does not stay full time at NBS, preferring to do much of the work in his home in Granville, Ohio, but he makes frequent trips to NBS and is in constant contact.

We have a procedure for solicitation of candidate SRM's and prioritizing them. Each year the chairman sends out to C14.91 membership a letter of SRM candidate solicitation. All entries thus received are sent out in a letter ballot to the membership with each entry described and justified in its sponsor's own words. Each member is asked to list the entries in order of preference assigning descending numbers from N (no. of entries) down to 1. On completion of the letter ballot, entry tallies are calculated and priorities established by totals.

None of the SRM candidates are totally rejected. We work harder on the ones toward the top of the list. Some of the candidates proceed slowly or sit on the shelf because of difficulties in finding the right material. Our number 1 priority established in our very first balloting for a 90 x 10^{-7}/°C expansion glass standard is still in limbo because we cannot find the right glass. We have already certified four SRM's, all chemical analysis standards:

SRM 1411, a soft borosilicate glass

SRM 1412, a multicomponent glass containing thirteen oxides

SRM 1413, a high alumina (10%, Al_2O_3) sand

SRM 1835, a borate ore

We are presently working on ten other SRM's

CHEMICAL ANALYSIS

1. A glass with iron content in the 0.05 to 0.15% range with a ferrous/ferric ratio between 0.5 and 1.0. This requires standard analytical procedures.
2. Replacement of existing SRM 93A which has run out of supply. This is a high boron glass.

PHYSICAL PROPERTIES

1. Replacement of glass viscosity SRM 710 which is out of supply.
2. High temperature electrical resistivity glass standard in the 1 to 1000 ohm-in. range.
3. Fused quartz, annealing and strain point standard.
4. Glass-ceramic thermal conductivity standard in the 0.04 to 0.05 W/cm-K range.
5. Glass with expansion of 90 x 10^{-7}/°C with no hysteresis in the 0-300°C range.
6. Glass with liquidus certified in the 1000 to 1200°C region.
7. High solar transmittance glass, certified between 91-92% in visible.
8. Glass density standards: near 2.2, 2.5 and 3.0 g/ml.

Many of these are nearing SRM certification. It takes quite a while from the time of concept to the moment of certification. The material must be sought, procurred, homogeneity assessed, round robin testing completed, statistical analyses of data carried out, and final drafting of the certificate before the SRM is official.

How is it working? It is another success on top of a string of successes that made C14.91 a reality. Not only is C14.91 going about its business of developing SRM's, but it has acted as a catalytic agent on the activities of many of our other C14

subcommittees. Committee C14 has never been stronger. It is a powerful example of dedicated people working together.

I have been in ASTM work for some thirty years and have always marveled at how well industry, ASTM, and NBS work together. Therefore, I should not be surprised on reflection, of how well this program developed and succeeded. We should be grateful to the many, many people who helped make it happen – a list too long for individual identification. We should be grateful, and speaking for the members of Subcommittee C14.91, **we certainly are** !

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THE DESIGN OF THE SMALL – MEDIUM GLASSBLOWING WORKSHOP

John C. Penno
Zenith Technology Corporation Ltd.
Dunedin, New Zealand

This paper will address the design of the glassblowing facility as a unit, rather than the usual arrangement of accumulated components. The paper will not present a set of specific mathematical formulae to be followed but will study each required function of the workshop, discuss alternatives and apply them to the workshop as a whole.

In referring to the small to medium glassblowing workshop I am viewing it more in terms of its required function than physical size or even number of people employed. A large glassblowing workshop in this context is one in which the emphasis is on factory style production, each glassblower carrying out a number of pre-determined tasks supervised by someone whose main function is the management of the workplace and workforce. A small to medium glassblowing workshop on the other hand, in this context, is one in which a range of widely different functions are carried out by the staff members who are at least to some degree responsible for their own jobs, customers and work schedules. In other words the sort of situation applying at the glassblowing workshop of most research establishments or custom glassblowing companies.

a) Functional systems

1. Premises

Traditionally the glassblower has been jammed into whatever remaining space is available when a building is occupied. Most commonly in my experience, the basement, equally commonly a great deal of time, effort and money is subsequently spent trying to overcome the problems of situation.

Orientation

Ideally the workshop should be on the cool side of the building for two reasons: firstly no solar heating to contend with, most glassblowing workshops have enough trouble disposing of heat and secondly, indirect light. As anyone who has worked on glass in direct sunlight will know the problems of glare are considerable with sunward exposure.

Room Volume and Ceiling Height

In each case for the hot working area of the workshop the rule is "the greater the better" – not only does this allow for better heat and fume dispersal but also tends to reduce reflected noise.

Ventilation Outlets

Obviously the ability to carry ducting vertically through the ceiling of a workshop is the ideal, but this is not always possible. In many basement workshops the ducting carrying the hot air away must be run beneath the ceiling in the work space, radiating the heat back into the room for its entire length. The practicalities of ventilation outlet siting must be taken into account when the workshop space is being chosen. In one workshop a new extractor from a large lathe was vented onto the main entrance steps of the building. The first time large work was undertaken on the lathe sufficient waste heat was generated to melt the nylons of a lady on the steps.

Access

It is essential that close and unobstructed access be available to the workshop from a nearby loading dock. Workshops sited on upper floors are often the worst in this respect.

Neighbors

There are few problems in this area although the heat from a glassblowing workshop can be a problem to those on the floor above.

2. Floors

The ideal floor would be one which was free of cracks and crevices, which may hold potential dangers such as spilled mercury; one which is fire proof, abrasion resistant, and easy to clean. Concrete would be ideal except for the comfort factor. Some forms of linoleum (not vinyl) are acceptably fire proof and meet the other criteria as well. Rubber duck-boards (figure 1) are available which are soft to stand on and keep the operator off the floor. These are ideal in a cold working room, around diamond saws and grinders for instance, where the floor is often wet and operators are standing in one position for some time. These can be lifted for cleaning. Mats of expanded metal mesh (figure 2) under lathes catch glass scraps, keeping hot glass off the floor and make clean up simple as the mesh is just pulled out, rolled and emptied into the scrap bucket (figure 3).

3. Gas Systems

Gas supplies should be stored away from the workshop with separate delivery access. Flashback arresters should be fitted, and control should be by solenoid valves operated from the workshop (figure 4). Reticulation in the workshop should be in metal tubing to a self closing keyed connection system, such as the Swagelok (R) (ref. 1) keyed quick connect system (figure 5).

4. Space

Wherever possible when allocating space for particular benches or items of equipment, allow for multiple use of the same floor space; for instance tubing racks which face each other can share the same withdrawal space. Whole facilities may have multiple use. Tubing racks may be placed in otherwise wasted space under a loading dock. Always bear in mind the access space required to fully utilize facilities. I have seen a diamond saw placed where it could not have a full 1.5 metre cane of glass placed on it. Avoid the use of built in equipment or workshop furniture. Modular fittings make rearrangement to take advantage of new personnel, equipment or changed procedures much more practical.

5. Layout

The three most common bench arrangements are: the cubicle type (figure 6) which is appropriate perhaps in a supervised factory situation, but not in the small to medium workshop as defined earlier as it restricts visibility and communication; benches which face the wall (figure 7) which have similar problems of visibility but can be useful where space is restricted; or free standing benches (figure 8) which use the same amount of floor space as the cubicle type but offer visibility of all other facilities in the workshop if properly sited. All round visibility in the workshop is extremely valuable in the type of workshop discussed, where people often help each other or cover for a colleague called away to a customer or to the telephone.

6. Safety Systems

The safety of those working in the shop must be paramount. All workshops must have easy access to first aid, a sink with eye-wash facilities and a mirror, fire blanket and fire-fighting equipment. That should be all that needs to be said on that subject. Various excellent safety and first aid manuals are available and the safety setup in the workshop is there for your survival.

7. Ventilation

The definitive work on ventilation must surely be "Ventilating a Scientific Glassblowing Workshop (basic principles)" by Frans M. Van Damme (ref. 2), and

this should be required reading for anybody designing or contemplating changes in a workshop. The basic rule must be "if you can see it or smell it you're in trouble". Heat also must be controlled; the ideal air temperature is certainly no more than ordinary room temperature. At temperatures over 30 degrees Celcius concentration begins to lapse. The guideline maximum air temperature of the New Zealand Department of Labour is 22 degrees Celcius and lower where the operator is exposed to radiant heat as they are in a glassblowing workshop (ref. 3).

b) Areas

Each area in the premises must be considered for its intended use and also for its position in relation to other areas and activities taking place in the workshop. (For years I worked in a workshop in which the working desk and main telephone were along side the cold-working equipment. Either the diamond saw could be used or the telephone, but not both at once). Figure 9 shows the areas laid out for a glass shop to service a university plus commercial customers, to include a retail glass store and glassblowing teaching facilities. This workshop will be examined in greater detail in the third part of this paper.

1. Access for customers and goods

Access is placed first for a very good reason; it must never be forgotten that the customer is the one and only reason for the glassblowers' existance, and the materials coming in and finished articles going out represent the only fulfillment of that existance. All too commonly the customer is seen as an unwanted and even unnecessary intrusion, and we have all known workshops which never seem to have anything either coming or going. In the example shown in Figure 9 the main doors open off a loading dock with pedestrian access and lead to an unpacking/dispatch area for the storeman, the store to one side and the workshop to the other. The whole premises is designed so that full-sized shipping pallets can be moved throughout it.

2. Workshop

Set off to one side of the customer access, the workshop has a four metre ceiling height and shielded windows on the north side, open vision to the south side (remember this is in the southern hemisphere).

3. Cold-working room

This is separated from the customer and office area by as great a distance as possible, opens off the workshop and has windows to the east and south. Ample water and drainage are provided. There can be problems with recirculating systems of insufficient removal of contaminants or even health danger (Ref. 4).

4. Storage

Aside from the main store which contains stock glassware retailed from this facility, the workshop has a separate tubing store, a separate goods received and dispatched area with storage around it and the essential backroom. The gas store is separate from the workshop and has its own access dock for the bottles.

5. Office Space

This should ideally be divided into two separate areas: The desk area used for the every day work of jobs coming and going, telephone messages, price estimates, etc. and if possible a separate quiet office for such things as design work, preparing quotes and meetings, in which papers can be left without the danger that they will be grabbed by someone for a quick phone message or sketch.

c) Three Workshops

(1) Figure 10 shows the workshop space from the previous figure detailed with furniture and equipment used. Three free-standing benches are placed along the

back wall of the main workshop space, from there they have a view of all other facilities in the workshop. There is a shelf and blackboard behind each bench. Two lathes are at right angles to each other and share the same operating floor space which allows three metre clear feed to either lathe to facilitate coil winding. A trolley is kept between the lathes which carries torches, tips, inset water bucket, etc. and each lathe is provided with a panel of gas connections like that shown in Figure 5. A teaching bench with places for ten students doubles as a set-up bench when not in use for teaching. It is provided with electricity, water, air and gas services. At one end of this bench, right in the middle of the workshop, is a safety station with sink, eye-wash, mirror and towel dispenser. The remaining wall space is utilized for the main oven, a fume cupboard and storage cupboards. The flooring is linoleum with expanded metal mats under the lathes.

The cold-working area is fitted with stainless steel sink bench with two large sinks, and carries the usual assortment of saws, grinders, etc. which share the same central access space. The floor here is overlaid with Safteytred (Ref. 5), a rubber duck-board system. The second half of this room has been fitted with tubing racks facing each other and walled in.

As shown in the previous figure the gas store is separate from the workshop, the gas control panel is mounted behind the workbench in the main workshop.

(2) The second example (Figure 11) is a one to two person workshop for a commercial enterprise. This workshop is designed to handle custom and small run production work. It has two benches of the same type as those in the first example and a side bench with cupboards for set-up which carries a sink and safety station. The lathe is placed under the window on the south side (southern hemisphere), again the central floor space is kept clear and allows a three metre approach to the lathe. A central service trolley is used, and the oven fills in the fourth side of the workshop space. The cold-working room and tubing and general storage use the space across the back of the facility and a small office is at one side (the workshop shares office and reception facilities elsewhere in the building).

An unusual feature is the treatment of the loading dock. The building is fitted with 3.5 metre warehouse type roller door, and as ready access was required for both truck deck height and street level goods reception and dispatch, a 1.2 metre high loading dock was included which is only 2 metres wide, leaving 1.5 metres free at ground level. The gas is reticulated from outside the building and controlled from inside the workshop.

This workshop fills only half the space in its building, the space behind being used at present for storage and the rear two partition walls have been designed to allow for future expansion of the workshop, by moving them back into this space.

(3) The final example (Figure 12) is also a design for a two person workshop and also features a large roller door for goods access; the problem with this design was the awkward shape of the space provided. As this design never proceded past the feasibility study level, the drawing is not as detailed. The most important factor in designing for the awkward space is to establish the floor space (usually rectangular) required for the primary facilities, establish access and vision between them and then fit the other facilities around them.

A rectangular space was allowed for the lathes. Only one lathe is shown although provision was made for two, which would either be at right angles in the space or facing each other across it (with the office door moved onto the next wall). The cold-working space with, in this case, a single sink bench also takes a rectangular space against the opposite wall. The work benches take the remaining straight space along the back wall. These are placed together, which is not ideal, but they do have

access to either end. The oven takes up the remaining wall space in the workshop area. The two odd shaped spaces left are used for office space and access and storage. A loading dock placed a the roller door doubles as a tubing rack; this places tubing stored a little low but uses space otherwise lost. Space around the loading dock is used for goods received and dispatched and storage for the workshop.

The key to this design is in establishing the rectangular and straight line requirements and having these meet in shared access space. Of these facilities only the coldworking area is walled off as a rectangle, to isolate noise and contamination.

This paper does not attempt to establish the requirements for furniture and fittings; information on these is available in any architectural handbook. What is intended here is to outline the specific requirements for a glassblowing workshop and glassblowing machinery so that these may be incorporated into the plan of a workshop from the outset, rather than added afterwards as is frequently the case. There can be no doubt that physical working conditions are a factor in work performance. I have personally seen a considerable rise in workshop output which came from moving the same staff and equipment from a substandard workshop to a purpose designed one, which was both more pleasant and easier to work in. While this paper deals with the design of complete facility, it is to be hoped that at least some of the concepts covered may be applicable to existing premises.

ACKNOWLEDGEMENTS:

The author would like to express his thanks to Murray Hamilton for the drawings, Brian Connor for the photographs and fellow Otago glassblowers for advice and assistance.

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3. "Atmospheric Conditions in the Workplace" New Zealand, Department of Labour, Wellington, New Zealand.
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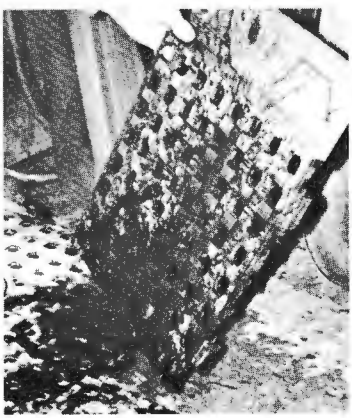

Figure 1: "Safetytred" rubber interlocking flooring.

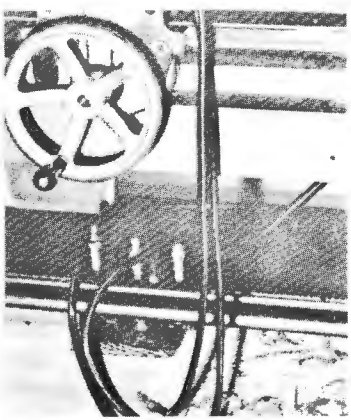

Figure 2: Expanded metal mesh mat under lathe.

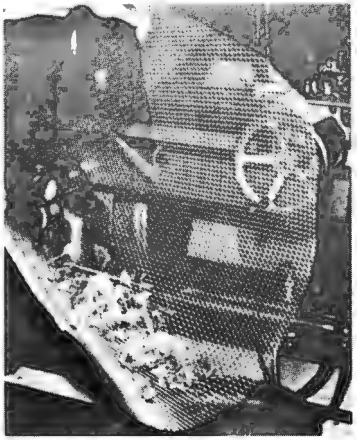

Figure 3: Mat being emptied.

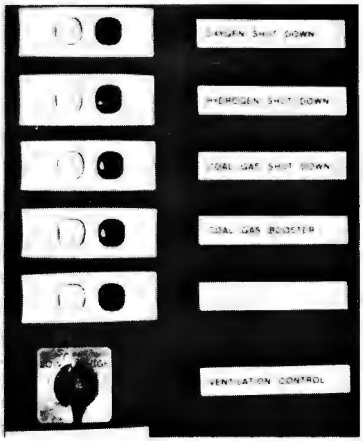

Figure 4: Control panel for workshop gas supply.

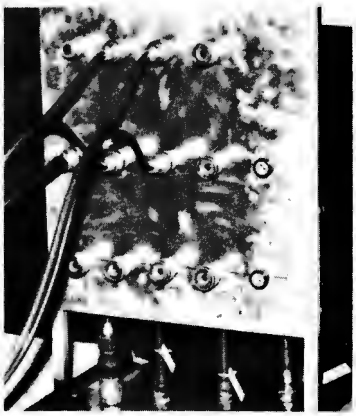

Figure 5: Connection panel for gas supply.

Figure 6: Cubicle bench arrangement.

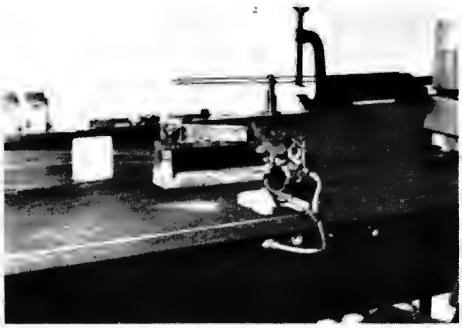

Figure 7: Wall bench.

Figure 8: Free-standing bench.

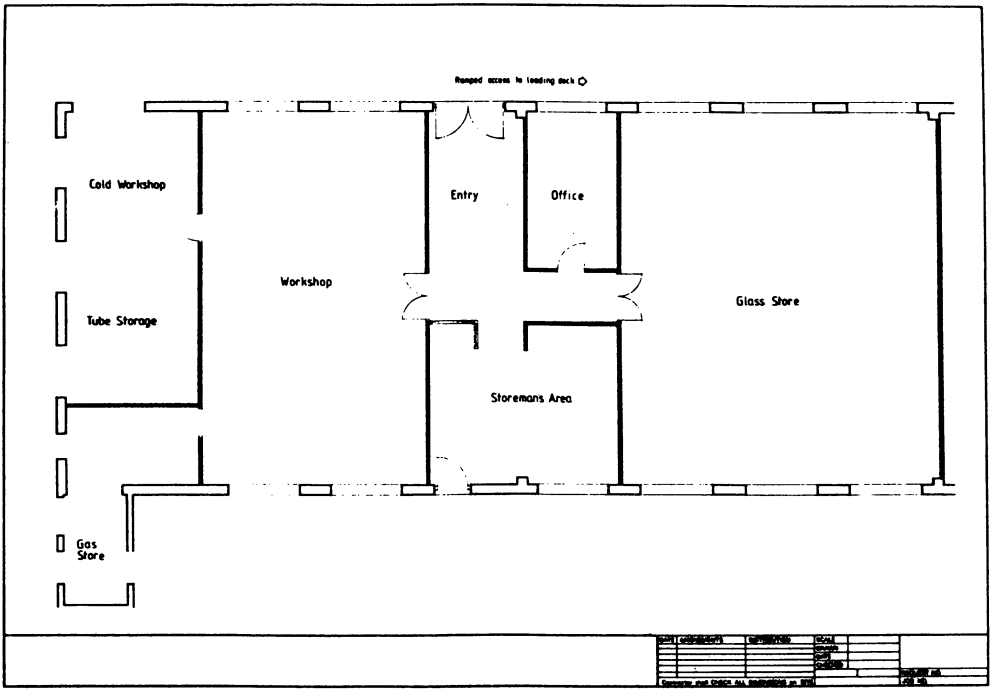

Figure 9 – Building space divided into areas

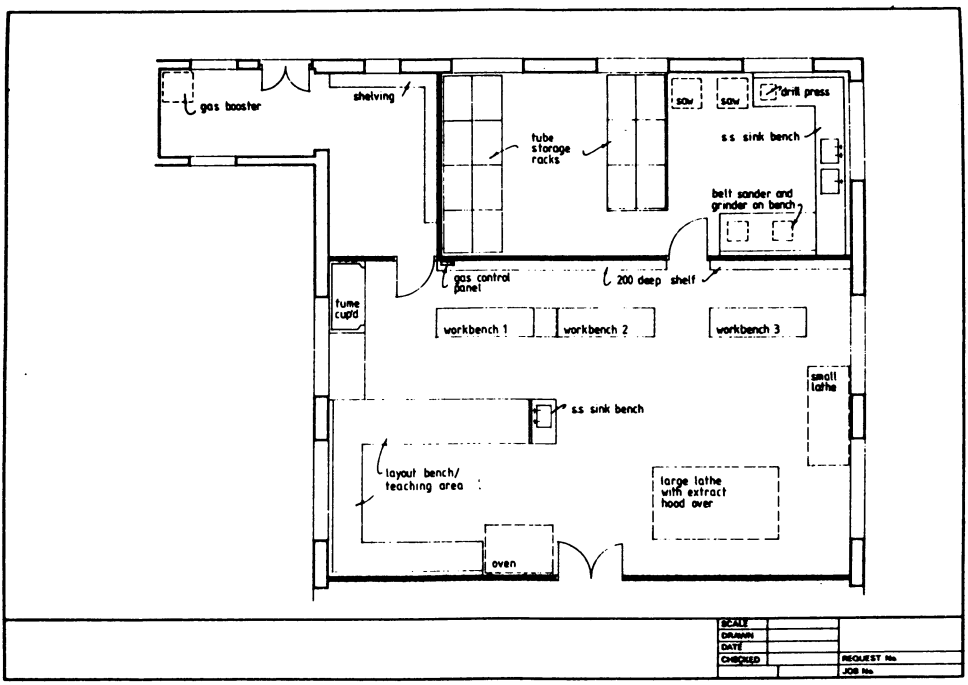

Figure 10 – 3 - 4 person workshop with teaching space for a university.

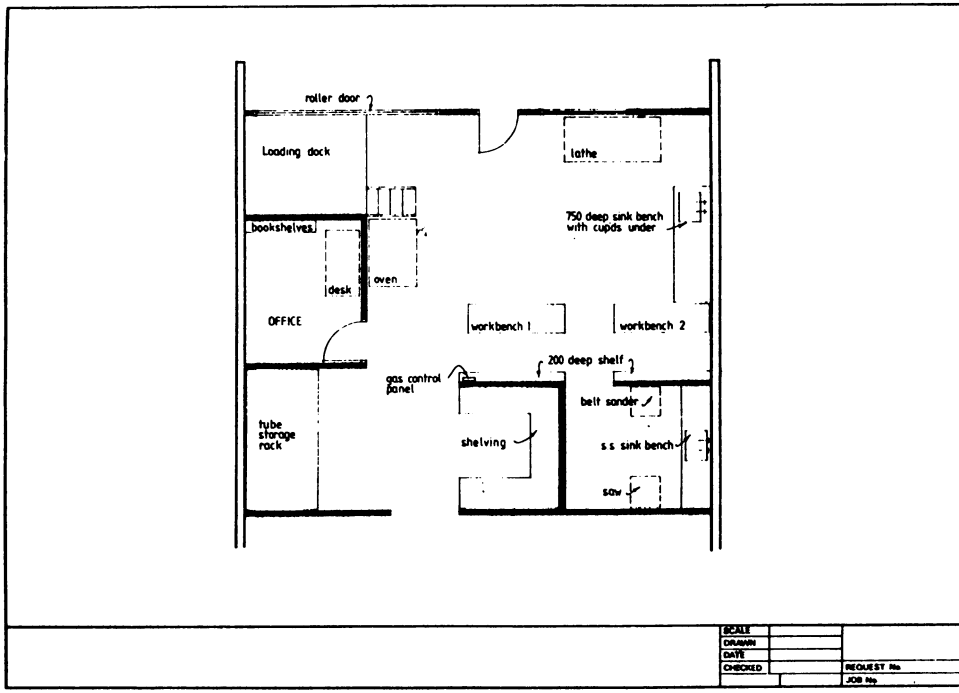

Figure 11 – 1 - 2 person commercial workshop.

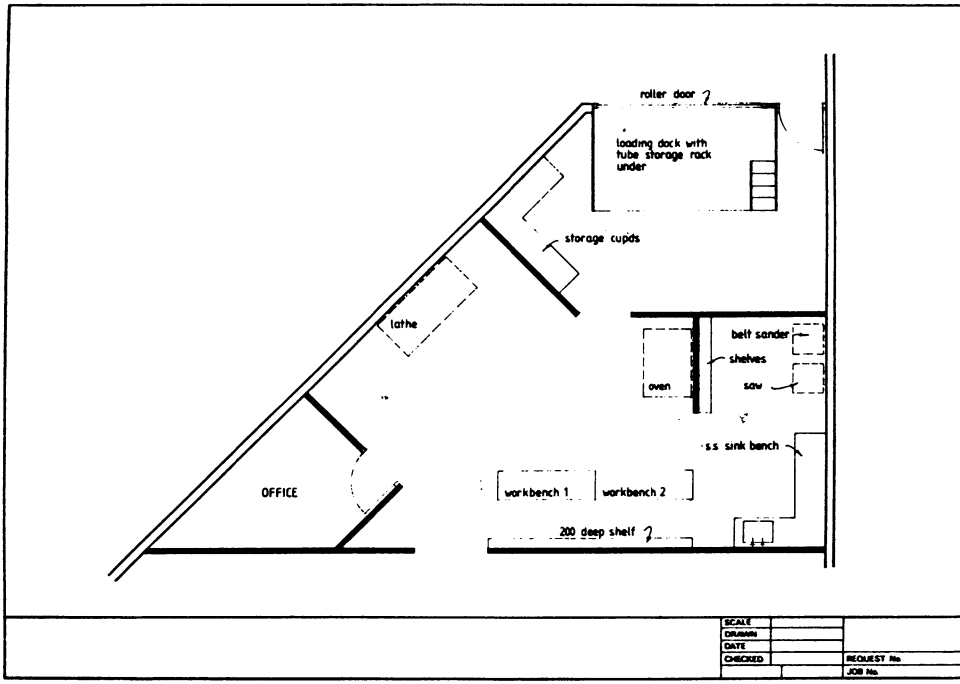

Figure 12 – 1 - 2 person workshop to fit an awkward space.

APPARATUS FOR CHEMICAL PROCESSING: ABSORPTION, DISTILLATION (RECTIFICATION) AND EXTRACTION

Karl Heinz Liedel
Mannheim, West Germany

Technical glass finds so many applications in the modern laboratory that it would take too much space here to list them all. You will find glass in the laboratory in a wide range of forms, from the simple bottles, flasks, test-tubes to complex constructions for chemical processing or analysis methods. Each application needs a great deal of know how, from the manufacturer as well as from correct handling by the customer.

Glass can be put to use in so many different ways in a modern laboratory, that simply to list all the possibilities would take up an excessive amount of space. Glass is such an unthinkingly accepted part of a chemical laboratory that it is hard to imagine life without it. In this paper no attempt will be made to cover more than a part of this very broad field, rather the subject of thermal separation, especially distillation and rectification columns will be looked at in detail.

Distillation columns are usually constructed of borosilicate glass and in some special cases quartz, fused silica and Vycor. The thermal separation processes, like distillation (direct flow- and counter flow-distillation), extraction and absorption are processes during which mass-and heat exchange between gases, vapours, liquids, and solids, from one phase to the other occur.

The quality of the apparatus determines the purity of the products and the speed and efficiency of the process. Distillation is one of the best known processes in chemistry and is so important that it has been devleoped to a high degree in both laboratory and industrial processing. In several branches of chemistry distillation laboratories have been established for continuous or batch working, either to prepare small quantities of valuable substances or gain experience with substances or mixtures during the distillation, to help in the planning of big industrial plants, or for comparison and simulation tests.

Simple distillation or direct flow distillation (Figure 1 a+b) is the separation of the mainly liquid mixture through (partial) vaporization of one component. Rectification, or fractional or counter flow distillation, needs a column, the rising vapour is condensed in the condenser (cooler) and a part of the condensate is fed back into the column in a certain reflux ratio. The rectification involves a forced mass- and heat exchange in the column, with which a better and multiplicated separation is achieved. Rotary evaporators as used in modern laboratories are very successful distillation apparatus, in spite of the expense of the mechanics and electronics: impulse required to drive the rotating vaporizerflask in a thermostatic heating bath. Rotary evaporators are an example of direct flow distillation.

Rotary evaporators are universal apparatus suitable for evaporating solvents, concentrating solvents and extracts, normal- and vacuum-distillations, as well as for reactions and crystallization drying processes. They generate a liquid film at the inner wall of the vaporizer flask in the heating bath, which renews itself all the time. It produces a large evaporation-surface with a good heat exchange between flask and heating bath. Therefore quick and gentle evaporation at a low temperature-gradient is possible. Foaming and delay in boiling is generally avoided in the rotary evaporators (Figure 1 c).

Rectification or fractionation -called in the laboratory column distillation- it is possible to separate mixtures whose components have smaller differences in boiling

points, sometimes to less than 0, 5 K, or even, in istope separation 0,05 K. The constructional characteristic of a rectification column is the column-head between column and condenser, which may be desired either as liquid or vapour dividing column-heads. The function of the column heads is to serve to adjust the reflux ratio on a time basis, electromagnetically or pneumatically controlled by automatic controllers. The liquid dividing column heads regulates the condensate from the total-reflux-condenser via a pivoting funnel as reflux to the column and when distillate is being taken off the pivoting funnel is moved electromagnetically and the condensate directed to the receiver. The vapour dividing column heads consists of two separate condensers for reflux and distillate, the vapour flow being regulated by solenoid controlled glass valves. (Figure 1 d) In reflux position all vapour is returned to reflux condenser, and when distillate is being taken off the reflux condenser is closed and the vapour passes to the distillate condenser. This construction is free of dead space and suitable for low and medium loading conditions for columns up to 50 mm diameter.

The vapour dividing column heads are independently of the loading of the column or the viscosity or surface tension of the distillate. The reflux discharge ratio of the distillation columns can rapidly and reproducible adjusted to almost any required value.

The rectification columns are divided in two groups: 1 columns with fixed mountings like wetting-, plate-, packed-, pulsation- and spraying-columns and in 2 columns with stirred mountings (flights, etc.) like thin film-, molecular-, rotation- and crystallization-columns. The commonly used types of columns in the laboratory are the packed- and plate columns. Packed columns combine good separation efficiency with high throughput, less holdup and minimal pressure drop preferable for hydrocarbons with good wetting properties.

Packed columns provides more theoretical plates by a given height in relationship with plate columns. From the glass aspect a packed column is a simple and cheap construction: a tube packed with Wilson helices in glass, Raschig-rings, wire mesh rings, wire spirals, wire gauze packings and metallic or ceramic packings.

Some factors have to be taken into consideration for selecting the most suitable apparatus for separation processing. The design depends mainly of the chemical and physical properties of the distillation mixture. The glassblower normally is not in possession of all the information about the mixture, either it is corrosive, or acid or aqueous solution, foaming, cracking, crystallizing, polymeric, combustible or toxic, etc. and the form of apparatus also depends on the size of the charge, etc. The selection from columns for separation processes have to be considered, because problems of operation charges, big or small, continuously or not, pressure conditions, all the facts will be cleared before operations be done. The choice of a distillation column is always specific to its application.

Plate columns like sieve-(perforated)plate and bubble cap tray columns are mostly preferred for laboratory separation processings. Sieve plate columns (Figure 2 a+b) used for high throughput in petrochemical laboratories, the equilibrium conditions are more difficult to regulate than a bubble cap tray column. The plate columns such as bubble cap tray columns obtain optimum results, a wide loading range and rapid equilibrium adjustment by high efficiency for wholly glass constructions. This type of plate column (Figure 2c-4) is nowadays well constructed by liquid- and vapour-flux for optimal mixing of the phases up to a high efficiency. Glass bubble cap tray columns requires a high skill from the glassblower, from his knowledge and work depends the precision of the column and their measured datas about substances, simulation- and comparison tests. For the glassblower important is the arrangement of the bubble cap trays at the plate,

spaces, liquid- and vapour leading pipes, dimensions of them, height of the weir and covering, the form of the slitting caps, etc. By this case the overflow pipe is constructed for e.g. with dividing wall in the overflow pipe and ventilates the gases. At the other side a good hold up from the liquid of the plate is also necessary. The construction of columns are not fixed for all times, special distillation problems requires cooperation between glassblower and laboratory assistant or chemist. It is true, that presupposition of a good result of a distillation is the information about substances, mixtures, their problems and the combination of an appropriate plant and to know the many-sided possibilities of such a unit. It is possible to work with bubble cap tray columns for processings like absorption, reaction and rectification.

The Labodest ® -bubble cap tray columns by Fischer and Stage (Fig. 4) are all-glass constructions for the operation under vacuum or over-pressure up to approx. 3 bar. The special characteristic of the bubble cap construction is the fact that in the bent edge of the bubble cap there are two cavities designed for liquid inlet (1) and outlet (2) which are of different heights by some millimeters, facing each other and situated approx. 90 degrees in opposite of the dividing wall.

As the dividing wall (3) is essentially standing out from the bubble cap and is closely moulded with it on both sides, the reflux (4) from the plate above must flow down in a semi-cycle on the left and right hand side around the bubble cap so that it can flow in the direction of the discharge tube (5) via the overflow edge.

In this construction 10% of the column sectional area is available for the rising vapour (6) within the column. This columns are fabricated with diameters from 50 to 100 mm, built-in length 500 to 1400 mm, number of plates 5 to 10, with heating or cooling jacket or with silvered vacuum mantle, and with nozzles for temperature measurement and sample take-off at each plate.

A new plate column construction is the slit bubble cap tray column of Guenzler and Rust. (Figure 5) The plate column is glasstechnical very important, because it come to low tensions in the column, the column-tube has only fused rings inside, of which the slit caps are punctual fixed with rod fused points. The overflow pipe is concentric arranged and combined with covering and funnel. With this new developed column, the liquid- and vapour guidance becomes most favourable and therefore the phase limit area is larger. The plate efficiency is very high from 100% up to 72% by total reflux and column-diameters from 50 to 200 mm. An exception of separation columns are the "Spaltrohr"-column by Fischer and Stage. The "Spaltrohr" consists of two concentric fused calibrated precision tubes with spiral ground profile on both sides. (Figure 6+7)

The separation efficiency is very high, the column permits operations at atmospheric pressure down to a low vacuum of 0,001 mbar. The operating content in a "Spaltrohr" with 1000 mm length is approx. 1 ml, number of theoretical plates up to max. 90. The "Spaltrohr" find their applications in the field of micro-, semi-micro- and preparative distillation under fine vacuum conditions. The "Spaltrohr" is perfectly suitable for separations of temperature sensitive substances, distinguished by extremely low pressure losses and a minimum hold up.

The extraction methods are divided in two groups: 1 solid-liquid and 2 liquid-liquid extractions. Figure 8 a-c shows apparatuses for solid-liquid extraction with periodical reflux and throughput-extractors (hot extraction). With the hot extraction it is possible to save 50% of the time of a normal extraction (cold extraction like Soxhlet-extraction), the method is only applicated for not thermal sensitive substances. Figure 9 a+b shows apparatuses for liquid-liquid-extractions with specifically light or heavy solvents. The light extraction agent rises from the

distributor to the top and then it flows back into the flask with the extract, while the heavy extraction agent takes the reverse way and sinks through the liquid which must be extracted. A stopcock, double bored with hollow plug, direct the extract into the flask, one position is for periodical and the other for continuous reflux.

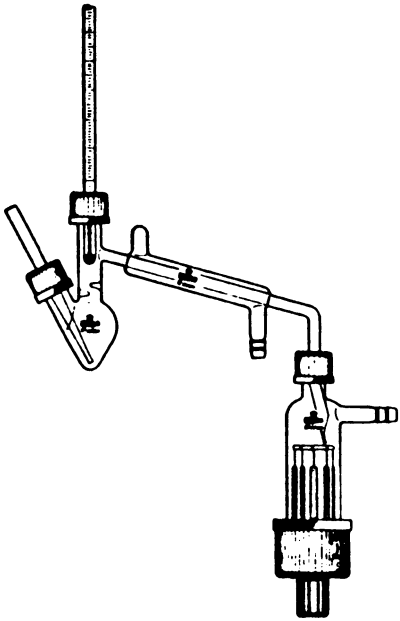

Figure 1a – Micro-distillation apparatus (direct flow distillation with inclined fused-on condenser and turning receiving tubes) Witeg, Wertheim.

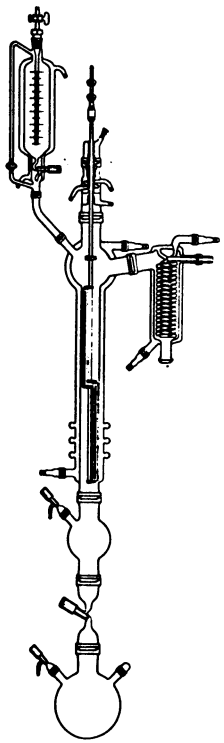

Figure 1 b – Thin film evaporator-system CWH- with descending condenser, for the gentle distillation of thermal sensitive products. (Normschliff, Wertheim)

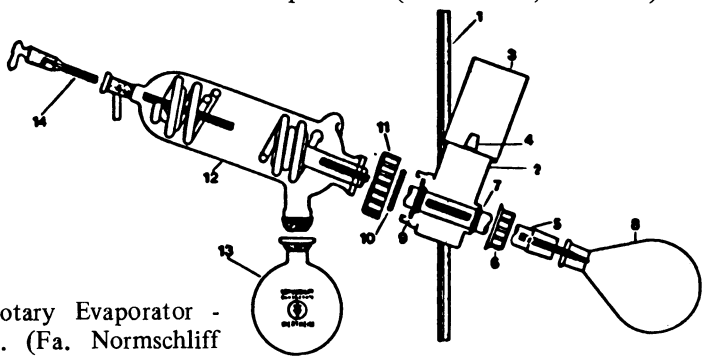

Figure 1 c – Rotary Evaporator - General Assembly. (Fa. Normschliff Glasgeräte, Wertheim)

1- Stand; 2- Adjustment ring for various inclination; 3- Drive unit; 4- Speed control; 5- Hollow shaft with conical joint; 6- Screwed collar ring for fastening the hollow shaft; 7- Clamping ring; 8- Evaporating flask; 9- Vacuum gasket (lip seal); 10- Clamping spiral; 11- Screwed collar ring; 12- Condenser; 13- Receiving flask; 14- Feed tube.

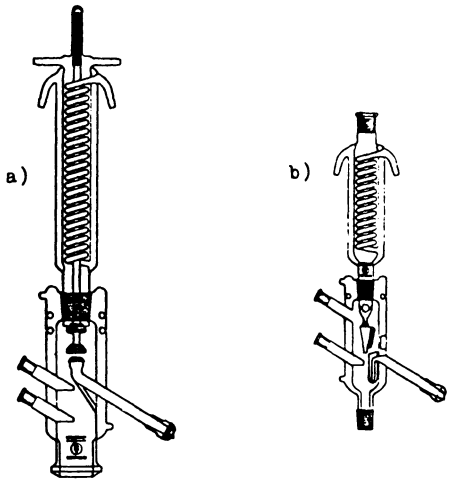

Figure 1d – Column heads: a) vapour dividing head; b) liquid dividing head (pivoting funnel). (Normschliff, Wertheim)

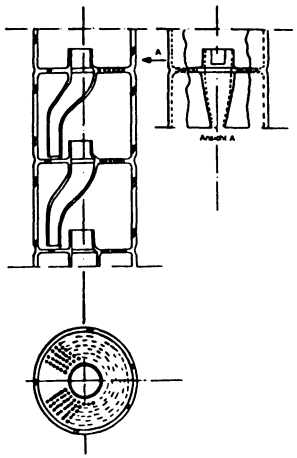

Figure 2a – Perforated plate column by Oldershaw.

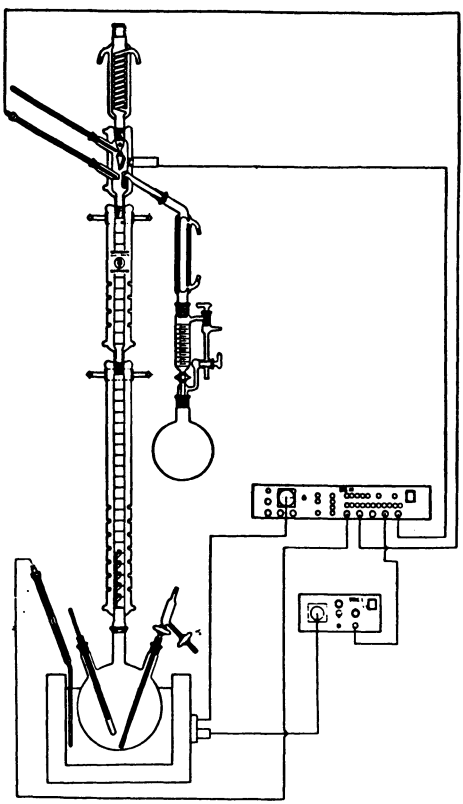

Figure 2b – Distillation plant with perforated plate columns, batch distillation. (Normschliff, Wertheim)

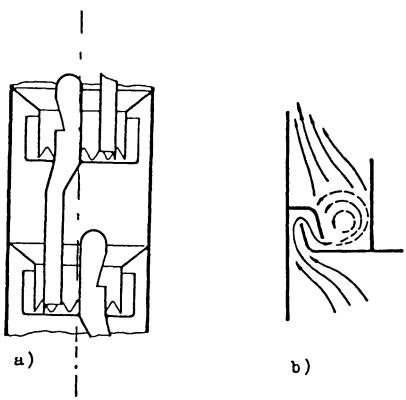

Figure 2c – Plate column by Stage: a) Scheme of "Dampfprallboden"; b) Flow diagram of the vapour.

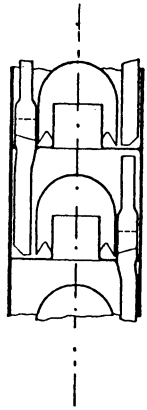

Figure 3a – Scheme of a bubble-cap-tray-column with covered weir and overflow pipe by Stage.

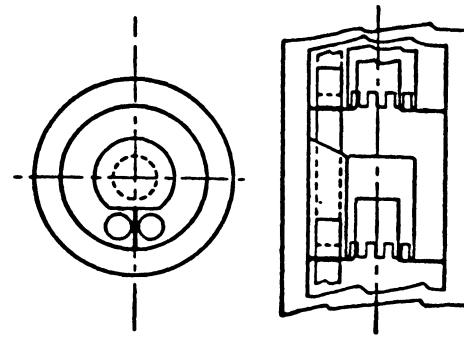

Figure 3b – Scheme of a bubble cap tray column with fused glassweir between pipes for inflow and overflow by Schmickler and Fritz. (Otto Fritz GmbH, Hofheim, Taunus)

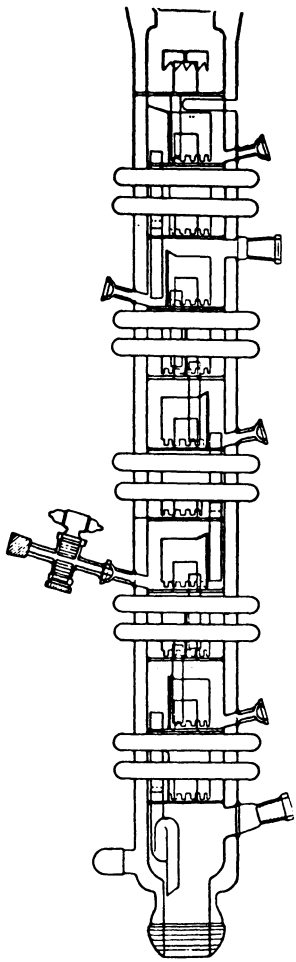

Figure 3c – Bubble cap tray column by Schmickler and Fritz with vacuum jacket, general assembly for testdistillations. (Otto Fritz GmbH, Hofheim)

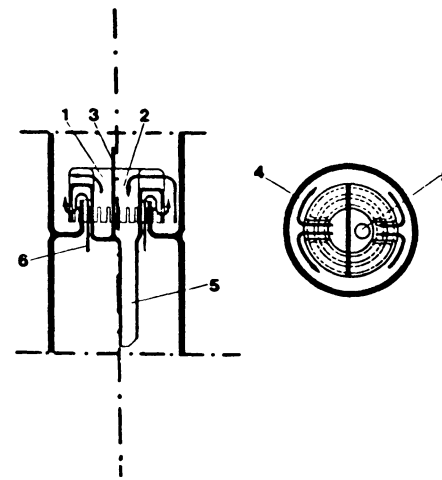

Figure 4 – Scheme of the plate construction by Fischer and Stage in sectional and top view. (Fischer Labor-und Verfahrenstechnik, Meckenheim/Bonn, W.-Germany)

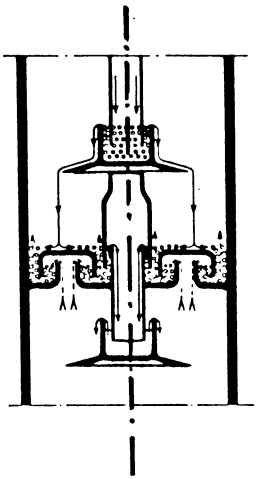

Figure 5 – Scheme and flow diagram of a slit-bubble cap tray column with an inner diameter of 50, 80 or 100 mm by Günzler and Rust.
(Normschliff, Wertheim)

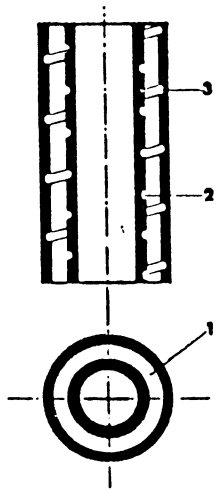

Figure 6 – Scheme of the Spaltrohr™ - Column (Fischer Labor-und Verfahrenstechnik, Meckenheim/Bonn, W.-Germany) – 1- Column-Ringgap; 2 and 3- Ground Profile.

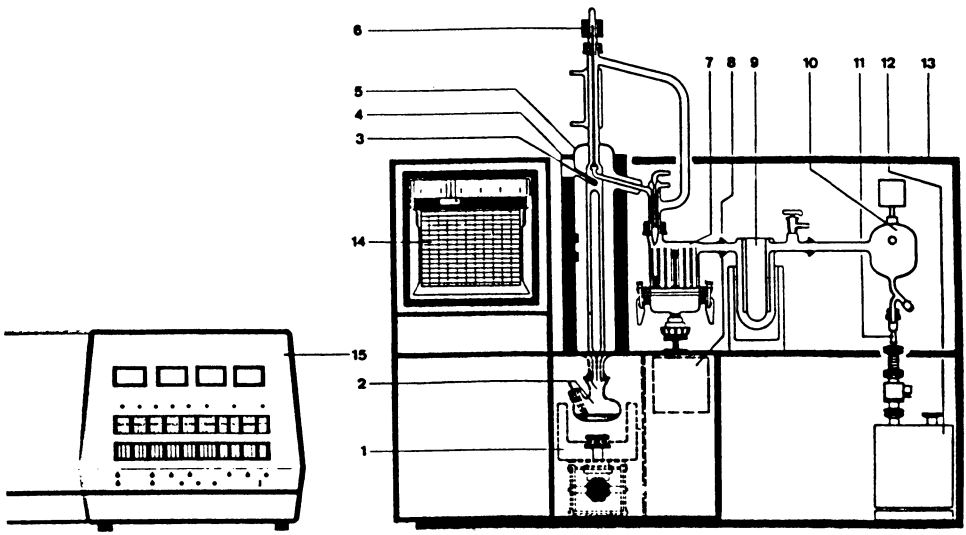

Figure 7 – Spaltrohr-distillation-plant. 1- oilbath with lifting platform and stirrer drive; 2- distillation flask; 3- probe head; 4- heating jacket; 5- column; 6- solenoid coil; 7- fraction collector; 8- drive; 9- cold trap; 10- buffer vessel; 11- vacuum line; 12- vacuum pump; 13- assembly frame; 14- recorder; 15- automation system. (Fischer Labor-u. Verfahrenstechnik, Meckenheim b. Bonn)

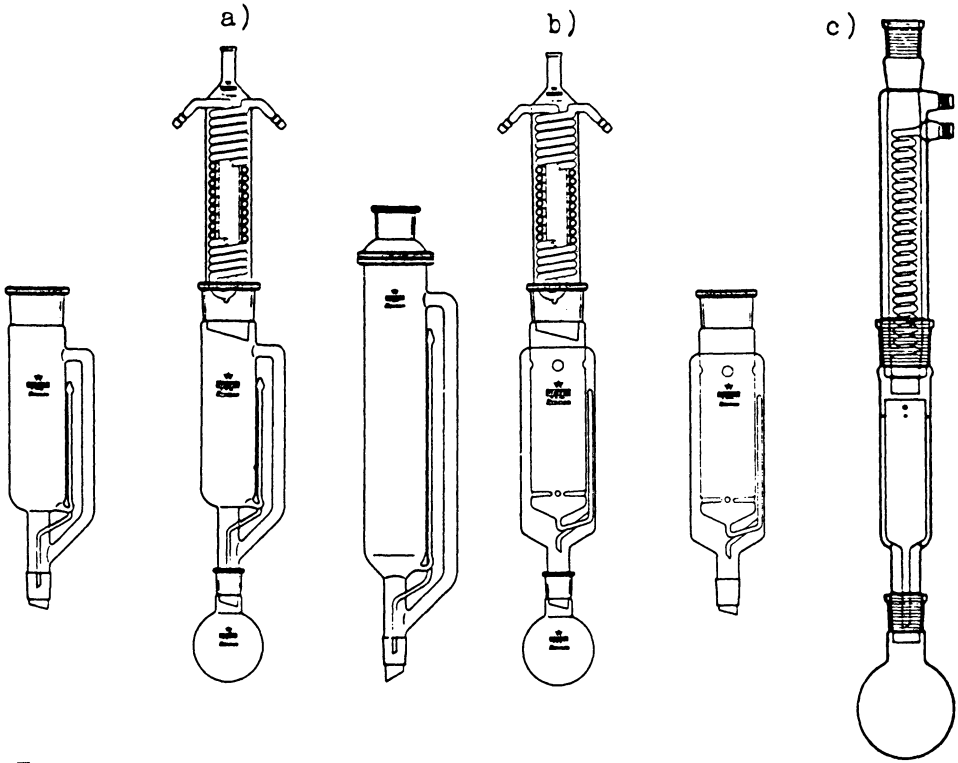

Figure 8 – Solid-liquid extractors: a) Soxhlet; b) modified by Böhm (jacketed extractor), Soxhlet principle; c) throughput-hot-extractor by Knöffler; a+b) (Witeg, Wertheim); c) Otto Fritz GmbH, Hofheim, Taunus.

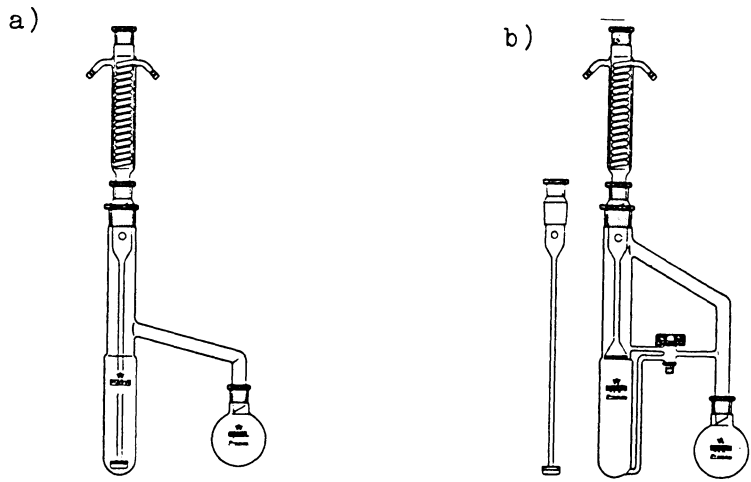

Figure 9 – Liquid-liquid extractors: a) for lighter solvents; b) for lighter and heavier solvents (combined version). (Witeg, Wertheim)

MULTIPLE WINDOWED QUARTZ CELL

by

Robert J. Ponton
Department of Chemistry
University of Wisconsin – Milwaukee

This paper will show techniques used in the construction of a quartz cell consisting of seven "compartments" separated by six windows and capped with two end windows (Fig. 1). Free gas movement into these "compartments" is accomplished by grinding two flat slots on opposite sides of the insert piece. These 6mm openings are sufficient to allow gas movement.

This cell is currently being used to observe surface absorptions of gases into the quartz. Experiments using standard two window cells showed a possible connection between loss of signal and the surface area of the quartz. By adding six more parellel windows the absorption rate should increase by a factor of twelve.

Figure 1

CELL CONSTRUCTION

The cell was made in two parts – the outside or sleeve was constructed as a standard two window cell (Fig. 2 No. 1). That cell being a quartz tube with parallel windows sealed at each end 90° to the axis of the tube.

The insert piece was more of a challenge (Fig. 2 No. 2). First, I selected tubing that would just fit inside the outer body. This tubing had to fit very snug. I cut four lengths of this tubing to ½" lengths and one to a 1" length. Two more pieces were flat bottomed with a small indentation in the center of the bottom. The indentation will accommodate a sharpened 3/8" carbon rod used during the final window sealing operation (Fig. 2 No. 5). These were also cut about 1" in length. A small vent hole was cut in the side of all seven pieces (Fig. 2 No. 4).

Figure 3

As explained in a paper given in 1977 by David Blessing of the University of Notre Dame, I ground and polished the open ends of the insert tubes and the ends of the outside jacklet in preparation for the low temperature window seals (Fig. 3).

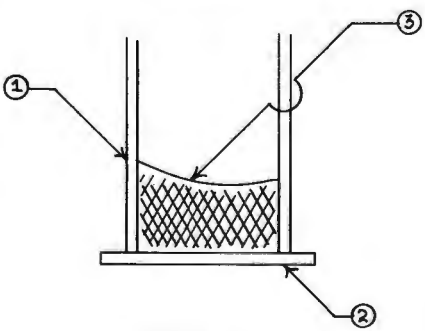

Figure 4

Finding windows from a standard catalog of the exact diameter to allow them free travel inside the cell body was

Figure 5

Figure 6

Figure 7

nearly impossible. To grind the windows to the proper diameter, I cut six more pieces of the tubing used for the insert spacers. These tubes were then used as templates to hold the windows while I ground them to the required size. Using black wax, I fixed ¾" windows to the ends of these tubes (Fig. 4). Grinding the windows until they matched the outside diameter of the tubes gave me the desired window size. To remove the wax, I soaked it in acetone, after which I ran the windows through the oven for final cleaning.

Assembly of the insert piece was as follows – I placed one of the tubes with the flat bottom on the table, open end up. Positioning the window and one of the ½" lengths on top, I then capped it with a second window. Holding this all in place with a ring stand and carbon rod, I was able to check the alignment with a section of the same size tubing as the main cell body (Fig. 5). This tube was carefully rested on the top of the assembly during the sealing process (Fig. 6).

Using a hand torch with a small tip, the bottom window was sealed to the adjoining tubes. I allowed this to cool for purposes of handling. Also, if hot, the alignment tube will hang up as you try to slide it over the heated section. All other window seals were accomplished in the same fashion. The alignment "problem" becomes more of a concern the higher you go. When stacking the insert pieces, be sure to keep the vent holes all in a line. This is so you can replace these holes with a common gas access slot.

The completed piece was now ready to be ground open. To accomplish this, I used 120 grit carborundum slurry and a lapping wheel (Fig. 7). I ground until I'd opened a 6mm slot down the length of the piece. Rotating 180°, I repeated the procedure (Fig. 2 No. 7). All that remained was to carefully cut the inner assembly to the appropriate length and clean (Fig. 2 No. 6).

Final assembly is accomplished by simply sealing a window on one end of the outer body. Turn the cell over and slide the inner assembly into the cell and cap with the final window (Fig. 8).

The cell now has almost 12 times the surface area. By using this method of low temperature window sealing, a distortion free light path has been maintained without increasing the size of the cell (Fig. 9).

ACKNOWLEDGEMENT

I'd like to thank David Blessing for his paper on windows from 1977 and his many demonstrations on window sealing from which this paper is a direct descendent.

Figure 2 – 1) Standard Quartz Cell Body; 2) Insert Piece; 3) Quartz Windows; 4) Vent Holes; 5) Indentation for Carbon Rod; 6) Final lengths (Cut); 7) End View After Grinding.

Figure 4 – 1) Same Size As Insert Tube; 2) ¾" Quartz Window; 3) Black Wax.

Figure 8 – 1) Carbon Rod; 2) Assembled Cell.

REFERENCE:

The Optical Window and What We Can Do With Borosilicate, Quartz and Sapphire by David Blessing, University of Notre Dame, 1977 A.S.G.S. Symposium Proceedings, pp. 26 - 32.

Robert J. Ponton

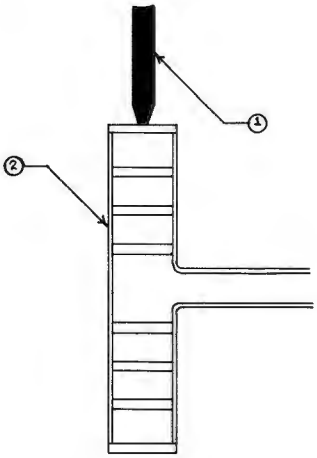

Figure 8

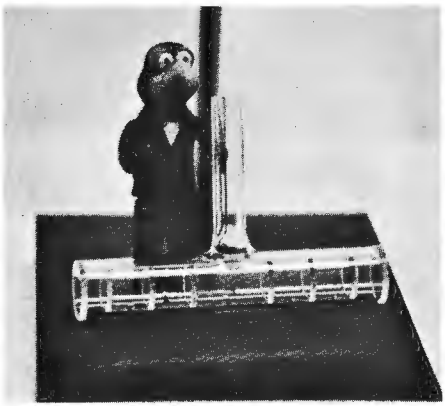

Figure 9

"GLASSING AND ASSEMBLY OF A FIVE WATT CONTINUOUS WAVE MAGNETRON"

Raymond F. Steiner *(Owner)*
Twin Industries
Ann Arbor, MI 48103

INTRODUCTION

During the time I was employed at the U. of Michigan Electron Physics Laboratory there was a need to produce a very small tube that could be used for research in the laboratory. There was a considerable amount of research to be done and this funding primarily came from the U. S. Signal Corps, using the University of Michigan equipment, which included an excellent machine shop and laboratory and items like a Brew Vacuum Furnace, Hydrogen Bell Jar, Stewart Hydrogen Furnace, three Litton Glass Lathes, Two vacuum stations, 10KW RF Generator, Leak Detectors, Heliarc Welder & a small dc arc welder for hydrogen atmosphere welding.

The materials used to build this small tube were: Kovar, OFHC copper, molybdenum, tungsten, monel, platinum, ceramic, lava and glass.

The purpose of this paper is to cover some of the techniques used to build this small tube. Needless to say, there are many techniques that have been used by well known electron tube manufacturers over the years.

BODY

In **Figure 1** we see the tube without the cathode inserted. The center conductor is 5/16 dia. Kovar tubing onto which is brazed OFHC copper fingers. The outer conductor is 3/4 dia. Kovar tubing into which are mounted small OFHC copper vanes equally spaced, thus creating an electrical interaction area between the center conductor and outer conductor, which are then insulated and equally spaced from each other with two discs of 7052 Corning glass.

In **Figure 2** we see the exact scale of the tube body for size. The assembly for the outer conductor is done by placing six copper vanes with the Kovar cylinder into a chrome oxidized 303 stainless steel fixture to Au-37% - Cu-63% braze the vanes and cylinder together. Melting point is 1040°C. This assembly is put into a temperature controlled hydrogen furnace for brazing. Fifteen mil Au-Cu wire is used.

The assembly of the six finger copper piece and Kovar pc is done with 303 chrome-oxidized stainless fixturing. A fifteen mil Au-Cu-ring is placed between the two parts for joining by heating in a temperature controlled hydrogen furnace to 1040°C.

Once the center and outer conductor are brazed there remains one brazing operation to be done before insulating and aligning them with glass.

Both brazed assemblies are placed in precision ground V-blocks on a ground surface plate where a center line is scribed along the axis of each unit. On the outer conductor the center line is scribed on the center line of one of the six brazed in place vanes. On the center conductor a scribed line is made along the Kovar axis. This line is located accurately between the copper fingers brazed to the 5/16 dia. Kovar so that when the final braze of the finger end cap is made the fingers are interdigitally located with respect to the vanes of the outer conductor assembly.

With a special chrome oxidized 303 stainless fixture, the two assemblies (center conductor and outer conductor) are placed together so that the copper end cap bushing can be hydrogen brazed at 1000°C with Au-37%-Cu-63% Wesco alloy to the

fingers of the center conductor. Now, the unit is ready for glassing on the 5/16 Kovar-copper brazed end. In **Figure 3** the outer conductor is accurately chucked in the headstock of the Litton F lathe and the center conductor is chucked in the tailstock so that the scribed center lines of both assemblies are accurately in line. This is done by using the lathe bed as your base reference and passing a scriber along the lines until indexed correctly. The tailstock is then moved in and out against an indicator until both readings in and out limits are made. That difference is divided in half to reach the correct spacing when the glassing is finally completed.

Glassing is done by feeding in by hand 7052 Corning 2mm cane until a disc is formed between the outer Kovar and inner Kovar conductors. Nitrogen bubbling through methanol is used for blowing the glass and for preventing too much oxidizing of the tube interior. The seal is flame annealed using a National torch with a No. 2 tip.

The metal-to-glass seal on the opposite relative position of the tube is done in the same manner with 2mm glass cane. However, there is a 10.5 expansion gap purposely made between the copper and the Kovar of the center conductor. This allows for coefficient of expansion differential between the outer conductor and center conductor of the tube during operation processing. A glass disc can be formed on this seal to the center conductor before sealing to the outer conductor. This seal is flame annealed also. Both seals are done so they are in a compressed state when finished.

The tube is cleaned of its residual oxides with chemical Oakite No. 32 and a very mild solution of nitric-sulfuric acid. It is immediately washed in distilled water and rinsed with methanol. It is then warm air dried in preparation to receive the cathode-glassing step. In **Figure 4** – The thoriated tungsten cathode consists of Kovar, monel molybdenum, fired lava, tungsten, ceramic, and glass. The center Kovar wire (.060 dia.) is just long enough to accommodate the glass seal safely. It is joined with a moly wire which continues to the top of the cathode. The upper end of the cathode is entirely moly aside from the tungsten filament. The molybdenum is fused together with platinum and the filament is fused to the molybdenum with platinum braze at one end and arc welded in a hydrogen atmosphere at the top end. Special fixturing is used to accomplish this step.

Figure 5 – platinum brazing fixture - filament to molybdenum heat sink.

Figure 6 – Arc welding fixture - filament to moly hat.

Figure 7 – Arc welding hydrogen chamber with pneumatic lift.

Figure 8 – Top end of tunsten cathode completed.

Figure 9 and 10 – Show us the set-up for inserting the cathode into the tube body. Tne correct distance is obtained by measuring accurately the distance from the center line of the interaction vane area to the mouth of the 5/16 Kovar tube. The center of the filament must move this prescribed distance to comply with centering alignment. The tailstock stop is set and the necessary glassing is done to seal in the cathode. This seal also is flame annealed. Nitrogen again being bubbled through methanol is used as a reducer to prevent internal oxidizing taking place. The tube is now ready for the vacuum station.

Figure 11 – Shows a drawing of the tube with an oxide cathode which also was successful.

Figure 12 – Old hydrogen furnace (horizontal and vertical).

Figure 13 – Hydrogen bottle for brazing different alloys to metals.

Figure 14 – Hydrogen bottle set-up for brazing BT silver solder to OFHC copper. This is installing a power output connector on a 500 watt-cw interdigital frequency modulated magnetron.

CONCLUSION

Though the electron tube industry is continuing in a limited way the "state of the art" will not be forgotten or ever be taken lightly. The basics are still being used and the techniques are still being applied. For those of you who may be interested the author has a sample electron tube, described in this paper, for you to look at and examine.

CREDITS

The author wishes to thank David L. Hovey, Technical Papers Chairman of this 32nd Symposium; James E. Panczner, Editor of Fusion, for their counsel to prepare this paper. The author also wishes to thank those engineers J. S. Needle and W. G. Dow with whom he worked while employed at the U. of Michigan 1947-55.

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Fig. 1 - Tube (no cathode)

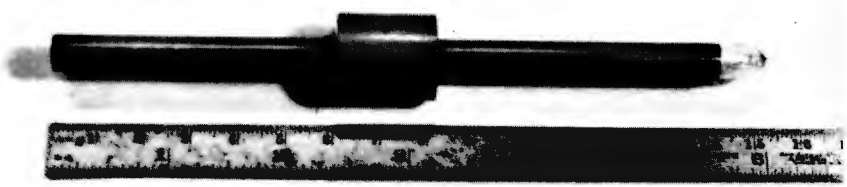

Fig. II

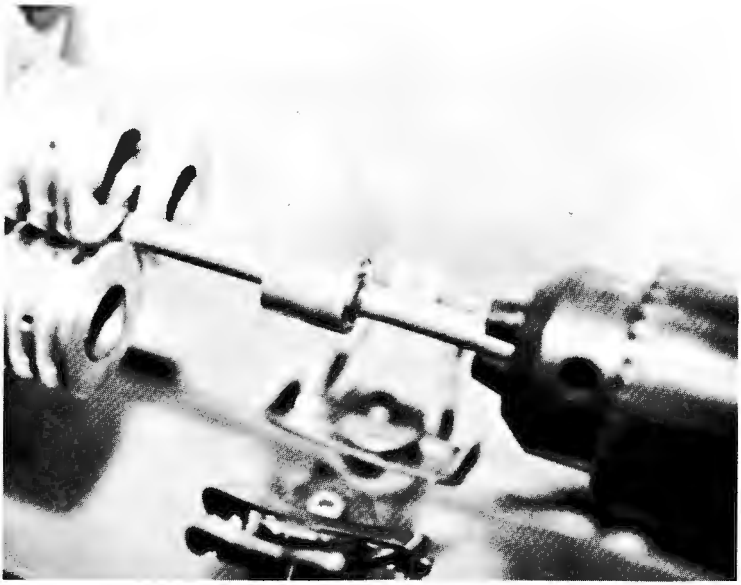

Fig. III

Fig. IV

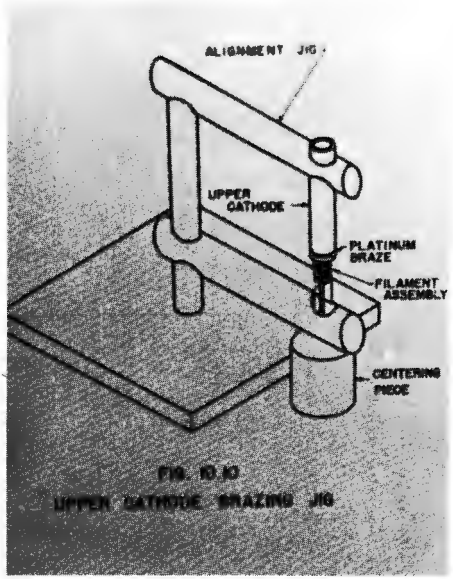

Fig. V

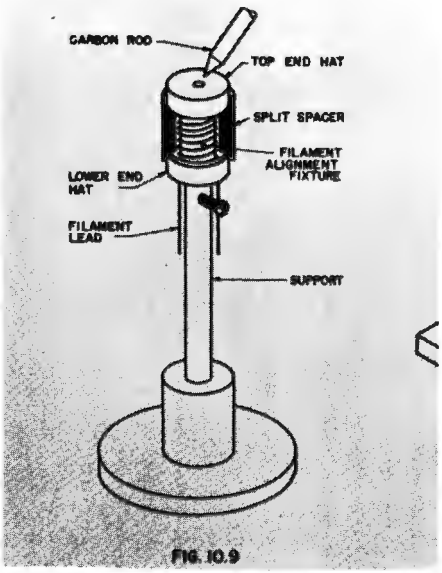

Fig. VI

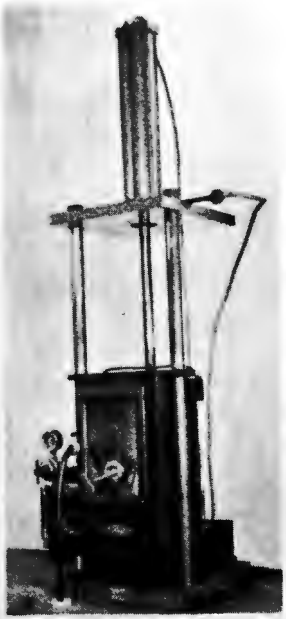

Figure 18.4
H_2 Atmosphere Arc Welder

Fig. VII

Fig. VIII

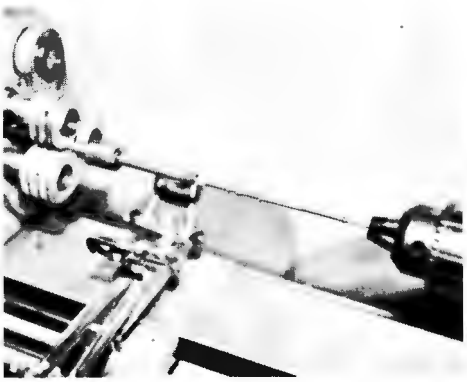

Fig. IX

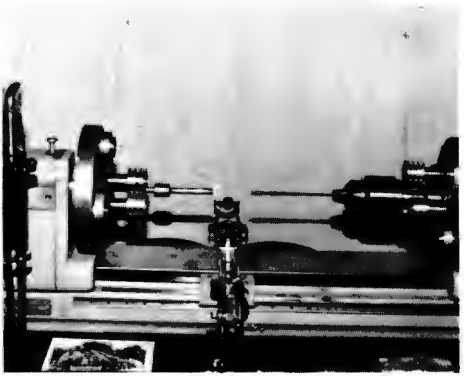

Fig. X

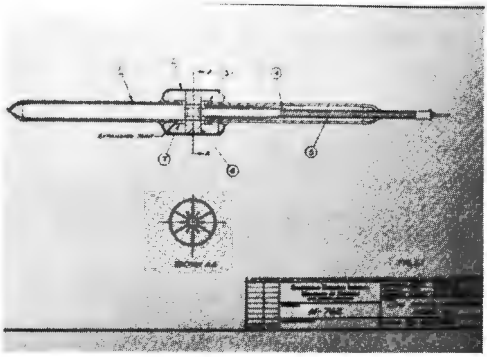

Fig. XI

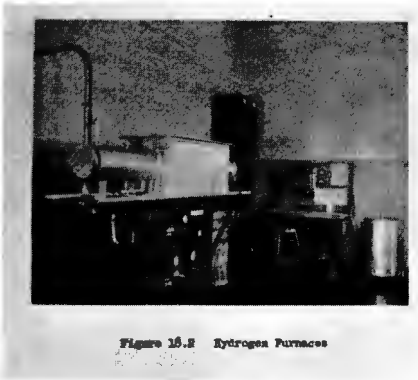

Figure 18.2 Hydrogen Furnaces

Fig. XII

Figure 18.3
Hydrogen Brazing Bottle

Fig. XIII

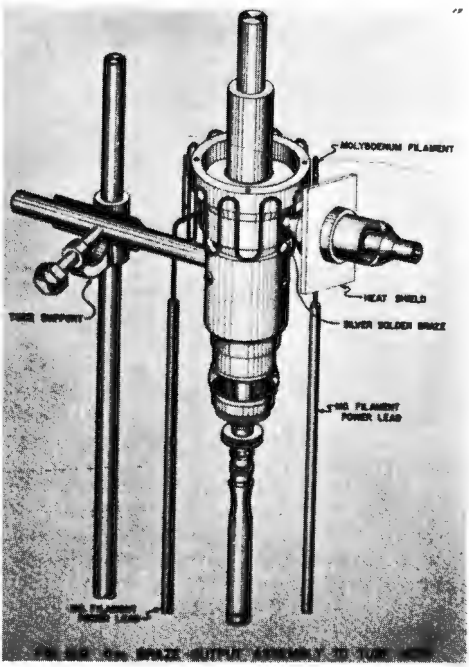

Fig. XIV

"SURFACE SEALING OF SINTERED DISCS IN FLAT FLANGES"

by

A. Stuart
Central Glassblowing Services
Aston University
Gosta Green
Birmingham B4 7ET
U.K.

INTRODUCTION

The making of thick flat flanges is made much easier with the use of a simple tool, which is basically a carbon rod fitted in a holder which has an adjustable bracket (Figure 1). This tool is attached by means of a set screw to one of the jaws of the lathe chuck (Figure 2).

By attaching it to the jaw and opening or closing the chuck, this makes it easier to adjust the carbon rod to suit the tubing diameter.

The thickness of the flange and the diameter is dependent on the amount of glass to be melted. This is found by trial and error, but the more that you make the more experienced you become (Figure 3).

By heating the glass to a high temperature and allowing it to creep and thicken up on its own accord (Figure 4), the point will come when with the use of two carbon paddles (Figure 5) it will be possible to press the molten glass between the paddles, squeezing the glass outwards and by varying the pressure on the paddles and thickness the width of the flange can be attended (Figure 6).

It is important in squeezing the glass that both the front and the back of the flange are parallel and that wedging does not occur as this would not allow the next stage of the operation.

As you will see in the following pictures, the flanges that were made incorporated a sintered disc, the sealing of the disc taking place on the inside of the tubing near the flange edge. Before the sealing of the disc it was necessary to reduce the diameter of the flange tubing to 15mm diameter tubing as required by the research workers drawing (Figure 7). The flange is now ready to have the sintered disc sealed in place (Figure 8) by remounting the glass flange in the lathe and heating on the inside of the tubing with a very fine hot flame, then with a carbon rod that has had a flat surface ground on it, to a depth of 2 - 3 mm, thus making a small step. This tool is used to enable a countersunk edge to be made (Figure 9). Figure 10 shows the sintered disc held by a homemade vacuum chuck, the tubing being made of translucent silica (Figure 10). It is important that the flange is heated so that the glass is very soft at the sealing point (Figure 11). The disc is then offered up to and pressed into the flange and then worked in (Figure 12) making sure that you don't overwork the sealing. With experience and trial and error it is possible to produce a very satisfactory end result (Figure 13).

It now only remains to grind both the flanges and sinter. This is achieved with the means of a peripheral diamond grinding wheel, which has been attached to a standard 6 inch diameter cut-off machine (Figure 14). By rotating the flange against the moving wheel, it thus enables a very good flat and level finish to both the sinter and the flange to be attained. As you will see by the previous pictures, the flame does have a tendency to catch the sintered surface. Should this happen and the sinter is glazed, this can and will be ground away exposing the natural sinter surface (Figure 15). The next picture shows the result of overheating as the pressing in stage.

You will see how the disc has become slightly soft leaving the inprint of the vacuum chuck (Figure 16). The 1st picture shows the finished product.

This method for making flat flanges produces a thick and strong flange, but with the sintered disc sealed in, it is necessary to grind by diamond wheel if you should require a good clean and acceptable surface.

ACKNOWLEDGEMENT

My thanks to Aston University for allowing me to present this paper.

Figure 1

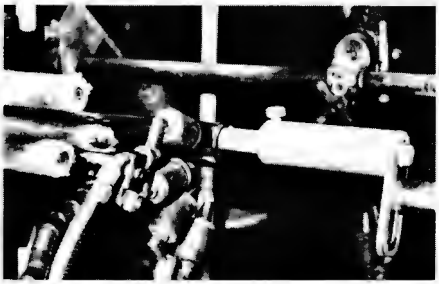

Figure 2

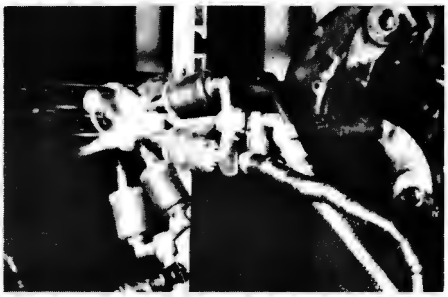

Figure 3

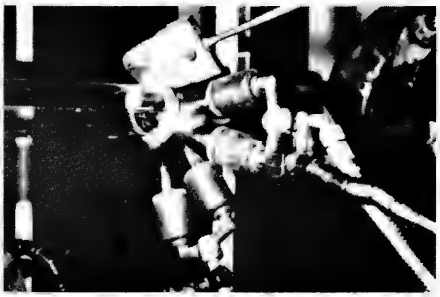

Figure 4

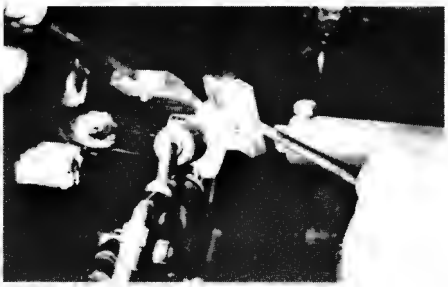

Figure 5

Figure 6

Figure 7

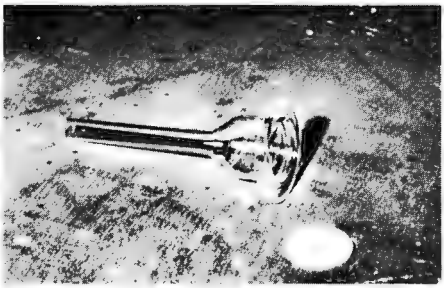

Figure 8

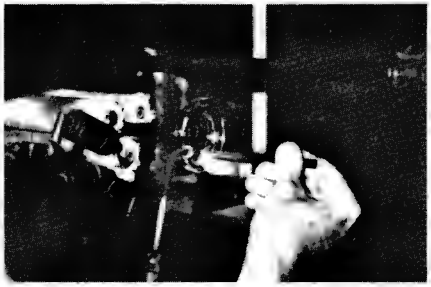

Figure 9

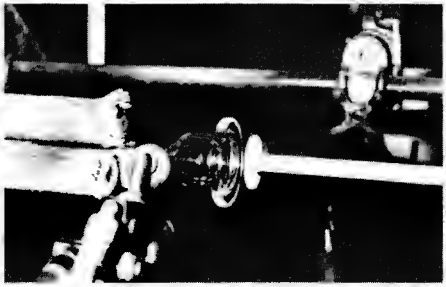

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

Figure 15

Figure 16

Figure 17

YOU CAN HOST A SECTION MEETING

Paper Presented At
American Scientific Glassblowers Society
Symposium 1987

by

A. Ben Seal
Scientific Glassblower – Development Specialist
Supelco Inc.
Supelco Park
Bellefonte, PA 16823

It is my desire to present to you not only the basics needed to host a section meeting, but to also share with you some of my reasons why you should feel it a responsibility to do so. I will suggest several types of meetings that you can hold, procedures to follow, problems that you can avoid, sources of help, and last but not least some of the benefits to you, your profession and your employer. You may want to consider additional items and/or share with others some of your own experiences with section meetings.

There are several types of meetings that you can host:

1. **SECTION BUSINESS** – regular section business meetings, such as election of officers, planning of future meetings, dissemination of society information and topics of concern to the section membership.
2. **TECHNICAL**
   A. PAPERS PRESENTATION – similar to those presented at a symposium and of interest to the section membership. Topics can include: safety hazards, new materials available, new applications of glassblowing procedures, or a different approach to an old procedure.
   B. WORKSHOP – demonstration of procedures and equipment.
   C. PLANT TOUR – manufacturing, fabrication, developmental facilities or universities.
3. **PROMOTIONAL** – presentations of equipment and material.
4. **SOCIAL** – a fun filled program where members of our common profession can get together, get to know one another, share our trials and tribulations as well as our successes.

THE PROCEDURES THAT MUST BE FOLLOWED ARE SIMPLE AND EASY TO USE. THEY ARE AS SIMPLE AS 1 - 2 - 3 . . .

1. Decide what type of meeting you want to host. Any one or combination of the previously mention types of meetings is possible. You must also decide if it is to be an evening, day or weekend (mini symposium) program. You may think that some of this kind of planning is a bit premature at this point, but since I am encouraging you to host the meeting it is imperative that it be something that you are interested in and not something forced on you by a committee. I suggest that you informally discuss what you want to do with section members and officers **before** you decide to host a meeting, but the decision must be yours if the meeting is to be successful. You are to be the primary motivator and driver of this meeting.

2. Obtain the necessary approval from the participants and the employers they represent. Form your committee – it can consist of you alone, or it can involve as many as you wish. You should decide where the meeting is to be held, when you would like to hold it, what you wish to present. (In general terms only.)

3. Obtain section approval. Present your suggested meeting to the officers/program committee/section members. You should have some particulars available, such as those mentioned in item 2 above. Try to generate enthusiasm and encourage attendance at your meeting.

4. Plan the meeting. You and your committee must now plan your meeting in detail. First lay out an agenda, setting date, time schedule and events. Things to discuss are facilities required, a sponsor (if desired) and personnel who will be needed. Your scheduled agenda should allow ample time for all activities but should be kept moving. I like to include time for questions and answers, fellowship and business of interest to the society and section. You may want to have a dinner meeting or a light buffet, especially if your fellow members have to travel considerable distances to the meeting. Plan to have enough people to carry out all events that you have planned. It may be desirable to plan for alternates in case the unpredictable happens. You should plan for one person and an alternate to be in charge. This will help to eliminate confusion and allow quick action when needed.

5. Invite the section members. You should prepare a written notification to send to all members. Include directions to the meeting place. Indicate if there is a cost involved, who may attend (members and/or guests) and if special dress is required. You may want to include an agenda and any special considerations which the members need to know prior to the meeting. Last but not least you should request acknowledgment from members planning to attend the meeting.

6. Have the meeting. You should have someone greet the people and have them sign the register, pass out agendas and collect fees (if necessary). Name badges are nice because they facilitate friendly conversation. You should start on time and try diligently to stay on schedule. This will be appreciated by all that participate in the meeting. Do not forget to clean up and return your meeting place to its original conditon, for you may want to return someday.

7. Write an expression of appreciation to all involved in putting on the meeting.

What I have covered thus far are the easy steps, for the most part. The resources are readily available and can be obtained in any section. The information is easily applied.

I would like to now cover that which is difficult. I want to convince you why you should want to host a section meeting or at the very least volunteer to help with a section meeting.

Individual sections are the life blood of this society. They are the meeting place of all who have an interest in advancing the scientific glass profession. We meet to exchange information, socialize, discuss our current problems and share our successes.

We should all be proud of our chosen profession and want to share our knowledge with our associates. We are all artists and professionals, whether we work in a production shop manufacturing standard products or in a research lab designing and developing the one of a kind apparatus required so often by the researcher. Our profession requires skill and training, plus artistic and innovative implimentation of our abilities. Products produced by the scientific glassblower are found in all walks of life. Only by sharing our information will we be able to continue to develop better ways of doing things. What works in one application may with modification work in similar applications by others.

I firmly believe it is the responsibility of all of us to participate in the advancement of our profession. I want to share some of my history with you. I

have been involved in the glassblowing profession since 1959, when I took a job as an unskilled worker for Fischer and Porter Co. It was my task to produce Precision Bore tubing. Fortunately for me, F&P was a leader and an innovator in this field. This gave me the opportunity to learn many methods of fabricating PB tubing in a great variety of shapes and sizes, from those I could barely see to those I had trouble lifting.

This basic training led me to seek what has proven to be a very rewarding career in the field of scientific glassblowing. I transferred to the glassblowing shop at F&P, where I met and was trained by Howe Smith (past president of the A.S.G.S.), then supervisor of the shop. With much perseverance, patience and encouragement I learned the basics of the world of scientific glassblowing. F&P was not only a leader in producing PB tubing, but also fabricated an extensive variety of glass products. This allowed me the opportunity to learn a broad range of applications.

After spending 18 years at F&P, perfecting my skills as a glassblower and obtaining an associates degree in science from Bucks County Community College, I felt the need for greater challenges. Something to stretch my abilities. I then took a position with my present employer, Supelco, Inc., now a subsidiary of Rohm & Haas. They have provided all the challenges that I have needed for the past 10 years. They have encouraged and supported my enthusiasm to produce quality glass products to supply the scientific community.

I have been truly fortunate to have had the opportunity to work for two great companies.

In addition to being my teacher and supervisor, Howe Smith did something more for me. He sponsored my application to this society and he encouraged me to attend the Delaware Valley section meetings. I was introduced to the truly professional members of our society. I came to know Mr. J. Allen Alexander, founder of our society; Mr. Helmet Dreschel, past president, and many others who provided me with reasons to pursue the scientific glassblowing profession. I remember the enthusiasm with which these men talked about their profession, its needs, and above all the necessity to share our knowledge. I can only wish you had the opportunity to know these men. They are the reason why I stand before you. Just as they encouraged me, I hope that I have encouraged you to host a section meeting.

I want to thank you for allowing me this privilege of addressing you, and for your kind attention. I want to recognize and thank Mr. Dave Hovey, technical papers chairman, and Mr. Larry Harmon, Pittsburgh Tri-state section director, for their unrelenting encouragement and support in developing this paper. I also wish to express a fond thank you to Mr. J. Allen Alexander, Mr. M. Howe Smith, Mr. Helmut Drechsel for the opportunity to come to know them, and for the influence of their enthusiasm, their skill, their professionalism and their desire to share information.

A SURVEY OF ASBESTOS SUBSTITUTES

by

Michael Olsen

Denver, CO

ABSTRACT

Asbestos products are quickly disappearing from the glassblowing shop, but what is available to replace them? How good are the substitutes, and what are current toxicological opinions regarding asbestos substitutes? This paper will attempt to answer these questions by alerting glassblowers to the working and health hazards of using asbestos substitutes.

TYPES OF FIBROUS ASBESTOS SUBSTITUTES

The refractory, fibrous asbestos substitutes widely available to glassblowers fall into four categories; glass (fiberglass and quartz), ceramic, carbon, and zirconia. Additionally, there are the various organic fibers which are not refractory but are heat resistant (e.g., kevlar and polyimide). These materials can be woven and knit, or made into ropes, paper, felts, and boards. They may be produced as (silicate or silicone) coated fibers, or with metal fiber reinforcements. Some have heat resistant adhesive backings, and others are produced with a metallic (usually aluminum) heat reflective coating.

SAFETY OF ASBESTOS FIBER SUBSTITUTES

The health hazards of asbestos and its substitutes are a function of the toxicity of their chemical natures, and the physiologic response of the human body to their inspired particles. Ironically, the attention given to asbestos toxicity may directly be creating a hazard if its substitutes are considered as being safe. There is evidence that they are not safe.

Whereas there has been ample research analyzing the health hazards consequent to exposure to asbestos, there has been very little scrutiny of asbestos substitutes. A health expert contracted by US insulation producers, the epidemiologist Philip Enterline of the University of Pittsburgh is quoted as saying, "if the question is, 'Do other [insulation] fibers besides asbestos cause cancer?' the answer is yes" (Meier, 1987). He has reported preliminary research indicating an increased lung-cancer risk associated with exposure to glass and mineral-wools, and although the evidence is sparse, there is good reason to suspect ceramic-wools as well.

The manufacturers of these fibers are so concerned with these findings that some label their products with cautionary notices, and the Manville Corp., "recently ordered its salesmen of glass-fiber products to certify in writing that they have divulged Mr. Enterline's findings to cutomers" (Meier, 1987). Some manufacturers now provide work clothes for employees to prevent their carrying potentially dangerous fibers home on their clothes, and one mineral-wool producer (USG Corp.) has banned cigarette smoking by its fiber workers because of evidence that cigarette smoking greatly increases their risk of developing lung-cancer. The US Navy has recently banned the shipboard use of ceramic fibers because of its anticipated health effects.

The last decade has witnessed an unprecedented development and marketing of new insulation fibers. Which of them are dangerous, why are they dangerous, and how can we best protect our health and our co-workers' and family's health? Because lung-cancer can take twenty years or more to develop, it is impossible to conclusively determine the hazards associated with exposure to the fibers recently

marketed, but there is now enough known to intelligently assess and limit the risks associated with using fine fiber products. In order to do this, we must each determine our 'acceptable level of risk'. Some workers make every effort to avoid the introduction of suspected hazardous fibers into the workplace. When necessary, fiber-shedding materials are used only according to established protocols and their use is restricted to designated areas by specially trained personnel who utilize physical barriers and respirators to prevent contaminating their workplace, their clothes and their bodies with shed fibers. Alternatively, there are workers who make a good faith effort to limit their exposure to those hazards which can be seen. Today, the first case is probably seen as an example of over-caution, and the latter, an example of ourselves. Unfortunately, in the interests of ourselves, our families and friends, current research indicates that we should be striving to emulate the first example, for it's what you can't see that'll get you.

The most dangerous fibers are those which are chemically toxic, extremely fine, brittle, and durable. Chemical toxicity of ceramic fibers has been reported by a Browning-Ferris Industries publication (1986) which indicates that ceramic fibers quickly break down (in furnaces) to form cristobalite (a form of SiO_2) which can cause the fatal lung disease silicosis. The largest manufacturer of ceramic fiber products in the US, the Standard Oil Co., has labeled its packaging to call users' attention to this cristobalite exposure risk. Long-term exposure of glass fibers to high temperatures can also result in divitrification to form cristobalite (Hedgecock, 1987).

Man-made fibers for insulation are most desirable when they are extremely fine and chemically durable, exactly the characteristics that are most hazardous. Fine particles are inspired deeply into the lungs, and chemically durable fibers resist the body's natural efforts of elimination. Whereas the nuisance factor of synthetic fibers has long been known (e.g., skin and throat irritation) their silicosis and lung-cancer risks are only now being investigated.

Silicosis is an immunologic response to the deep inhalation of very fine (0.5 to 5 micron) cristobalite (silica) particles. The nodular lesions of fibrous tissue initially formed aggregate to form fibrous masses resulting in progressively severe emphysema and ultimately death from heart failure. Lung-cancer is a carcinoma of the bronchus, and is synergistically aggravated by cigarette smoking. It has no know dose/response ratio, and has a latency period of up to twenty years or more. Lung-cancer is almost always fatal.

The particle sizes responsible for respiratory disease is important, for particles larger than 20 microns settle quickly in the environment and are seldom inhaled. Particles from 20 to 5 microns are caught in the cilliary lining of the bronchus and are cleared from the lungs with the phlegm. Particles from 5 to 0.5 microns are the most hazardous, and particles smaller than 0.5 micron can be inhaled and exhaled without imbedding in the lungs. If you are depending upon your better judgment and senses to avoid excessive exposure to hazardous dust, then avoid breathing particles 0.00002 to 0.0002 inches in diameter. If you can do this, you're safe! Particles of this size are inhaled deeply and imbed into the tiny alveoli of your lungs.

Careful shop cleaning methods are imperative, for more hazardous particles are liberated into the shop atmosphere during cleaning than during working. The most dangerous shop cleaning technique is the use of compressed air to blow dust from difficult to clean areas. Vacuuming is far safer, but again, the most hazardous dust will blow through the filter bag of a conventional vacuum. To be safe, HEPA filter equipped vacuums must be used. For the conventional glass shop, the most

effective and least expensive cleaning method is probably washing with water, for when wet, the particles are trapped and can be safely handled.

WORKING HAZARDS OF ASBESTOS SUBSTITUTES

Aside from the health hazards indicated previously, there are working hazards consequent to using asbestos substitutes in glassblowing. These include particle shedding onto hot, softened glass; combustible binder material contaminating glass in the hot zone; failure and fragmentation of the material at temperatures lower than that which asbestos can withstand; non-wettability; non-moldability; slick and slippery gripping surfaces; and the inability to make relatively air-tight seals. As asbestos containing materials have fewer of these drawbacks, it might be considered that their judicious and careful use in certain applications is irreplaceable.

NON-FIBROUS ASBESTOS SUBSTITUTES

What are conventionally considered asbestos substitutes are not the only substitutes suitable for the glassblowing shop. The ultimate asbestos substitute is absolutely nothing at all! If the procedure for constructing an apparatus can be accomplished utilizing the components of construction themselves, then the health and working hazards of asbestos and its substitutes are avoided. As an example, Vigeroux-like indentations can be made to hold inner members of an apparatus in place. If they are made in the expendable end of the workpiece, they will be pulled or cut-off prior to completion of the piece. A piece of tubing extending through a cork can be used for centering a concentric component, as in condenser construction. Indeed, this can be accomplished with the tube you plug your blowhose into.

Other non-fibrous asbestos substitutes are corks, aluminum foil, copper screening, spring steel and brass, carbon, and ceramic and quartz tubing and rod. Corks can be sculpted into reusable spacers or air-tight seals, and can be wrapped with aluminum foil (shiny side out) for additional protection from radiated heat. Crumpled aluminum foil, while not air-tight, can be used as a spacer within a construction, yet can be stretched over very large diameter open ends and made relatively air-tight by cinching with thin copper wire used as a twist-em. Similar to aluminum foil, copper screening can be rolled or crumpled and used as a spacer within a workpiece. Unlike asbestos and its substitutes, both aluminum and copper can be used deep within a construction where it cannot otherwise be easily extracted prior to completion of the workpiece. Care should be taken to avoid allowing the metal to become incorporated into the softened glass surface. To remove either metal, simply dissolve it with a dilute solution of nitric (for copper) or hydrochloric (for aluminum) acid prior to annealing (remember: always add the acid to the water!). Using hydrofluoric acid is not advised, as it will etch the glass by the time the metal has dissolved. Be certain to use a very dilute solution (approximately 10:1), for concentrated acid will break into a dangerouly explosive boil upon contact with the metal, and can generate enough heat (and pressure) to fracture an unannealed workpiece. As the likelihood of catastrophe increases with the complexity and delicacy of a project, it is very important to heed this warning. Do not oven-anneal the piece before removing the metal, for doing so will irreparably contaminate the glass surface with the metal. Careful and localized flame annealing must be employed.

Reusable clips and holders constructed from spring steel and brass are especially handy for positioning small components (e.g., frits) prior to sealing. Carbon can be sculpted into holders and spacers. Carbon is a tremendous heat sink or wick, so it may be desirable to reduce its surface area contacting the workpiece by sharpening it to a point, or making numerous shallow cuts across the contacting surface

yielding a grid-like complexion. Coating the surface of your carbon with Aqua-dag will yield a smooth and more durable surface, although care must be taken to guard against the Aqua-dag flaking off and sticking to softened glass.

Quartz or ceramic rods and tubes can also be fashioned into heat resistant holders and spacers.

Of particular concern to production operations is the utilization of precision, reusable spacers and positioners. As a rule, economy of time favors the construction of such aids as opposed to the repeated fabrication of disposable components for precision positioning.

SUMMARY

There is no consensus regarding the safety of fibrous asbestos substitutes. With a current understanding of the hazards involved, those who work with asbestos and its substitutes must calculate their acceptable level of risk, appreciate the potential consequences of exposure, and arrange their work to limit the use of, and exposure to fine fibers in the workplace.

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HOW TO MAKE NOTCHED AND BEVELED THIN LAYER CHROMOTOGRAPHY PLATES ON A CUT OFF MACHINE

Allan B. Brown
Glassblower
University of Connecticut

ABSTRACT

This paper will discuss a procedure to make notched and beveled Thin Layer Chromotography Plates for Electrophoresis Cells. By making an adjustable table attachment, it is possible to manufacture these plates using a standard Pistorius cut off saw.

Being in a university atmosphere, our glassblowing shop is constantly being asked to come up with a less expensive way to produce glass items. I was asked if our shop could make Thin Layer Chromotography Plates not only notched but also beveled in several different sizes. I accepted the challenge and here is the way the problem was solved.

The parts required for producing glass Thin Layer Chromotography Plates. The main item is a standard Pistorius cut off machine with a 12" O.D., 180 grit diamond saw blade. This cut off machine has to be modified. When the glass plates are notched, the face of the saw blade needs to be perpendicular to the glass. Therefore, a new table has to be manufactured in order to achieve the correct height. To do this, the back stop is removed. The next step is to calculate the height from the table to the center of the wheel. This height will determine the new table size. After the new table top and short legs are made, they can be screwed to the existing table.

The saw is now ready to notch a glass plate, for which it will be necessary to use the forward feed stop. A glass plate is selected; a piece of tape is placed on one side of the plate and the depth is marked with a pencil to determine the first cut. The glass plate is placed on the new table and the right side is adjusted so that the blade lines up with the pencil mark. The same procedure is repeated for the left side. These side stops prevent the plate from sliding too far either way and bending the saw blade; they also allow a perfect reproduction of the notched area. The plate is cut to the desired depth on the right side. Then the saw is shut off and the depth stop is set. Once the saw is restarted, the right side should be recut, followed by the left side, pushing until the stop is reached. The cut plate can be removed, washed and dried.

The plate is now ready to be scored and have the center piece broken out. A flat table and a glass knife along with a straight edge are used to score the glass plate approximately 1 mm. above both saw cuts. Next, a small piece of wire is placed under one edge of the scored glass. When pressure is applied to the center of the glass, the piece will snap out. The cut off machine is now used to square off the bottom of the notch in the plate by sliding the plate either left or right from one notch to the other.

The squared notch on the plate must now be recut on a 45° angle. The new table top should therefore be removed and longer legs added. The table top with the new legs is then screwed back in place. The glass plate is taken and cut to the desired depth. The saw is shut off and the new depth stop is set. Once the saw is restarted, the right side should be recut, followed by the left side, pushing until the stop is reached.

Although this procedure requires some metal working to modify existing equipment, it greatly simplifies the production of notched and beveled Thin Layer Chromotography Plates. Several size plates have been successfully made and reproduced in our glassblowing shop.

THE REVIVAL OF THE GLASS HARMONICA: FROM A SCIENTIFIC GLASSBLOWER'S PERSPECTIVE

Gerhard Finkenbeiner
G. Finkenbeiner, Inc.
Waltham, MA

Vera Meyer
Glass Music International
Cambridge, MA

People have been tapping and striking glass objects as a means of making music for over 600 years. It wasn't until the mid-1700's, however, that history records the first occurrences of music made by rubbing the rims of glass goblets with moistened fingers to produce various notes. The goblets or wine glasses were firmly affixed to a table, each precisely tuned with water to a different pitch. The musician would sit in front of this assembly, making the glasses sing as he moved a wet finger steadily and with a light pressure around the rims. This arrangement was called the "musical glasses" and, for a time, it was quite the rage of high society in Europe.

When Benjamin Franklin was in Europe as Ambassador to the Colonies, he chanced to hear a concert played on a set of fifty such tuned water glasses. Being charmed and captivated by the beautiful sounds emitted from the glass, he immediately set out to design a more convenient and practical form of the instrument. His idea was to start out with already perfectly tuned glasses, doing away with the water tuning altogether. He thought to remove the stem and base from each glass, then slide them one by one, progressing from the lowest note to the highest, on a steel shaft. With a hole through the center of each glass they could all be made to nestle quite comfortably within each other, close but not touching, while the spindle could then be safely set into rotation, the glasses spinning securely along with it. Then the player would only need to touch the glass rims as they passed under wet fingers, and the instrument could be played much more like a piano, with chords and faster musical passages being much easier to achieve than having to awkwardly coordinate turning the finger around the rim of each separate glass.

Glassblowing was much more common in Franklin's time than it is now, and Franklin put many glassblowers to work on his ambitious project. For every one hundred glasses that were blown, only one ended up being properly sized, perfectly tuned and usable, so the completion of an entire four-octave glass harmonica was a very arduous task. But finally, in 1761, the goal was accomplished, all 48 notes, two octaves below and two octaves above middle C. In honor of the Italian word for harmony, Franklin named his invention the "armonica", or as it later came to be known, the "glass harmonica".

This instrument enjoyed a very wide popularity in Europe for about forty years. Our research indicates that there was a large glass harmonica factory with over 100 full-time employees, building hundreds of instruments. Today only a few of these instruments exist in museums around the world. Further research has also turned up over 400 original compositions for the glass harmonica, by such great 18th century masters as Mozart and Beethoven, as well as by many lesser-known composers.

After about forty years the instrument suddenly lost its popularity; it quite literally vanished from public view, presumably (from what we can gather) because people came to fear its powers. They believed it caused insanity, nervous disorders, convulsions in dogs and cats, marital disputes, and could even wake people from the dead. It was actually banned from being played in some German communities. People so feared to touch it that a keyboard form of the instrument was devised,

whereby striking a key a spring would activate a wooden hammer covered with a piece of wet leather. The hammer arm would reach out and make contact with the glass rim, producing a note in the same manner as direct contact with the natural finger could produce.

To what might one attribute all this craziness? One theory is that the lead in the type of glass used at the time would leach through the fingertips, into the bloodstream, and negatively affect the nervous system. Another idea revolved around the distrust and suspicion people had of Dr. Franz Anton Mesmer, the psychologist who brought us the word "mesmerize." He was a great lover of the glass harmonica and, in fact, he used it in conjunction with his "animal magnetism" healing cures, to induce deeper states of hypnosis in his patients. Perhaps this use of the instrument was enough to give it a very bad reputation, encouraging people to fear it and think it evil.

Regardless of all this controversy, during its heyday the glass harmonica was the talk of the town, said by some to be more popular than the violin. Its sounds have been described as ethereal, haunting, ghostlike, mystical, angelic, coming from nowhere, pervading everywhere. Two of the leading virtuosos of the day were a blind woman and friend of Mozart by the name of Marianne Kirchgessner and the niece of Ben Franklin, Marianne Davies.

Now, finally, after over 150 years of obscurity, this fascinating instrument is back in production, built by a master glassblower from Waltham, Massachusetts, Mr. Gerhard Finkenbeiner. Finkenbeiner saw one of the original instruments in a museum in Paris in 1956 and carried the idea and the desire to build one himself in his head for many years. He completed the first prototype in 1982, based on the original Franklin blueprints, but also incorporating a few changes based on modern glass manufacturing capabilities and technologies.

First, the foot-powered treadle used to turn the original spindle has been replaced by a silent 110 volt electric motor. When Franklin designed the foot treadle mechanism used on his original instrument he was faced with several problems. One was the slow speed (30 - 50 rpm) that was necessary to get a good response on the middle and lower glasses. It is difficult to operate a foot pedal at low speed; Franklin installed a heavy flywheel on the direct drive spindle (25 pounds of lead) and solved the problem this way. Later instruments used speed reduction mechanisms, allowing the spindle to turn more slowly than the cycle of foot pedaling. The ultimate solution was found on some later instruments made around the turn of the century. The rather large flywheel was tacked horizontally under the spindle in a sort of double-bottomed suitcase where it could hardly be noticed. A clever leather belt arrangement drove the flywheel at high speed while the spindle rotated slowly.

Today Finkenbeiner uses a constant-speed motor which uses a voltage feedback regulation. When set at 50 rpm it will hold that speed quite well, even if the load on the glasses is increased, for example, during the playing of chords or crescendos. The Dayton DC motor controller model 5X412A used with the Dayton DC motor 42142 offers reasonable quietness while performing an adequate job. The player controls rotational speed by having a foot pedal attached to the knob on the speed control.

For a second modern innovation, the type of glass used now is far superior to the old soda-lime glass previously used. The individual cups, or bells, are fashioned from 100% pure silica, or semi-conductor grade fused quartz. This is the type of glass Finkenbeiner uses daily in his shop for doing his more traditional work as a scientific glassblower. For years he has experienced sounds using all possible types

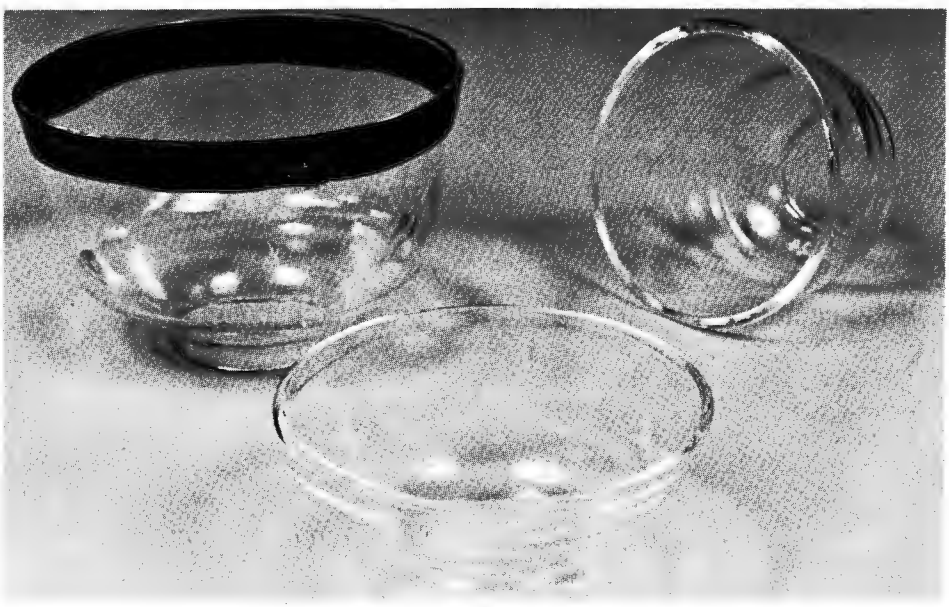
of glass. In judging their quality of sound for use in a glass harmonica he finds quartz glass by far the best, being of superior resonance. Quartz is followed by lead glass (crystal), then soda-lime glass and finally borosilicate or pyrex.

Finkenbeiner begins the manufacturing process by mounting long tubes of quartz glass on his glass lathe. For the lower notes he will use tubes of larger diameters; for the higher notes he will use tubes of smaller diameters. Then, by a combination of blowing and turning, he tools the molten glass at temperatures around 1800°, fabricating a series of elongated spheres along the entire length of the cylinder. Each of these spheres will later be sliced in half to produce two unrefined glass harmonica bells. The following is Mr. Finkenbeiner's own description of this work:

"When getting set up on the lathe to do a number of new cups, the following details might save a lot of wasted time and energy. It is important to select concentric tubing since the slightest amount of uneven wall thickness will produce cups that are musically unacceptable. The experienced glassblower (who preferably also has a good ear for music) should be able to spot poor tubing simply by tapping and listening to a full length of quartz tubing. It is very difficult to exactly describe what I mean here other than by saying that a good tube will sound "harmonious" whereas a bad tube will sound "discordant". This audible check is much more precise than measuring the walls with a caliper or micrometer would be.

When a good length of 5' tubing is selected it is installed on the lathe between two holding tubes that are preferably secured in four chucks. The glassblower then has to decide whether he/she wants to make lower-pitched thinner-walled cups or the higher-pitched and thicker-walled cups which have a more resonant and higher-quality sound. A 4" diameter and 2.5 mm wall tubing will produce cups in the medium range of the instrument. A 4" long section is heated and then necked down to the cork size which will be used to mount the cup, approximately 40 mm in diameter. Later the cups will be cut and separated in this necked-down area. Then a second necked-down section will be made approximately 8" down the tube from the first one. This 8" section is tooled and blown up into the typical shape (somewhat spherical) of two semi-cups shown in the picture. This is achieved by a combination of heating, blowing through a blowhose, and reducing the distance between the two heads of the lathe – all done simultaneously. This is the work which requires the greater degree of skill, patience, and craftsmanship in the process of glass harmonica construction. For the more experience the glassblower has, the better he/she is able to control the outcome of the size and pitch of the cup being made. A 10-flame 7-jet set of torches is perfect for the 4" - 5" diameter cups. Using hydrogen and oxygen, each section of the cup can be worked separately so that the curves are smoothly blended into the previously-determined "best-sounding" shape, that with the rounded shoulder between the neck and the cylindrical section of the cup. The larger cups are made with a water-cooled 4-head 1.5" diameter Futerko set of torches. Usually tubing of 6" - 7" diameter is used for these larger cups.

As many cups as possible are made out of the original 5' length of tubing. Usually 10 "spheres" are able to be fitted along this length, resulting in 20 individual cups after each sphere is cut in half. After spheres are produced along the entire length of tubing, its length will have shrunk to about 3½', because of the effort to keep the wall thickness constant as the spheres are blown up. No mathematical method is used to achieve this constant wall thickness; so far I have just succeeded in this endeavor by visual judgement and "feel". However, in the future my plan is to exactly calculate the amount of lathe head movement that is required in conjunction with the blowing, in order to produce cups of any given



wall thickness. Also in this calculation, it is important to include the loss of quartz through evaporation during the normal blow-up operation (usually 3% - 5%)."

Immediately after reading Finkenbeiner's own description of his work on the construction of a glass harmonica, I think it would be of great interest to glassblowers to hear some directly-quoted passages out of the only self-instruction manual written specifically for the glass harmonica. It was written by Johann Christian Muller in Leipzig, Germany, in 1788.

"The bells of a good armonica must therefore be the best selected ones in the world. They must be of the same strength or thickness, and none must have an uneven edge – otherwise, while they are rotating during playing, a whining, whimpering tone is produced, now high, now low, according to whether the thicker or thinner portion of the edge is running under my extended finger; in brief, a tone that is not uniform in character and vibration."

"The form of each bell must have a correct circular rounding. None must have any projections or be in any way uneven, which causes an uneven sound and a similarly uneven movement of the hand or finger; such a disturbance produces an excessive sustaining of a second or third tone. It is also necessary to be attentive to the playing surface of each bell: it should not have a raised or indented edge, which causes very troublesome and difficult playing. The best form for a good bell still seems to me to be the half-sphere. In general, anyone who involves himself in the manufacture of the instrument – whether for profit or of his own accord – should be more concerned with good form in blowing the glass bells than has been the case, by and large, until now; in this way, we will soon have better bells, and consequently, better instruments."

"The arrangement of the bells on the spindle must be correctly symmetrical. It is necessary that – from the lowest to the highest note – the bells should be gradually placed slightly closer to each other, so that if the surfaces of the lowest bells project the width of a thumb from each other, the little finger should completely cover those of the highest bells. The tonal equality itself, the air stream of every large or small musical sounding body, necessitates this correct measurement."

"A good complete armonica will sometimes require a hundred or even more bells, depending upon how fortunate one is. Would this occur if Germany's scholars gave us more support and if individual experience and caprice did not play so great a role in instrument building generally?"

"A good armonica must be judged particularly by both the correct pitch of all its notes, as well as by its essential nature. In choosing an instrument, one should not be deceived by its enchanting tone if one should chance to find a couple of perfectly pitched chords. Great artists can err in this respect if they are not thoroughly acquainted with the tones of the instrument."

After Finkenbeiner has made the cups on the lathe, he then begins the next phase of work. With the aid of a musical stroboscope, he classifies each cup according to the exact note it is closest to in pitch. Holding each glass loosely in his hand, he raps it sharply with a striking object to make it ring in its particular frequency. It would take years to complete a single harmonica if one went about trying to make one note at a time precisely the right shape and pitch. To circumvent this problem, Finkenbeiner uses the approach of making hundreds of cups of all shapes, sizes, and tonal qualities at random. In this way he acquires an unrefined supply of many potential middle C's of all differnt sizes, many C#'s many D's, etc. It took him about one year to produce a stock of 500 cups at this rough stage of completion.

When his supply of cups is large enough, Finkenbeiner turns to the real precision work, that of fine-tuning each cup to exact concert pitch. He does this in the following way: if the cup is slightly flat he grinds away at its base to create less

mass; this makes the pitch higher. If, however, the note is too sharp, he uses a different process; acid etching. He immerses the cup in hydrofluoric acid solution for a precise amount of time. The acid eats away the glass, thinning the walls and thus lowering its pitch. If, for example, he were to take a middle C cup with a base diameter of 4" and immerse it in a 50% hydrofluoric acid solution for 20 minutes, two thousandths of an inch (.002) of wall thickness would be removed, and the former C note will now be a B, one half-step lower. This explains why a glassblower has a difficult time producing a given note **and** a given diameter. A glass blower can control wall thickness within ± ten thousandths of an inch. Therefore, the note he/she is making might be five halftones higher or lower than the one needed in order to fit perfectly as the next note in sequence on the glass harmonica currently under construction. Once again, it would be an impossible task to complete a harmonica by making one note at a time.

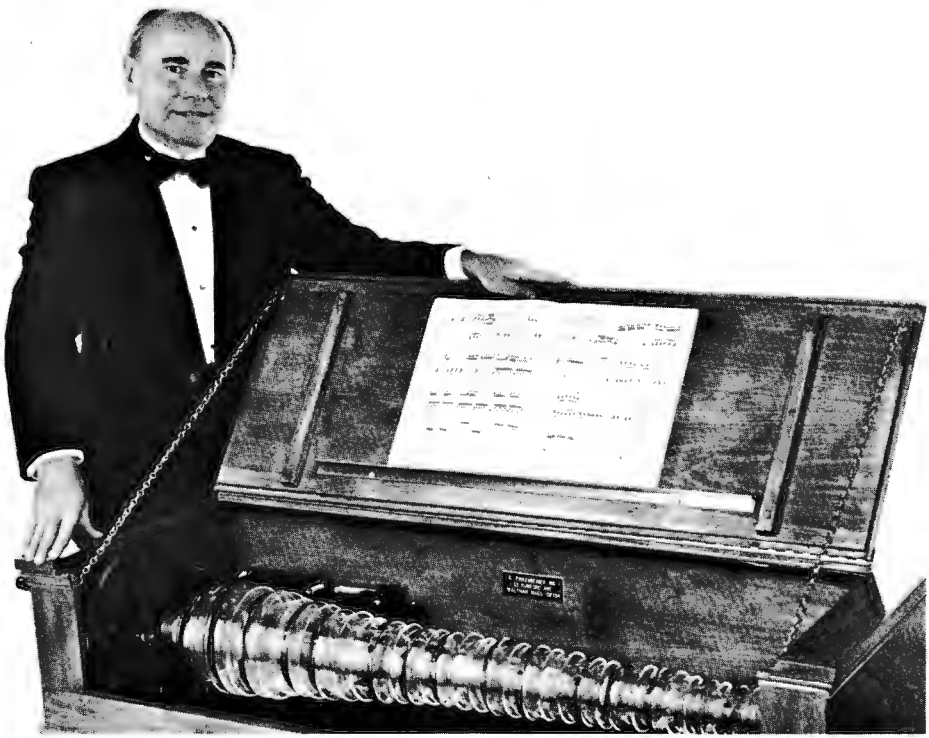
With his large supply of tuned notes of various sizes and diameters, the last step is now easy. Finkenbeiner has only to select the best fit out of his large selection of each note, when choosing the cups to slide one by one, side by side, onto the spindle. To mount the cups securely on the spindle, he has devised a clever method of using corks as the ideal material to use as a buffer between the bare metal rod and the glass. The corks get holes drilled through their centers and are slid on the spindle first; the cups then come sliding directly on top of the corks, one by one. The corks are cut to fit just perfectly to keep the cups both tightly seated in correct position on the spindle, wedged in, and also to keep them distinctly separated. It is critical that the glasses not touch each other, to ensure that the vibration of each individual glass is free and unrestricted, with unimpeded rotation through the air. The trick is to get the glasses very close to each other, perhaps with a ½" space between rims, but still not touching.

With the glass harmonica completed for the specific range of notes he desires, Finkenbeiner now adds one last touch of practicality combined with beauty. Using liquid gold he paints a gold band along the inside border of just the sharps and flats, to mark them just as ebony wood marks the black keys on a piano. Baking these cups at high temperature will permanently fix the gold to the glass, marking these notes for life, thus serving as a visual aid to orient the player with reference points in the musical scale.

The glass harmonica is an idiophonic instrument. It is different from most other idiophones in that it is not struck percussively, but rather it is rubbed. The vibration is not set in motion by a blow but rather by the same principle we see acting in a violin, i.e., the sticking and slipping of the bow on the strings. The key element in this stick-slip principle is friction. In a violin bow we use rosin for the grip – on a glass harmonica we use water on the well-washed finger. If the fingers are not "squeaky clean," having traces of body oils on them, the glasses will feel only slippery under the touch, there will be no firm grip established in contact with the glass, and there will consequently be no sound produced. With friction at work the finger is constantly sticking to the glass and only slipping on it when the momentum becomes too great and forces the grip to yield and to break. This repeated action causes the vibration of the glass and the resultant note in the frequency of that vibration.

The optimal speed of rotation is around 50 rpm. If the speed is too slow, an even and solid tone will not be produced; if it is too fast the glasses will revolve too quickly to allow the finger to develop any grip at all, and there will be only slipping and sliding. Since the higher notes are smaller in diameter, they could use a slightly faster rate of rotation than the lower notes in order to allow the rims to pass under the fingertips at the equivalent rate of speed.

To this date very few people have studied the acoustics of the glass harmonica from a purely scientific standpoint. People have suggested that the sound seems very pure but the harmonics quite complex. It would be interesting to play a glass harmonica into an acoustic spectrum analyzer in order to see what interesting things might be revealed by this wave analysis. We welcome all interest, scientific or otherwise, in the glass harmonica. In fact, we have recently founded a new non-profit organization, called Glass Music International, designed to attract and bring together all those people who are interested in, or just simply love the sound of glass music. Our common aim is to promote glass music amongst ourselves at the same time that we promote its renaissance around the world. We would certainly welcome any scientific glassblower, who also shares an interest in making music, in any and all conceivable form, from glass.



CREDIT:

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Monsanto Research Corp.
Mound Road
Miamisburg, OH 45342

Benjamin Agam
School of Chemistry
Tel Aviv University
Tel Aviv
69978 Israel

Charles Amling
5837 E. Hawthorne
Tucson, AZ 85711

Jeff Anderson
National Bureau of Standards
Bldg. 304, Rm. 136
Gaithersburg, MD 20899

Gary L. Anderson
Ciba-Corning Diagnostics Inc.
63 North St.
Medfield, MA 02052

J. David Andres
221 Cuauhtemoc Ave.
Mexico City
06700 Mexico D.F.

Joel M. Babbitt
University of SC
Dept. of Chemistry
Columbia, SC 29208

Joel Jeffrey Babbitt
Univ. of Michigan – Chem. Dept.
930 N. University
Ann Arbor, MI 48109

Kendall G. Bailey
United Technologies
Silver Lane
E. Hartford, CT 06108

Daniel J. Baker
29 Jacklin Circle
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John T. Balkwill
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Scott Bankroff
2823 Tammany
Lansing, MI 48910

Joseph S. Barker
Greatglas, Inc.
2040 Telegraph Rd.
Wilmington, DE 19808

Andre Barrette
Universite Du Quebec
Chicoutimi Blvd.
Universite Of Quebec
Chicoutimi, Que G7H 2B1 Canada

Joseph W. Baum
200 Highland Ave.
Rensselaer, NY 12144

Eugene Bayne
6818 Renoir Ave.
Baton Rouge, LA 70806

Helmut Becke
6 Banner Road
Nepean Ontario
K2H 5T2 Canada

Marc Bedard
Verrerie D'Art Scientifique Inc.
1721 Begin
Chicoutimi Quebec G7H 5Z1
Canada

Hans Bischof
4905 Calabazilla Rd.
Las Cruces,NM 88001

Melvin Bishop
Lawrence Livermore Nat'l. Lab
P.O. Box 808, L-332
Livermore, CA 94550

David Blessing
Radiation Lab
University of Notre Dame
Notre Dame, IN 46556

Walter C. Boger
P.O. Box 51
Carrboro, NC 27510

Theodore Bolan
29 Hankin Loop
Poughkeepsie, NY 12601

Christian B. Boussert
Louisiana State University
Coll. Basic Sci., Choppin Hall B30
Baton Rouge, LA 70803

Walter Brereton
University of New Brunswick
Fredericton, NB Canada

Allan Brown
University of CT
Tech. Services Ctr. U-108
Storrs, CT 06268

Robert Brunfeldt
R. J. Brunfeldt Co.
P.O. Box 2066
Bartlesville, OK 74005

Michael Burchfield
2698 Jupiter Dr.
Fairfield, OH 45014

Stewart W. Burt
1825 Wickersham Dr.
Knoxville, TN 37922

James Cafferty
56 Grey Crescent
Box 316
Pinawa Man, Roe 1L0
Canada

Raymond Carew
UCLA, Chem. & Biochem.
3079 Young Hall, 405 Hilgard Ave.
Los Angeles, CA 90024-1569

Colin L. Chandler
43 Brookside Crest
Kitchener, Ont. N2N 1H2
Canada

David Chandler
43 Brookside Crst.
Kitchener, Ont.
N2N 1 H2 Canada

Ronald F. Chipperfield
2100 Rissler Rd.
Canandaigua, NY 14425

Jerry A. Cloninger
2816 Arden Way
Smyrna, GA 30080

Frank Cooper
Laser Ionics Inc.
701 South Kirkman
Orlando, FL 32811

Ward A. Cornell
174 Brookside Lane
Mansfield Ctr. Ct. 06250

Dumitru Costea
The Glass Menagerie, Inc.
Route 209, P.O. Box 4017
Westbrookville, NY 12785

Melvin P. Courtney
Rd. No. 1, Box 134
Avonmore, PA 15618

Gary Coyne
Chem. Dept., CSULA
5151 State University Dr.
Los Angeles, CA 91411

Louis Cribaro
Amoco Corp.
P.O. Box 400
Naperville, IL 60566

David G. Daenzer
52 Miller Street
Mt. Clemens, MI 48043

Dieter Damrow
2014 E. Decorah St.
West Bend, WI 53095

Edward N. Davidson
10 Timber Acres
Millsboro, DE 19966

Patrick De Florio
Yankee Glassblower
P.O. Box 486
Concord, MA 01742

Czes Deminet
14220 Piedras Rd.
Albuquerque, NM 87123

Richard N. Dickinson
Box 228
Center Valley, PA 18034

Robert DiGiacomo
Mass Instit of Tech
Chem Dept.
77 Mass Avenue, Bldg. 6-031
Cambridge, MA 02139

Arthur Dolenga
44045 Donley
Sterling Heights, MI 48078

James P. Downey
665 Parkway Ave.
Trenton, NJ 08618

John G. Dryden
367 Whittier
Fairborn, OH 45324

Jean-Marc Du Buc
Mitel Semi Conductor
18 Airport Blvd.
Bromont Quebec J0E 1L0
Canada

Ian B. Duncanson
1950 Thornhill Dr.
South Bend, IN 46614

Igno Dur
University of Utrecht
Padualaan 8
3584 Ch Utrecht,
The Netherlands

David W. Edson
Lurex Manufacturing Co.
P.O. Box 220
Vineland, NJ 08360

Charles R. Ehrhardt
Procter & Gamble
5299 Spring Grove Avenue
Cincinnati, OH 45217

Richard Elvin
Univ. of Saskatchewan
Rm. G-37, Thorvaldson Bldg.
Saskatoon Sask S7N 0W0
Canada

Fernando Escamilla
221 Cuauhtemoc Ave.
Mexico City
06700 Mexico D.F.

Kenneth J. Everingham
210 Briar Lane
Carney's Point, NJ 08069

Dennis Falconer
Rd. 7, Box 71
Gibsonia, PA 15044

Gabor Faludi
355 Toyon Rd.
Sierra-Madre, CA 91024

Gerhard Finkenbeiner
G Finkenbeiner Inc.
33 Rumford Ave.
Waltham, MA 02154

James R. Finley
2612 Clipper Ct.
Bartlesville, OK 74006

Hans Florell
Univ. of MN
S-146 Kolthoff Hall
Minneapolis, MN 55455

Kim Foley
Stillmeadow Glass Works
Box 23
Hampton Falls, NH 03844

William E. Fox
74 Bandolina
Los Alamos, NM 87544

John L. French
MPB Technologies Inc.
1725 N. Serv. Rd., Trans Can Hwy.
Dorval, Quebec H9P 1J1 Canada

Hendrik Frimout
15 Bareellaan
Kapellen
2080 Belgium

Larry Fuller
4101 W. Golden Lane
Phoenix, AZ 85051

Jack Fuller
National Bureau of Standards
Bldg. 304, Rm. 136
Gaithersburg, MD 20899

Jim Futrell
Rd. No. 1
Box 114-G
Apex, NC 27502

Angela Gatesy
P.O. Box 66
Huntington, VT 05462

Hans P. Geyer
282 Bridgepoint Rd.
Belle Mead, NJ 08502

John L. Glossinger
Contemporary Kiln, Inc.
26 "O" Commercial Blvd.
Novato, CA 94949

Teddi Goldsworthy-Hanner
RPC Industries
3210 Investment Blvd.
Hayward, CA 94545

David A. Gover
Washington State University
Tech Services W.S.U.
Pullman, WA 99164

Richard A. Grant
3717 Wenbrook Dr.
Kettering, OH 45429

Joseph P. Green
A H Robins, Inc.
1211 Sherwood Ave.
Richmond, VA 23220

Joseph S. Gregar
464 Nassau Ave.
Bolingbrook, IL 60439

Kurt O. T. Greiner
4321 S. 58th St. No. 9
Lincoln, NE 68156

Siegfried Greiner
Zenith Electronics Corp.
1000 Milwaukee Ave.
Glenview, IL 60025

Adolf P. Gunther
3468 Sulin Court
Yorktown Hgts., NY 10598

Moshe Hakak
Ben Gurion University
Beer Sheba, Israel

John Hamarik
Rd. No. 4, Box 188A
Reading, PA 19606

Richard J. Hapstack
212 Marcella Rd.
Parsippany, NJ 07054

Larry Harmon
Carnegie Mellon University
4400 Fifth
Pittsburgh, PA 15213

Laurie Harnick
Univ. of Western Ontario
Chem. Dept., Glass Shop
London, Ont. N6A 5B7 Canada

Peter Hatch
1010 Wylde Green Rd.
Iowa City, IA 52240

Paul Henrickson
Lawrence Berkeley Lab
M/X 77/125, One Cyclotron Rd.
Berkeley, CA 94720

Winfield Hill
Box 151
Springtown, PA 18081

Craig M. Holt
Ceramic Fiber Fabrication, Inc.
592 W. Explorer
Brea, CA 92621

Billie Marie Horn
Hach Co.
100 Dayton Ave.
Ames, IA 50010

T. Anne Hostetter
University of Guelph
Dept. of Chemistry
Guelph Ont. N1G 2W1
Canada

David L. Hovey
Mass Inst. of Tech., Lincoln Lab
244 Wood
Lexington, MA 02173

Lee R. Jasper
Westinghouse R & D
1310 Beulah Rd.
Pittsburgh, PA 15235

Richard F. Jozwiak
Carnegie Mellon University
4400 Fifth Avenue
Pittsburgh, PA 15213

Linda Kellc
Rd. 2, Box 421
Birdsboro, PA 19508

Frederick Kennedy
Texas Instruments, Inc.
P.O. Box 655936 M/S 145
Dallas, TX 75265

David M. King
Brown University
324 Brook St.
Providence, RI 02912

Owen J. Kingsbury, Jr.
104 Briarwood Dr.
Greenville, NC 27834

Russell H. Kloess
Monsanto Co.
800 N. Lindbergh
St. Louis, MO 63167

Nontas Kontes
H.S. Martin Inc.
Box 661
Vineland, NJ 08360

Doni J. Kornahrens
629 Maplewood Ave.
Peekskill, NY 10566

Ralf H. Koslow
Koslow Scientific
75 Gorge Rd.
Edgewater, NJ 07020

Glenn Kostick
Kostick Glass
15 Poplar St.
Winchendon, MA 01475

Chris Kowalewski
5186 Hutchison
Montreal, Quebec H2V 4AD
Canada

Benjamin Kresge
National Vacuum Lab
1125 Longwood Ave.
Bronx, NY 10459

Milan Krmpotic
Adria Scientific Glass
2683 Rt. 534 S.
Geneva, OH 44041

Keith A. Kuehl
University of Illinois
1406 W. Green
Urbana, IL 61801

Egon Kummer
140 Old Post Rd. South
Croton-Hudson, NY 10520

Fred H. Kummer
5 Forsythe Dr.
E. Northport, NY 11731

Timothy E. Landers
99G Southwood Apt.
Amherst, MA 01002

Manfred Langer
4504 Dobie Rd.
Okemos, MI 48864

Ron Legge
100 Andrea Rd.
Ajax, Ontario L1S 3V9
Canada

John Legge
University of Toronto
60 St. George St.
Toronto, Ont.
Canada

William Lenard
1424 Pepperell
Temperance, MI 48182

L. Frederick Leslie
3 Durie Street
Toronto Ont. M6S 3E5
Canada

Vernon C. Lewis
2904 W. Daniel St.
Champaign, IL 61821

Donald Lillie
Lillie Glassblowers
3431 Lake Dr.
Smyrna, GA 30080

Thom Lillie
Lillie Glassblowers
3431 Lake Dr.
Smyrna, GA 30080

Richard Logsdon
Behm Quartz Tech
8624 East Ave.
Mentor, OH 44060

Orta Luis
Trokar Sa
Centeno 691
Col Granjas, Mexico

Joseph Luisi
2798 Bryant
Vineland, NJ 08360

Eugene Lutter
6243 Brigadoon Ct.
Longmont, CO 80501

Elco Machek
228 East 80th Street
New York, NY 10021

Elmo Maiolatesi
35 Henry Avenue
Baltimore, MD 21236

James L. Mansfield
VMV Optics Inc.
165 Front St.
Chicopee, MA 01013

Wilbur C. Mateyka
3536 Creekwood Dr., No. 13
Lexington, KY 40502

Lester Mattison
Wholesale Glass Fabricators, Inc.
1380 No. Kerr Ave.
Wilmington, NC 28405

Frank Meints
The UpJohn Company
7000 Portage Road
Kalamazoo, MI 49001

James Merritt
17018 Jeanine Pl.
Granada Hills, CA 91344

Edward Mitchell
15 Tingley Road
Braintree, MA 02184

Marvin Molodow
431 Kentucky Ln.
McKinney, TX 75069

Donald Morgan
27 Clemson Dr.
Aiken, SC 29801

Sandra M. Morin
GTE Sylvania
100 Endicott St.
Danvers, MA 01923

James F. Morris
716 Clinton
Evanston, IL 60201

Phillip Motyka
Vitro Dynamics Inc.
P.O. Box 285
Rockaway, NJ 07866

Emile Munschy
37 Rockland Ave.
Woonsocket, RI 02895

Robert L. McAnally
15 Forest Rd.
Murray Hill, NJ 07974

Joseph McCallie
R.V.A.
New Boston St.
Woburn, MA

Mike McDonald
Tektronix, Inc.
P.O. Box 500, M/S 46-762
Beaverton, OR 97077

T. Thomas Nagami
LaSalle Glass Blowing Co./Canada
121 Malcolm Rd.
Guelph, Ontario N1K 1A8
Canada

Earl R. Nagle
18 Sky View Drive
Cohoes, NY 12047

Richard C. Nagle
421 E. 22nd Street
Euclid, OH 44123

Mathew Nazzewski
9½ Richmond Lane
Adams, MA 01220

Ronald Neill
283 Pharmacy No. 1403
Scarborough, Ont. M1L 3G1
Canada

Ervin M. Nichols
T.V.A.
T107 NFDC Bldg.
Muscle Shoals, AL 35660

Larry Novak
1887 No. 9 Mile Rd.
Sanford, MI 48657

Ilse Nuytemans
21 Dullingen
Brasschaat 2130 Belgium

Carl Nyman
18280 S.W. Butternut
Aloha, OR 97007

Donald M. O'Brien
Univ. of Il., 114 Noyes Lab, BX 52
505 So. Mathews Ave.
Urbana, IL 61801

Michael Olsen
341 S. Clarkson
Denver, CO 80209

Kenneth L. Opsahl
8143 Homestead Ave.
Cottage Grove, MN 55016

Malcolm B. Palmer, Jr.
General Electric Co.
Box 414
Milwaukee, WI 53201

Beverly Panczner
1507 Hagley Rd.
Toledo, OH 43612

James Panczner
1507 Hagley Rd.
Toledo, OH 43612

Ed Parillo
1363 Dill Rd.
So. Euclid, OH 44121

Charles L. Patterson
Iowa State University
34 Gilman Hall
Ames, IA 50011

Gary Pedersen
Vitro Dynamics, Inc.
P.O. Box 285
Rockaway, NJ 07866

John C. Penno
8 Tomkins St.
Green Island
Otago, New Zealand

Salvador Perez
Trokar Sa
Centeno 691
Colonia Granjas, Mexico

David Perry
Univ. of Illinois
505 So. Mathews
Urbana, IL 61801

E. Victor Pesce
At-Mar Glass Co.
611 W. State
Kennett Square, PA 19348

Grant Platt
Dept. Chem/Biochem, Massey Univ.
Palmerston No., New Zealand

Robert J. Ponton
4940 W. Vienna Ave.
Milwaukee, WI 53216

Jacobus B. Poot
8000 Ginger Rd.
Liverpool, NY 13090

Edwin A. Powell
468 Fairway Ct.
Carney's Point, NJ 08069

Sally Prasch
696F Bridge Rd.
Northampton, MA 01060

Douglas K. Reichardt
141 Woodbury Rd.
Pitman, NJ 08071

Lucy Rhamy
Conoco Inc.
1000 S. Pine
Ponca City, OK 74601

Arno Roensch
1511 Roma NE
Albuquerque, NM 87106

Paul W. Roman
57 Everett St.
Patchogue, NY 11772

Bill Ryan
NW 2025 Friel
Pullman, WA 99163

Lawrence W. Ryan, Jr.
L W Ryan Associates, Inc.
951 Main Street
Wakefield, MA 01880

Richard E. Ryan
Bomco Inc.
Rt. 128 Blackburn Circle
Gloucester, MA 01930

Ottmar A. Safferling
86-31 107th Street
Richmond Hill, NY 11418

Walter F. Sampson
502 Nye
Hudson, WI 54016

Lynn Schlickenrieder
14 Briarcliff Dr.
Nashua, NH 03062

Rudolf W. Schlott
32 Highland Down
Shoreham, NY 11786

Lloyd Schneider
Sterling-Winthrop Res. Inst.
81 Columbia Turnpike
Rensselaer, NY 12065

Joe Schrauth
591 Rutland St.
Westbury, NY 11590

Thomas R. Schul
Widgett Scientific Inc.
6818 Renoir Ave.
Baton Rouge, LA 70806

A. Ben Seal
Box 247J, R.D. 2
Bellefonte, PA 16823

Peter J. Severn
221 Jefferson
Chelsea, MI 48118

William Shoup
Univ. of Va., Glass Shop
Chem. Dept., McCormick
Charlottesville, VA 22901

Brad Shute
Univ. of Kentucky
Rm. 128 Tobacco & Health Inst.
Lexington, KY 40502

Stanley Sierodzinski
Krest Glass Inc.
7 Royal Cr.
Newburgh, NY 12550

Craig M. Sill
Greenbush Road
Box 884
Erin, NY 14838

Robert Singer
Behm Quartz
8624 East Ave.
Mentor, OH 44060

Dave R. Smart
Lorillard, Inc.
420 English St.
Greensboro, NC 27405

William T. Smith, Jr.
Laser Ionics Inc.
701 South Kirkman
Orlando, FL 32811

Gordon Smith
1114 Northern Hts. Dr.
Rochester, MN 55904

Richard C. Smith
215 Maple Ave.
Marietta, GA 30064

Ronald D. Snidow
Sandia National Labs
P.O. Box 5800
Albuquerque, NM 87135

Raymond L. Souza
59 Mishawum Rd.
Woburn, MA 01801

Andre W. Spaan
6 Headland Close
Carbis Bay
St. Ives Cornwall
TR26 2NX England

Guy J. Squeo
No. 068 Robbins St.
Winfield, IL 60190

Michael E. Steed
University of Georgia
Rm. 136 Chem. Bldg.
Athens, GA 30602

Raymond F. Steiner
16220 Renwick Circle E
Presque Isle, MI 49777

Siegfried Stolp
1043 E. 23rd Ave.
Eugene, OR 97405

Charles Stone
Univ. Research Glassware
P.O. 368
Carrboro, NC 27510

Shere Stone
Univ. Research Glassware
P.O. Box 368
Carrboro, NC 27510

Wayne Strattman
Strattman Design
791 Tremont St.
Boston, MA 02118

Stephen Stroschein
J C Schumacher
580 Airport Rd.
Oceanside, CA 92054

Alex Stuart
124 Maney Hill Rd.
Sutton, Coldfield
West Midlands, England

Roy Swain
99 Stardust Trail
Ponca City, OK 74604

Andrezej Szewczyk
Amoco Corp.
P.O. Box 400
Naperville, IL 60566

Laura Thacker
Univ. Va. Glass Shop
Chem. Dept., McCormick
Charlottesville, VA 22901

Julie Thompson
IBM
East Fishkill, Route 52
East Fishkill, NY 12590

Robert B. Tobin
Univ. of Pittsburgh
3841 O'Hara St.
Pittsburgh, PA 15260

Janos Verebi
J & V Glass Co.
2 Apache Lane
Cumberland, RI 02864

Leon Vezina
139 Colgate Road
Nashua, NH 03060

Leonard J. Wachel
Petrolab Corp.
3 Walsh Lane
Clifton Park, NY 12065

Joseph W. Walas
345R Haddam Qtr. Rd.
Durham, CT 06422

Robert Wallace
Ciba-Geigy
444 Saw Mill River Rd.
Ardsley, NY 10502

Lawrence A. Waller
Westinghouse
P.O. Box 398704
Cincinnati, OH 45239

Merrill B. Watson
4518 - 26th Street East
Tuscaloosa, AL 35404

David S. Wedsworth
Union Carbide Corp.
Old Saw Mill River Rd.
Tarrytown, NY 10591

David Wentzel
GTE Labs
40 Sylvan Rd.
Waltham, MA 02154

Warner Whitfield
Whitfield Crystal
Rt. 194
Whitefield, ME 04353

Sieglinde Widmann
1165 Oakdale Dr.
Smyrna, GA 30080

Randolph B. Wilkin
University of Houston
4800 Calhoun
Houston, TX 77004

Larry R. Williams
University of Maryland
Rm. A19, LGRC
Amherst, MA 01003

Robert R. Wilson
10483 Wyscarver Rd.
Cincinnati, OH 45241

William J. Wilt
Glastron
510 Northwest Blvd.
Vineland, NJ 08360

David P. Wise
317 Pioneer Rd.
Painted Post, NY 14870

Lee Wong
Hamamatsu Corp.
360 Foothill Rd.
Bridgewater, NJ 08807

Donald E. Woodyard
Georgia Tech., Chem. Dept.
Atlanta, GA 30318

Wendy Wymer
Texas Tech. Univ.
Dept. of Chem., Box 4260
Lubbock, TX 79409

M. D. "Shorty" Yeaman
310 Cedar Creek Dr.
Needville, TX 77461

Joseph L. Zagorac
7520 Calumet St.
Pittsburgh, PA 15218

NON-MEMBERS

Paul D. Andrews
26 Myers Rd.
Lansing, NY 14882

Richard P. Ayotte
Ayotte's Artistry in Glass
15 Coleridge Rd.
Nashua, NH 03060

Dennis Briening
Hercules Inc.
Hercules Road
Wilmington, DE 19708

Gregory Burns
Kimble Glass Inc.
1022 Spruce St., P.O. Box 729
Vineland, NJ 08360

Jack Capel
General Electric
24400 Highland Rd.
Cleveland, OH 44143

Edmund Czohara
DuPont
549 Albany
Boston, MA 02118

Roger Donovan
Verteq (U.S. Quartz Division)
45655 North Port Loop
Fremont, CA 94538

Norm Douglas
Motorola S.P.S.
MD P006, 5005 E. McDowell
Phoenix, AZ 85008

Joseph Elharar
48 Kehilat Lodge
Tel Aviv, Israel

Lisa Fox
Burito Brothers Scientific
5612 Jensen St., Suite G
Harahan, LA 70123

Thomas C. Garling
Eastman Kodak Co.
66 Eastman Avenue
Rochester, NY 14650

Douglas A. Grady
Kimble Glass, Inc.
1022 Spruce St., P.O. Box 729
Vineland, NJ 08360

Frank Guest
Kimble Glass, Inc.
1022 Spruce St., P.O. Box 729
Vineland, NJ 08360

Gary D. Hooper
12250 Abrams Road
No. 1177
Dallas, TX 75243

Karl H. Liedel
Heckerstr 19
D-6800
Mannheim
24 West Germany

George Luke
Martin Marietta Aerospace
P.O. Box 9316
Albuquerque, NM 87119

Richard Mattison
Wholesale Glass Fabricators, Inc.
1380 No. Kerr Ave.
Wilmington, NC 28405

Lothar F. Morgenfruh
159 Gary Dr.
Trenton, NJ 08690

Bob Morley
University of Washington
FM-15
Seattle, WA 98195

Tony McManus
DuPont
549 Albany St.
Boston, MA 02118

John McMillan
MIT, Lincoln Labs
244 Wood Street
Lexington, MA 02173

Dan O'Grady
Northern Telecom Ltd.
185 Corkstown Rd.
Nepean, Ontario K2H 8V4
Canada

Michel Oppenheimer
Petrolab Corp.
3 Walsh Lane
Clifton Park, NY 12065

Phillip R. Sargent
3496 Orange St.
Los Alamos, NM 87544

David Scheid
Eastman Kodak Co.
66 Eastman Avenue
Rochester, NY 14650

Edward Schram
Eastman Kodak Company
66 Eastman Avenue
Rochester, NY 14650

Terry Scott
Verteq (U.S. Quartz Division)
411 W. Orion St.
Tempe, AZ 85283

DAY CARD

Stephen Bate
IBM
East Fishkill
Hopewell Jct., NY 12533

E. B. Brown
1172 N.W. Blvd.
Vineland, NJ 08360

Wayne Creeden
Vitro Dynamics Inc.
P.O. Box 285
Rockaway, NJ 07866

Robert G. Doyle
IBM
East Fishkill, Rte. 52
Hopewell Jct., NY 12533

Maurice Doyle
Thermo Jarrell Ash
590 Lincoln
Waltham, MA 02254

Stephen Gustanson
64 Thornhill
Stratham, NH 03885

John R. Kraus
DuPont Experimental Station
Wilmington, DE 19808

Richard C. Marlor
GTE Products
100 Endicott St.
Danvers, MA 01923

Wayne C. Martin
Thermo Jarrell Ash
590 Lincoln St.
Waltham, MA 02154

Darryl S. Mix
Custom Glass Design
24 Levesque Ave.
W. Hartford, CT 06091

Noshir Motivala
Thermo Jarrell Ash
590 Lincoln
Waltham, MA 02254

Mike Trembly
5 Quarry Lane
Wework, DE 19711

Roland Trinquart
Z I Thibaud
31084 Toulouse, France

EXHIBITS ONLY

Nelson Alvarez
Lunzer Industrial Diamonds, Inc.
48 E. 48th Street
New York, NY 10036

Arline B. Barnes
109 Riverdale Rd.
Concord, MA

Barrie Bergman
One Fortune Dr.
Billerica, MA 01821

Britt Bolnick
31 Jane St.
New York, NY 10014

Luis A. Bonilla
105 Gore St., Apt. 3
Cambridge, MA 02141

Valerie Bowe
Ace Glass Inc.
Vineland, NJ 08360

Lipot Braunstein
Crystal Clear
Woodridge, NJ

Tanya Butler
14 Dodge Street
Cambridge, MA 02139

Dave Chandler
43 Brookside Crst.
Kitchener, Ontario N2N 1H2
Canada

Kane D. Conway
Digital
Hudson, MA

John E. Custer
N. M. Knight
P.O. Box 1099
Millville, NJ 08332

Richard P. DiRenzo
Precision Electronic Glass, Inc.
1013 Hendee Road
Vineland, NJ 08360

Dennis Dillinghan
Commerce Park Dr.
Danbury, CT 06810

Douglas Dreissigacker
Mountain Glass Co.
Whiteface Mem. Hwy.
North Pole, NY 12946

Frank Ducharme
George Behm & Sons Co.
8624 East Ave.
Mentor, OH 44060

Mark A. Edin
Strattman Design
791 Tremont St.
Boston, MA 02118

Blake A. Emmerich
110 N. Main St.
Florida, NY 10921

Salvador Escamilla
Medi AB S.A.
Av.A. Obregon No. 178
Mexico City, 06700 Mexico

Robert Forgnoni
Research Glass of NJ
P.O. Box 1019
Vineland, NJ 08360

Moshe Hirshberg
Orion Research
Boston, MA

Joseph Kakareka
Chem. Dept., Tufts Univ.
Medford, MA 02155

Robert A. Kierst
Electrothermal Inc.
275 Moorristown Rd.
Gillette, NJ 07933

Juergen Kramer
Glausstr 1, Geisenheim
D-6222 W. Germany

Eric Kummer
140 Old Post Rd. South
Croton, NY 10520

R. T. Machado
CPI Controls
29 Mendon Ave.
Pawtucket, RI

Randy McClellan
183 Warner Ave.
Worcester, MA

Joseph F. McLay
Fischer & Porter

Craig Nagami
LaSalle Glass Blowing Co., Ltd.
121 Malcolm Rd.
Guelph, Ontario N1K 1A8
Canada

Jack D. Narbut
N. M. Knight Co., Inc.
P.O. Box 1099
Millville, NJ 08332

Steven L. Pesce
At-Mar Glass Co.
407 East State St.
Kennett Square, PA 19348

Esther Plumbo
4 Sunset Ave.
Linwood, NJ 08221

James Ray
941 Kathryn
Wilmington, OH 45177

Kevin Reynolds
Omni Glass

Ric Rodriguez
Swift Glass Co.
244 N. Melrose
Elgin, IL 60120

John Rossi
Precision Electronic Glass, Inc.
1013 Hendee Rd.
Vineland, NJ 08360

James Shulman
J. S. Shulman
241 Perkins St.
Jamaica Plain, MA 02130

Ruth A. Smith
Elgin Precision Glass
1200 Abbott Dr.
Elgin, IL 60123

Leonard Spinoso
Crystal Clear Industries
Woodridge, NJ

Steve Steinbis
Elgin Precision Glass
1200 Abbott Dr.
Elgin, IL 60123

Jeffrey P. Swinchatt
Heathway Inc.
903 Sheehy Dr.
Horsham, PA 19044

Daniel Thiel
Cornell University
Ithaca, NY

Anna F. Turpin
28 Vernon St.
Malden, MA 02148

Anthony Velluto
2170 N.E. 51 Cort
Apt. C2
Ft. Lauderdale, FL 33308

Florence Velluto
2170 N.E. 51 Cort
Apt. C2
Ft. Lauderdale, FL 33308

Karl VonEntress
Mountain Glass Co.
Whiteface Mem. Hwy.
North Pole, NY 12946

Edward C. Wheaton
Wheaton Scientific
1000 No. 10th St.
Millville, NJ
08332

Donald Wilson
6 Hinckley Road
Tewksburg, MA
01876

Kathy Wilt & Sons
Wilt Industries
Route No. 8
Lake Pleasant, NY 12108

John A. Ziegler
MC Danel Refractory Company
Beaver Falls, PA 15010