COMPARISON OF FIBER OPTIC LIGHT GUIDE MATERIALS

FIBER-OPTIC LIGHT GUIDES

Fiber optic systems are the only light sources that can provide a museum with UV and IR free artifact lighting. They are also the only systems that can safely move lighting into a case to eliminate glare and reflection. Lastly, only fiber optic systems allow a museum the ability to illuminate varying artifacts at varying intensities and to do effective Reflected Energy Matching filtering to extend exhibit life.

To confuse things, there are a number of fiber optic systems on the market using several kinds of fiber. Some of these are modified swimming pool or communications systems. Other were designed for effects, like fiber optic Christmas trees and yard lights. These systems are not applicable for museum use. A conservator needs to be able to identify a system by type and know which system or systems are capable of meeting their needs.

Although some people only recognize a difference between “glass” and “plastic” light guides, there are actually three types of fiber optic light guides; acrylate “solid-core”, “glass”, and pMMA (polymethyl methacrylate) “acrylic” fiber. In a further division, pMMA “acrylic” fiber is manufactured both as a single fiber, and as bundles of small multiple strands of fiber. Each type of fiber has its own characteristics, in terms of transmission efficiency, spectral color transmission and optical emission pattern.

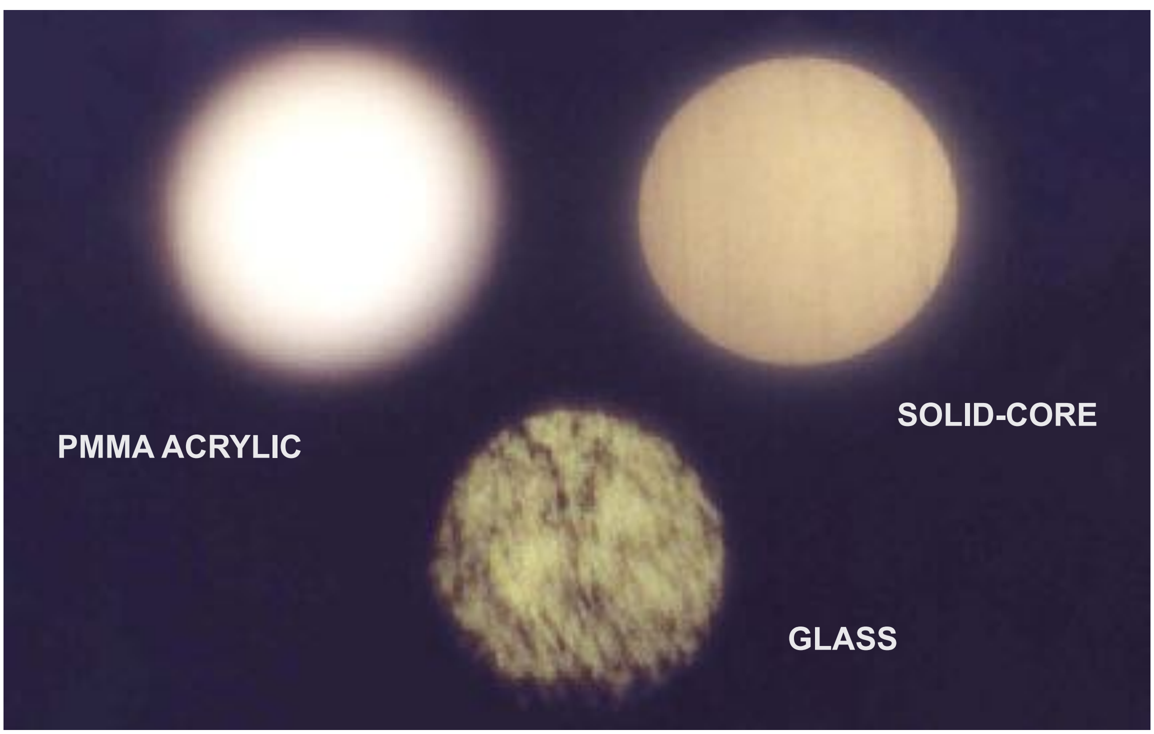

Figure B-1. The three types of fiber-optic light guides.

All the fiber ends in Figure B-1 were photographed together and underexposed to show brightness and color differences. In this photograph each fiber is 3mm diameter and 10 feet long. All three fibers were mounted in the center of a single common-end bushing, so they received identical light intensity and spectral power distribution. Each fiber type is described in more detail below.

GENERAL CHARACTERISTICS

All fiber optic light guides share certain characteristics. All light guides transmit light down the middle of the fiber by internal reflection. Surface reflection at grazing angles is naturally efficient. (Cladding, which is described next, increases that efficiency.) In general, the lower the angle that the light strikes the surface, the greater the percentage of light reflected. This is one of the reasons lasers are used in fiber optic communications systems where signals are sent over miles. Collimated light focused perpendicular to the end of the fiber will have very low internal reflected angles within the fiber.

Source optics are, therefore, extremely important in fiber optic illumination systems. Good optics in a projector will focus light on the fiber ends at very shallow angles. Just pointing a fiber at a bright source is terribly inefficient. So is using an unfocused source.

The problem is that many systems today deliberately defocus their source illumination in order to avoid overheating and damaging the fiber. They degrade the optics because they have no other method of effectively filtering the huge IR content of the source. They will have very powerful sources in terms of wattage or illumination and very poor output at the end of the fiber where effective light is needed. This is why projector output means little in evaluating fiber optic illumination systems.

Cladding

All fiber also has some form of cladding. This is a coating on the glass and acrylic fibers, and an air pocket inside the outer tube on solid core. The cladding increases the internal surface reflection of the fiber. It makes the fiber more transmissive.

The cladding itself does not carry light. Light hitting the end edges of the cladding is lost. Cladding increases the fiber’s ability to transmit light. At the same time it slightly decreases the amount of light a fiber is able to carry.

Picture a water pipe. A pipe must have a wall. But, the thicker the wall; the less cross-sectional area the pipe has for water. Clad fiber works the same way.

With relatively large acrylic fibers, 1mm and up, this decrease in light carrying ability is insignificant. The 0.00013 inch cladding of a 3mm diameter acrylic fiber represents only about 0.3% of its cross section. (Cladding represents about 0.8% of a 1mm diameter fiber.) With both, over 99% of the fiber carries light. With glass fiber, where each individual strand is only 0.002 inches in diameter, the same cladding represents 17% of the cross section. This represents a significant reduction in optical efficiency. Solid-core, which is a special case, has a fairly thick outer tubing for structural reasons. Add the air gap between the core and the wall as cladding and solid core also has a greatly reduced optical efficiency.

Cross Section of Normal Glass Fiber

In addition to the reduction in cross section and the attendant reduction in optical efficiency caused by cladding, stranded fibers loss a significant part of their cross section to the interstices between the strands. With loosely woven stranded acrylic fiber, the spaces between fibers within the thin-wall tubing used to hold the strands together can equal 50% of the cross section. With glass fiber, although there are many more individual strands, the optical efficiency is only a little better, 58%. The epoxy film between each strand, holding the strands together, the 17% cladding and the spaces between the strands account for over 40% of the cross section. Calculating usable cross section alone shows that a single-strand acrylic fiber will be expected to transmit twice the light of any multi-stranded fiber, glass or acrylic.

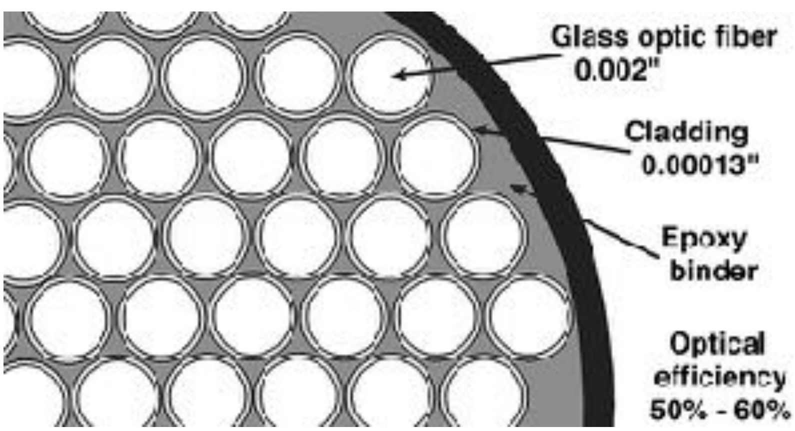

Figure B-2.
Geometric inefficiency of glass and stranded fiber.

The cross section of individual strands is important also. Although internal reflection in a clad fiber shows extremely low losses, there is some loss with every reflection. This is why lit fiber will have a slight side glow.

The cumulative loss from these repeated reflections is a function of the ratio between the cross section and surface area. Smaller fibers have higher surface-area to cross-section ratio (more reflections per foot) and lower transmission efficiencies. The transmission loss of a 3mm acrylic fiber is 0.7% a foot. A 1mm acrylic fiber, or a larger fiber made of 1mm strands, will have a loss of about 1% a foot. A 1/4mm fiber is slightly higher yet. Glass fiber with hundreds of very small strands will have losses of 2% per foot or more.

Cross Section of Fused Glass Fiber

Fused glass fiber is not to be confused with a “fused connection” used to bond one glass fiber to another glass fiber. This is fusing, or the controlled melting *at an end of the whole fiber.* The process gets rid of the epoxy between the individual tiny fibers bonding glass to glass making the fiber a slug of mono-like fiber at each end, but stranded fiber between the ends over the full length of the fiber.

To make the term fusing even a little more confusing, some manufacturers strip the jacketing from the fiber at the bushing end and fuse the whole bundle where the aims light into the fibers. The technique is careful melting. The process squeezes the fibers together.

The melting deforms the fibers against one another to get rid of the area around each individual fiber. The process crams more tiny fibers into the ferrule, the metal part that holds the fibers making the strands a single fiber. The process offers more fiber surface area to carry light.

The technique has to be done with extreme skill. The more the fibers are heated, the more the crystal structure is scrambled. And the more the fibers are not pushed into a hex shape, but instead are deformed and even overly melted.

Done well, footcandles increase. Done marginally, the fiber gets dimmer. But the process can allow light sources with a lot of IR content not to burn the epoxy holding glass fiber together.

For any fiber, the long chains of molecules lined up inside the material are important for transmission. This is especially true in sending visible light. The more these crystals are twisted or distorted, the more the light loss.

For acrylic fiber, no type of deforming is “good” over time. The stress by twisting the molecular chains starts degradation as cross-

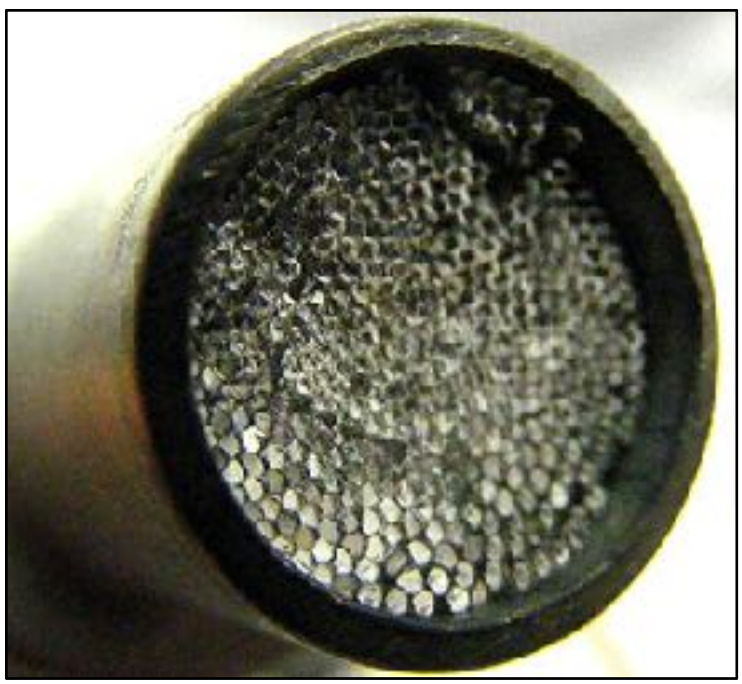

Figure B-3.
Fused end of a fiber. Some of the strands are hex shape, yet others are overly melted.

linking. The crystals are turned on their side and attaching to other chains at the fusing. But because the fusing destabilized the plastic, the cross-linking continues as the fiber drops more and more long crystal links started at the fused end. Eventually the fiber yellows, embrittles and dims. If the fiber is bent under any mechanical stress, the cross-links are not strong like the original chemistry of the acrylic. The fiber will sheer. It will break. Therefore, acrylic fiber should never be heated, reformed or “relaxed” even by as little heat as that from a heat gun.

For glass fiber, the fusing works well if the glass is not over melted. The glass is stabile after the process. The overall transmission increases.

But the crystals are still skewed. Cross-linking and swirling has occurred. There is a the loss per foot on an individual fiber by fiber basis. And the more aggressive the deformation of the fiber, the greater the loss.

Fusing the fiber ends add 98% more fiber surface. Only 2% of the area remains of what was originally filled by epoxy. Since high-temperature epoxies are how many glass fibers fail over time, fusing makes the fiber more durable as well as adding intensity.

However, the fiber is not that efficient of a carrier for visible light compared to a non-stranded, mono-fiber. The stranded fiber still has 17% of the area as cladding. The fibers on the outside at the ferrule are also severely deformed. The perimeter fibers carry little light with a loss of 10% to 12%.

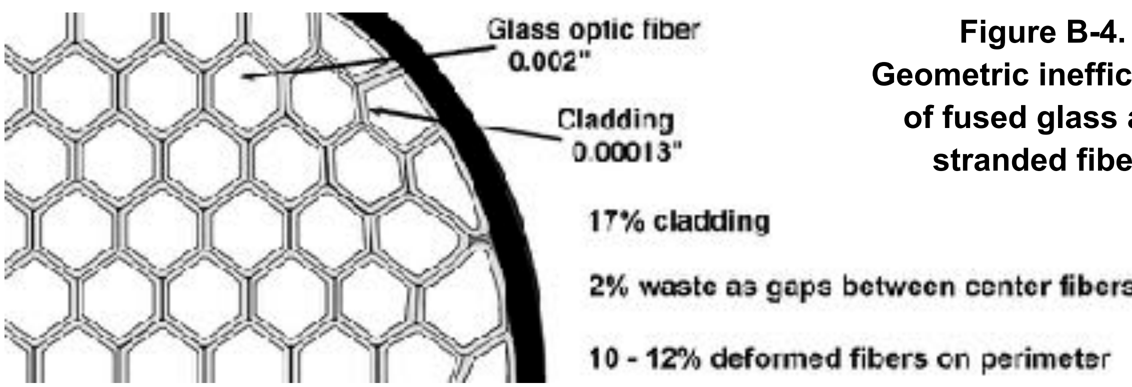

Figure B-4. Geometric inefficiency of fused glass and stranded fiber.

The cross-section shows an improvement compared to 40%. But the optical inefficiency is still 29% to 31% with a gain in useable fiber area of only 25% (not 98%). The higher cost of fusing can be well worth it in some applications, like medical, and not in others, too high a cost for a collector’s case.

A question might be asked, “Why not just make hexagonal fiber?” The diameter as a curved surface shape helps bounce the light internally down the fiber like a reflector. Corners let light escape. The bushing end and termination ends of the fiber can handle a short section of angles where light easily escapes out of the fiber. But if angles were down the whole length, the fiber would be very inefficient with dim output.

Transmission

The physical properties of the fiber material will also impact the optical efficiency of the fiber. Obviously, the more transparent the material, the more light it will transmit, and the better it will function as a light guide. This is an area where solid-core fiber suffers.

It is possible, however, to efficiently transmit the wrong wavelengths. Glass fiber will transmit ultraviolet radiation. More importantly, glass is extremely efficient in transmitting infrared energy.

Glass fiber was designed for communications use with IR lasers centered around 1440 nanometer infrared energy. The web site and other pdf documents cover the photochemical and photomechanical dangers of IR radiation in detail. But a conservator of a world-famous institution stated it this way, “Increase the artifacts’ temperature by just 10°C and cut their exhibit life in half.” This alone should disqualify glass fiber for museum use.

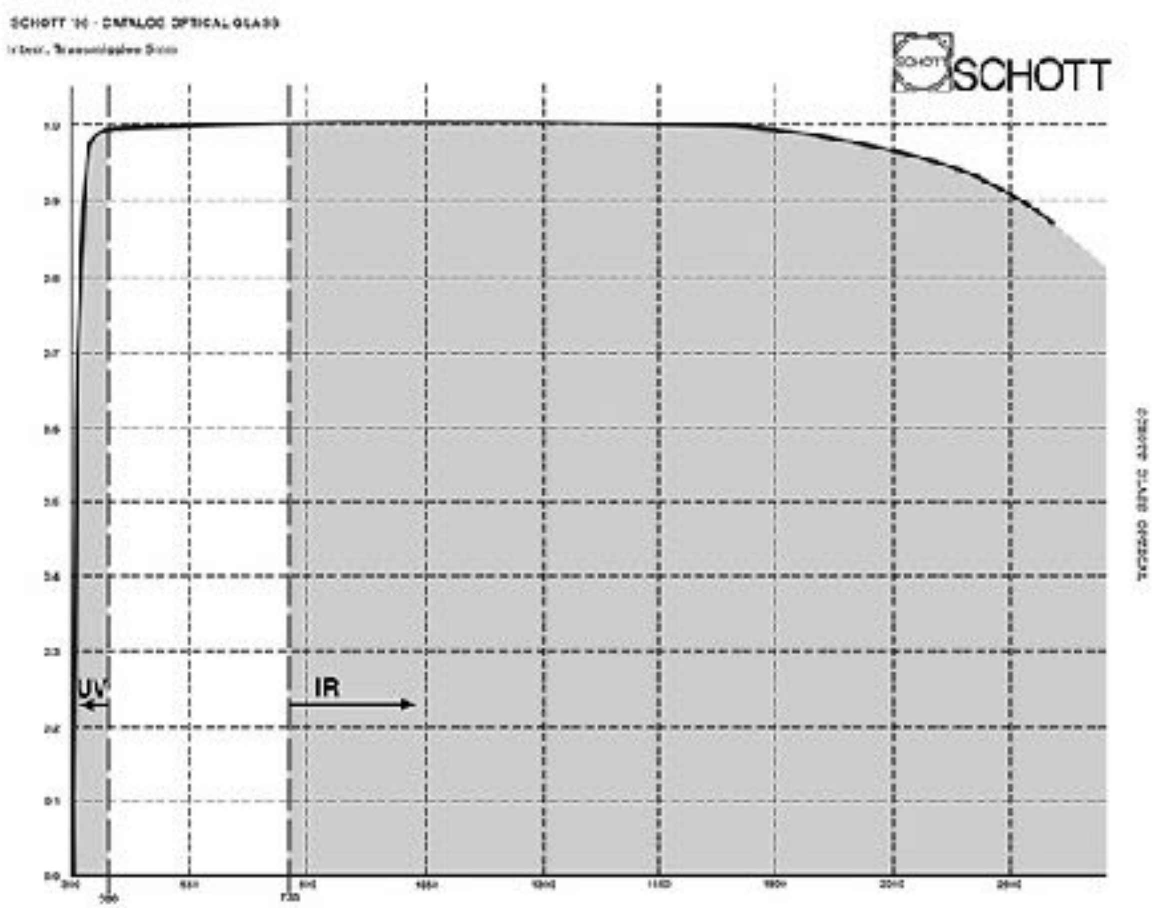

Figure B-5. Spectral transmission for glass fiber[1]

[1] Data provided by Schott Glass Optical, 1991, (UV and IR information added).

In contrast, acrylic fiber is an extremely efficient transmitter of visible light. It has the lowest loss of any optic fiber available today. It is also opaque to both UV and IR. This makes it an attractive choice for conservation lighting providing that the IR energy is removed from the source before light is focused onto the fiber.

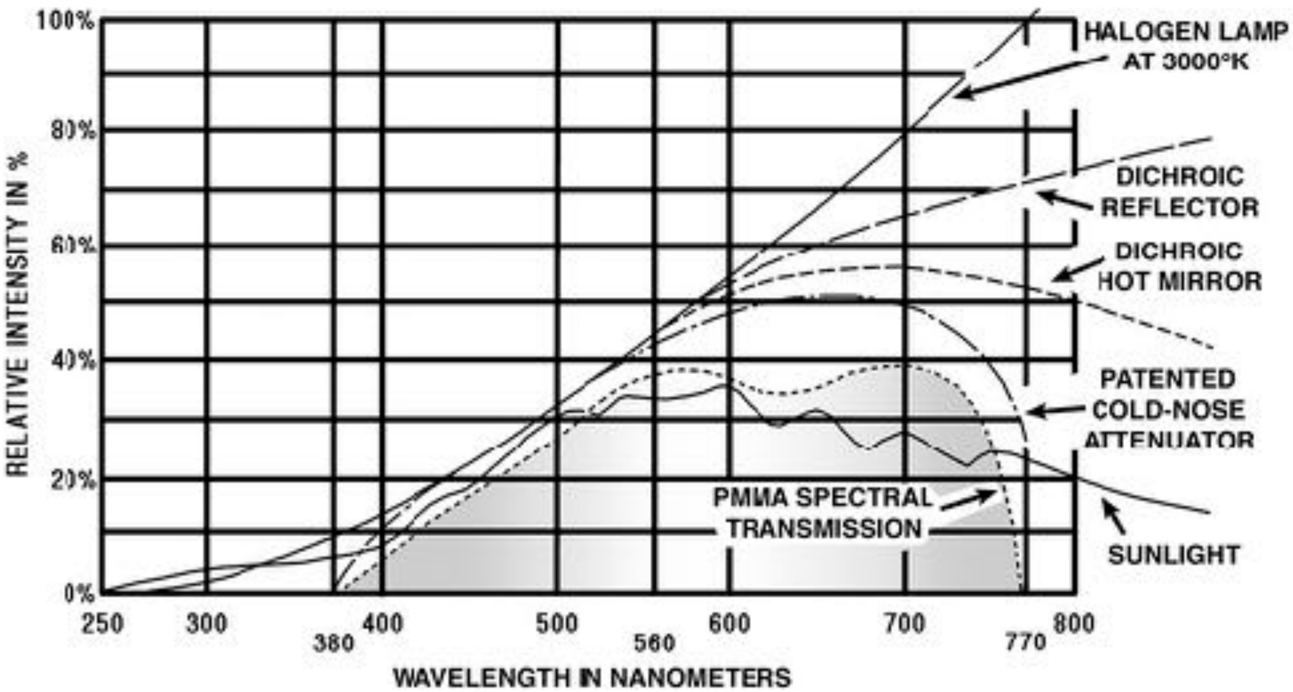

Figure B-6. Spectral transmission of pMMA "acrylic" fiber.[2]

But using acrylic fiber in focus in a technical challenge. It is beyond most companies abilities. NoUVIR fiber does not change even with decades of service. One of the reasons NoUVIR can offer a limited, but complete warranty, including fiber is because of the above curve. The heat does not reach the fiber. Just visible light goes into the acrylic.

Others cannot make this claim. This is a halogen-driven fiber optic system bushing with only a few years of service life. The acrylic fiber melted. The system went dim and then dark. Fortunately there was enough service loop to trim the fiber far back past scorched fiber, past embrittled fiber and past cross-

Figure B-7.
A melted acrylic bushing found in a competitor's system that could no control heat build-up.

[2] Data provided by NoUVIR Research, 2002

linked fiber to make a new bushing and light the fiber with a NoUVIR projector. Using a LED-driven projector could also have been a solution. An LED lamp is automatically out of focus and cool enough the acrylic fiber should not melt. But a LED fiber optic projector driven system produces only 13% of the illumination.

Bend Radius

All fiber has a minimum bend radius. You will have to consider this bend radius when designing. Generally, the larger the fiber or strand diameter, the greater the minimum bend radius.

Stranded fiber will have a smaller bend radius than solid fiber providing that individual strands are able to float within the bundle. But beware. The jacketing hides the stress. Glass fibers can break just from gravity pulling on the weight of the fiber.

Bending fiber too tightly either breaks the fiber immediately or it induces stresses that will result in fiber failure in the near future. This is true for all fiber. Figure B-7 shows glass fiber damage as a result of too tight a bend.

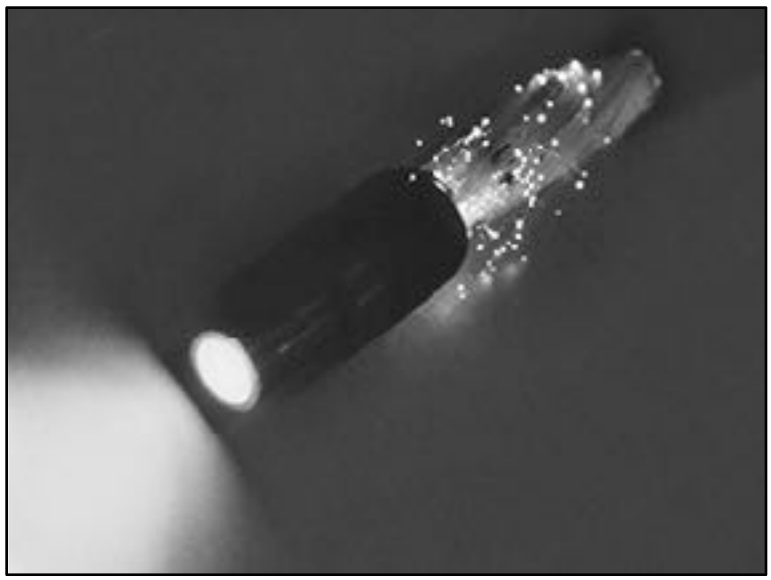

Figure B-8.
Glass fiber breakage at 90° bend.

Some manufacturers suggest heating acrylic fiber to relieve the stresses of over bending. **DO NOT DO THIS!** Heating acrylic fiber changes the crystalline structure of the acrylic. It will lose transmission ability, become brittle and begin to yellow. Live with the minimum bend radii.

Well-designed systems will provide a means of off-axis aiming for individual fibers. With proper luminaires you should be able to aim the light from any fiber up to 90° to that fiber. This makes lighting design simple. It will also make it easy to conceal luminaires in casework and exhibits.

Focus

By definition, tightly focusing the light from any fiber will project an image of the end of that fiber. Therefore, multi-stranded fiber and multi-fiber luminaires cannot physically be focused. Attempting to do so projects the images of all of the ends of all the strands of all the fibers, giving you a mottled image of bright and dark spots.

Focused fused glass fiber will show the individual tiny fibers that make up the whole fiber with the dark spots of the cladding making an uneven beam with dim spots scattered within the beam. Regular glass fiber with its epoxy that cannot carry light is worse with more mottling. Focused solid-core fiber or fiber cut with a hot knife shows the striations from cutting. The beam has lines in it if focused. But acrylic fiber can be polished into a lens. That fiber end can be focused as a tight image producing a smooth beam. With patented optics, properly polished acrylic fiber will focus down to a perfectly smooth 5° beam with no spill.

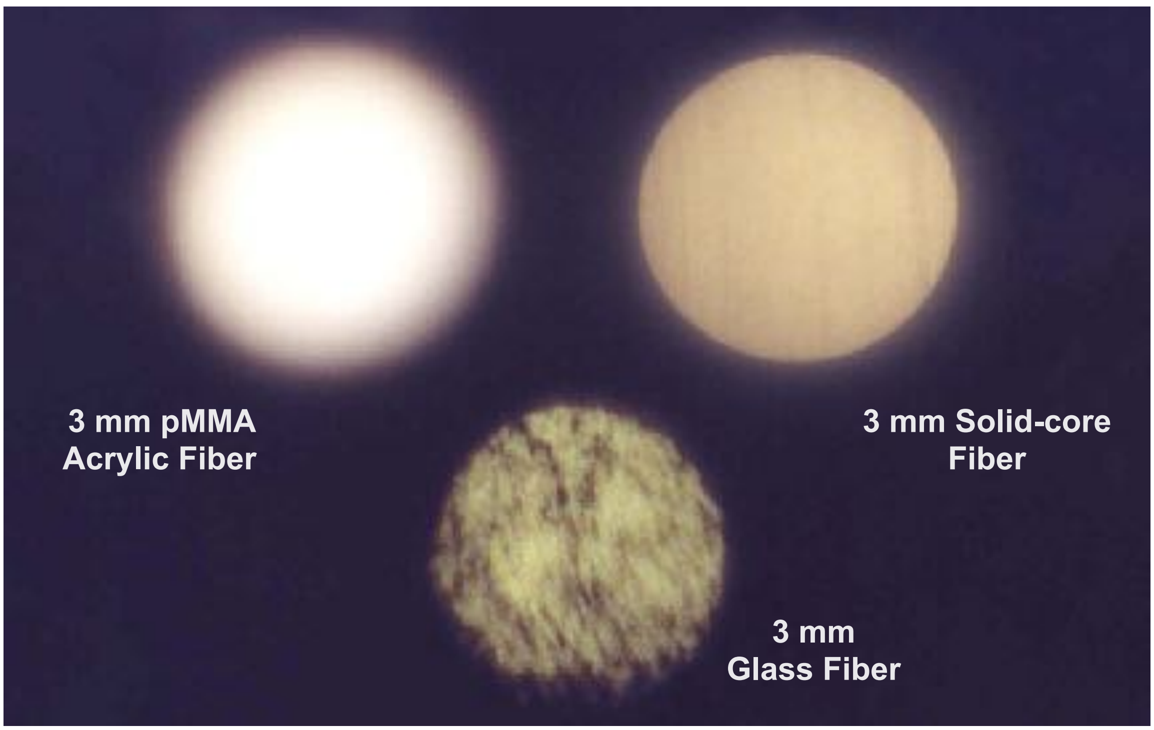

Figure B-9. Focused beams of glass, solid-core and pMMA acrylic fiber.

Glass Fiber

Glass fiber is a misnomer. Pure glass fiber doesn't exist. Regular glass fibers must be bonded together with epoxy to be held in place and polished to transmit light. Therefore, the proper description is "epoxy-bonded glass fiber".

Suppliers of these materials may claim that glass fiber will last forever. This is not true for two reasons.[3]

First, epoxy is sensitive to both intense light and heat. Even “high temperature” epoxy darkens, causing it to absorb more heat and decompose. In the common-end bushing heat causes the epoxy to soften and expand out to partially obscure the light coming into the fibers.

Figure B-10.

On the left, a glass fiber common-end bushing, obscured. The lines and dark holes are the epoxy. On the right, a new unused bushing. The obscured end was removed from a museum installation after failure as a result of heat and intense light.

Fused glass fiber does not have the epoxy. It will not fail in this way. But glass fiber is still a misnomer. Pure glass fiber doesn’t exist. The whole fiber is made up of tiny strands of glass covered in cladding.

That cladding is melted into the fiber. So there is still a lot of dark material inside the fiber that will not transmit light. The beam is not as bad as regular glass fiber and the epoxy failure problem has been solved, but the beam is still mottled and uneven from edge to edge.

The second form of glass fiber failure is stress failure. Glass fiber is very flexible as each fiber has a very small cross section. The fiber moves inside the protective jacketing. It is also, however, very fragile.

Glass is a heavy material for fiber. As a fiber, it does not support itself well. That is usually not a problem in communication applications. The fiber is supported by conduit, pipes, hooks, etc. However, for lighting applications, the fiber often ends up in free air supporting itself as it bends into a luminaire or into a projector. In stress, the fibers fracture. As individual fibers break, the whole

[3] When one of these reasons results in fiber failure, you will be told that fiber replacement is a normal part of maintenance. The only way to avoid getting caught between the “last forever” promises and the “normal maintenance” reality is with a good warranty. A promise not written into a warranty is just noise.

fiber or bundle looses its ability to carry light.

Figure B-8, shown earlier and reprinted here, is a photograph of an actual glass fiber end removed from a museum installation because of this kind of bend-radius fiber failure. The trouble is that the heavy jacketing of glass fiber hides the breakage. The luminaire over time simply gets dimmer and dimmer as more and more fibers of the whole fiber sheer.

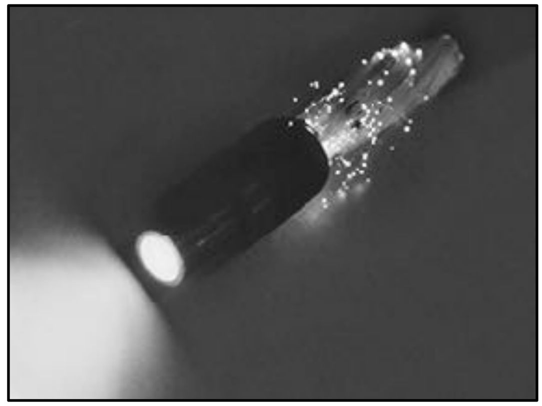

Figure B-8.
Glass fiber breakage at 90° bend.

Note that this was a failure at the luminaire. Fiber optic luminaires do not support the fiber as it bends into the optics. That bend creates stress on the fiber. The glass breaks.

Another drawback for visible lighting applications is that glass fiber harnesses are relatively inefficient light transmitters. Losses are over 2% per foot. As mentioned above, this is because of the microscopic size (50-micron diameter) of the individual glass fibers and the low ratio of cross-section (light carrying ability) to surface area (potential loss).

Lab measurements comparing 3 mm diameter glass fiber tails 10-feet long to 3 mm pMMA acrylic fibers showed glass transmitting less than 1/3rd the light of acrylic fibers. Losses added up. Many fiber optic lighting manufacturers that use glass fiber recommend a limit of 3 meters or 9 feet for any length of fiber, and prefer fiber length less than 6 feet. Acrylic fiber installations use 20 to 30 feet lengths of fiber all the time and have installations in use with fiber runs as long as 50 feet.

Another important characteristic of glass fiber is its efficient transmission of IR energy as shown in figure B-5. This heat transmission is ideal for communication. But it is a serious problem in a museum environment.

I know one museum technician who actually burned (blistered) his finger in front of a glass fiber tail. Picture what that heat energy is doing to the artifacts in that museum. I know medical applications where glass fiber is used to cauterize to stop bleeding.

Glass fiber cannot be focused. As a result glass fiber luminaires need to be placed close to artifacts. Luminaires become obvious and distracting.

Figure B-11 shows a typical glass fiber application. The luminaires are mixed in with the artifacts. The problem is the lack of focus. Notice that the glass fiber is not supported where is comes out of the luminaire. Over time this fiber will fail. (Given its high IR transmission, the lack of focus might be considered a benefit for glass fiber. Tightly focused IR could literally cause fires with some materials!)

Figure B-11. Glass fiber application[4]

Figure B-12. Glass fiber gallery.

Figure B-12 is a better example of using glass fiber. The fiber is supported through the curve of the tube. The luminaires are in the corners of the case. But notice the beams. The necklaces are lit. But so are half of the forms where there is nothing. Half the light is in front of the jewelry. This is typical of glass fiber installation. The inability to focus forces the design to place the fiber close to the objects and there is still a struggle to control the beams.

Glass fiber is expensive. It must be ordered precut and polished from the factory. In practice this means extensive design work, lead times of 8 to 12 weeks or more, and zero flexibility during or after an installation. Paul Mathieson detailed the costs of the installation shown above (Figure

[4] Paul Mathieson, Color, Cut & Clarity, Lighting Design & Application, October, 1994

B-11) as $24,000.00 for 14 fiber optic harnesses plus $22,500.00 for the lenses and mounting hardware. This is without a cost for design time. Because of the difficulty of design, and the hard fact that most exhibits end up changing right up to opening, glass systems frequently go over budget and over time.

Figure B-13. Acrylic fiber can light from a distance. Note the tight beam control from luminaires hidden in the top of the case.

Glass is an excellent communication fiber. Data can be transmitted, usually by infrared lasers, down individual strands within the fiber. It has wonderful capabilities for high intensity surgical applications where routine fiber replacement is expected. As a fiber it is readily available and can be bought in a number of grades.

But it is not a good choice for visible lighting. Because of its cost, its lower transmission efficiency, its inability to focus and most of all its transmission of frequencies outside the visible spectrum (UV and IR), glass fiber should not be considered for museum use. Other fiber materials offer superior performance.

Acrylate Solid-Core Fiber

Acrylate solid-core fibers are made of a gelatinous resin that is extruded into sheathing much like stuffing sausages. The sheathing has fine, internal ribs to create an air space between the core and the sheathing. This space creates a “cladding” of low-refractive index air capturing the light in the fiber by internal reflections. Solid-core can be made very large, over 1/2” in diameter. Solid-core fibers are very soft and easily bent when new, but subject to substantial light losses if bent too sharply.

Originally designed as neon type side-light illumination for swimming pools and ponds, solid-core fiber is heat sensitive and has a slight yellow tint even when new. A 10-foot fiber will reduce the color temperature of a 3000 K° light source to around 2800 K°. Color temperature will drop another 20 K° with each additional foot of length. The resin interior is mildly photosensitive. As it ages, it begins to turn more yellow and becomes brittle. We have replaced some systems that turned caution-light yellow and developed internal cracks in less than 2 years.

Striations are visible on the solid-core fiber in the projected image of the fiber (Figure B-9), and on the fiber itself (Figure B-4). Cutting the fiber always produces these striations, even when using the fiber cutter provided by the fiber supplier. The striations cannot be removed. Solid-core fiber is not hard enough to polish.

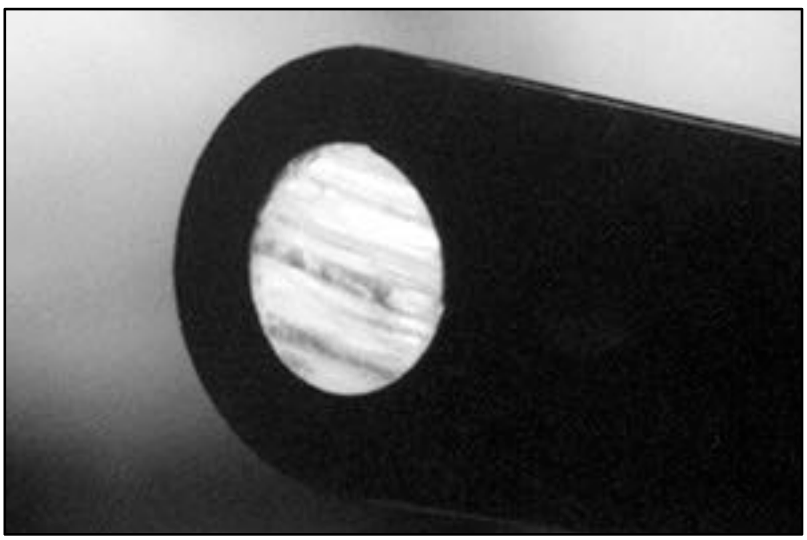

Figure B-14. Cutting striations on solid-core fiber. The fiber was dimly illuminated on the far end to clearly shown the striations.

While solid-core fiber may eliminate UV and IR, its initial color distortion, very high transmission losses, further color shift over time, poor focussing and extreme lack of durability make it a poor choice for task lighting. It is effective in side lit, neon-effects lighting. It works in underwater applications where temperature is never a problem. It is a solution for certain architectural applications as it comes in very large diameters.

Remember to leave extra fiber at the projector end and plan on cutting the end off every year or two as the fiber closest to the projector becomes brittle and discolored. This is normal maintenance for this type of fiber. Museums using solid-core fiber are commonly forced to replace their lighting systems in a four to six years.

Multi-Stranded Acrylic Fiber

Multi-stranded acrylic fiber is made up of a number of small strands of acrylic fiber braided or bundled together and run through a plastic jacket. It is sold by a number of companies under different names. The advantage to multi-stranded fiber is that it is more flexible than single-strand acrylic fiber and has a smaller bend radius. The other advantage is that the manufacturer of the fiber can offer a variety of fiber sizes (diameters) while purchasing a single, small-diameter-sized fiber that make up the strands from the source.

Multi-stranded acrylic fiber is not, however, a very efficient transmitter of light. As described above, about half of the fiber bundle cross section is air, not acrylic. The small fiber ends are not usually polished so focusing light into and out of the fiber results in high losses. Because the strands are loosely organized, it is impossible to keep them all oriented toward a light source. This inefficiency makes multi-stranded acrylic fiber systems susceptible to heat damage as manufacturers try to overcome transmission losses with higher power sources.

Like glass, multi-stranded systems cannot be focused. This means that throw distances are very limited. Even when used for general short throw flood lighting, multi-stranded systems require 3 to 5 times the hardware (and fiber) of a single-strand acrylic system to provide the same light level over a given area.

These inefficiencies generally result in higher costs. Advertised cost savings (usually comparing just projector costs) rapidly evaporate as hardware requirements go through the roof. Factor in the added installation costs and inefficient systems can become very expensive.

Solid (pMMA) Acrylic Fibers

Extensive investigation and testing at NoUVIR resulted in the selection of acrylic fiber as the only acceptable candidate for museum fiber-optic lighting systems. It is, to this day, the only fiber that could be found that met all the criteria necessary for museum exhibit use. Polymethyl methacrylate (pMMA) is an extremely durable. It is a reliable, clear plastic that has been used for decades in museum exhibit cases, in windows and even jet aircraft canopies.

In the standard 3mm diameter, single-strand acrylic is strong, efficient and reasonably flexible with a 6” minimum bend radius. Visible light transmission loss is a minimal 0.7% per foot. This means 81% of the initial light is available at 30 feet. (Compare this to 54% for the best glass fiber at the same distance). Acrylic fiber is inexpensive ($1.00/foot for 3mm), available by the roll, and easily cut and polished in the field.

The ends of acrylic fibers may be polished in minutes by hand, or in seconds on a buffer, to a shiny, perfect, lens-like surface (Figure 8-10). This makes light-as-you-go installations with existing museum staff simple. It also makes lighting changes to exhibits almost as simple as moving the artifacts.

Figure B-15. Polishing solid pMMA acrylic fiber with a hand buff like those used on acrylic nails in a beauty salon.

Single-strand pMMA "acrylic" fiber is opaque to both UV and IR energy. UVP (Ultraviolet Products) in Ontario, California is a leading manufacturer of UV meters and sources. They reported that the acrylic fiber powered by a NoUVIR projector was the only light source they had ever tested that had no UV energy (0.000 μw) at any wavelength from 100 to 380 nm.

As mentioned above, heating acrylic fiber results in damage. It is easy to melt acrylic, as a number of museums with inferior projectors have found out. For this reason an acrylic fiber optic system must have a well-designed projector with an optical system capable of removing the lamp IR before it reaches the fiber.

Acrylic fiber has a rated continuous operating temperature of 70°C (158°F) and a peak operating temperature of 80°C (176°F). Not only should a system operate well below this 70°C, it should operate well below that temperature internally in the focused beam at the fiber.[5] A projection lamp in a box with a simple hot mirror (and maybe a dichroic color wheel) won't do this. Ask for test data. More important, ask for a warranty. NoUVIR® offers a 10-year full replacement warranty against yellowing or loss of transmission.

Acrylic fiber is the only fiber optic light guide that can be polished and effectively focused. With an efficient projector a single 3mm acrylic fiber is capable of powering cross-room throws at tight focuses. (As an example a NoUVIR ULTRA-FOL™ Pinspot on a 10-foot acrylic fiber will light a 20-inch circle to 9 footcandles at a throw of 20 feet.) An example of the focus possible is shown in Figure B-11.

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[5] A NoUVIR projector will operate continually at 40°C to 45°C at the fiber face. As a matter of fact, a NoUVIR projector is designed so well that you could cut the wires to the cooling fan and wrap it in fiberglass insulation and it will shut off the lamp before it burns the fiber.

Figure B-16.
A single pinspot powered by a single 3 mm acrylic fiber shines a beam from the outside wall of the lighting lab clear across and through the inventory stacks at the NoUVIR facility. This is over a 60-foot throw.

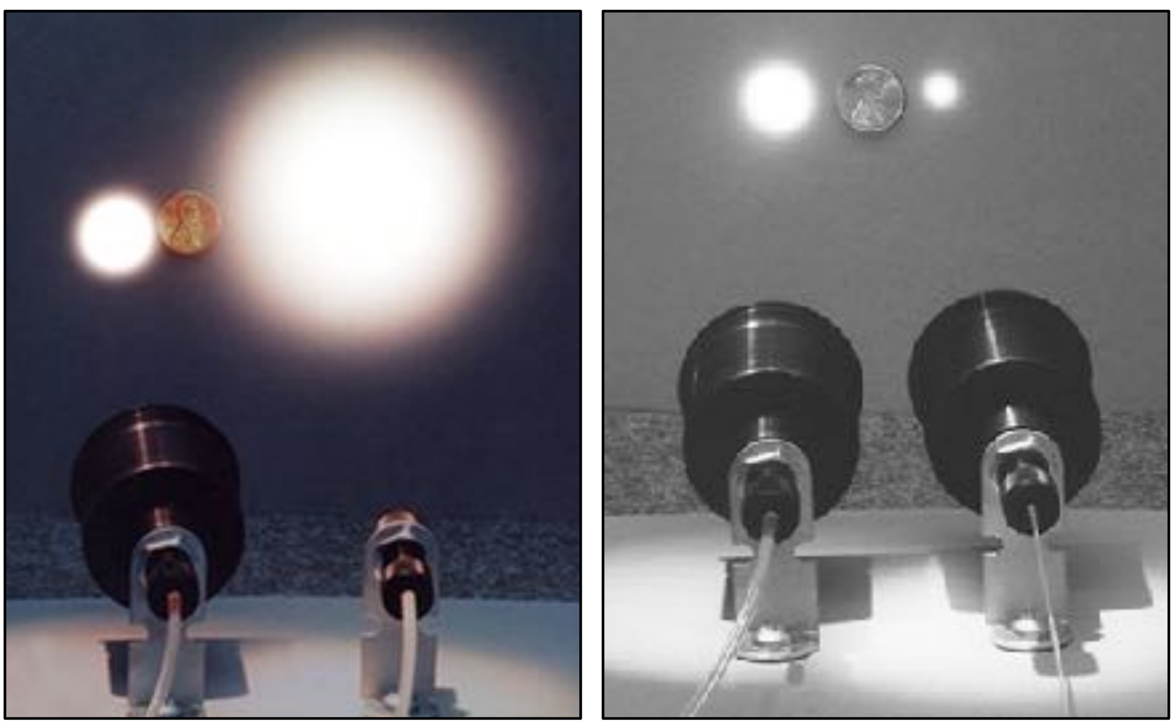

Figure B-17. Focus possible with solid acrylic fiber.

Additional Information

You are in the educational site at www.nouvir.com. It is impossible to describe the NoUVIR line of fiber optic lighting in detail here. The complete NoUVIR Catalog is over 130 pages. Roughly half of that information is instructional, describing the principles of exhibit lighting, the processes of controlling glare and reflection, the principles of reducing or eliminating photochemical damage, and fiber optic design and applications in detail. See the other web site at www.nouvir.com for the catalog or request a printed catalog from NoUVIR. For questions, comments or more information contact:

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