MOLECULAR SPECTROSCOPY WORKBENCH

SCOTT WOHLSTEIN

Shedding Light on Fiberoptics

A personal note before I get to the business at hand. At this past PittCon in Atlanta, I was a bit irritated by some booth personnel. My fiancée (University of Maryland) and I (Seton Hall) were wearing "student" badges in the exhibit halls. On several occasions, as we entered company booths, I heard the comment, "Oh, only students." I would like to remind the vendors that "mere students" are potential customers for the very near future and should be treated with a little professional courtesy. One company (of many, I hasten to add) that always gave special treatment to my students (while I actively taught) was Waters/Millipore. The students were always given test kits along with a tour of the booth. 'Nuff said, vendors?

This month's guest author has written in this space before (on lasers, Nov/Dec '89). Scott Wohlstein (SD Laboratories, Inc., [SDLI] P.O. Box 230, Convent Station, NJ 07961) is a photonics specialist, which is to say he uses light like a chemist uses chemicals. I asked him to tell us about fiberoptics, but not necessarily how they are used. He obliged with this piece on their theory and production and added a bit of a glossary to help us understand the jargon. With the inclusion of fiberoptics as an option in nearly every spectrometer sold today and their growing use in process control, I believe that this explanation is timely.

Emil W. Ciurczak
Contributing Editor

The field of fiberoptics has enjoyed explosive growth since its humble beginnings more than 100 years ago, thanks to John Tyndall, a British physicist. AT&T was awarded a patent in the early 1930s for the "Light Pipe," the first glass fibers developed to transmit light over short distances. They were engineered by American Optical Corporation, and Corning Glass Works developed the technology to produce fibers capable of transmitting light over long distances.

The basic theory of fiberoptics is straightforward and is primarily based on total internal reflection (TIR). This phenomenon describes the path taken by the light as it travels through the fiber and the way the light should encounter a higher refractive index in the buffer or cladding material than in that of the fiber core material (more on these materials further on). The ideal fiberoptic element would present 100% transmission, 100% reflectivity (off cladding material), and 0% absorption of light to be launched down the fiber (Figure 1).

Fiberoptics show many advantages over copper and electrical conductors, including low signal radiation; immunity to radio frequency interference (RFI), electromagnetic interference (EMI), and lightning; absence of ground-loop problems (and associated hazards); low attenuation and high bandwidth; and a smaller size per relative volume.

Construction. Fiberoptics are made up of core materials surrounded by cladding materials. The cores are made through a pulling or drawing process in which a molten glass boule is drawn (much like taffy) and then processed though various heating, forming, and cooling processes. Core materials typically used (followed by their respective wavelength bandwidths) include chalcogenide (5–15 μm), zirconium (1–6 μm), glass and glass-enhanced materials (0.4–6 μm), and silica (0.17–2 μm).

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The final step in the process is to "clad" the bare fiber with a protective coating then wind it onto a spool for storage and handling (Figure 2). Cladding materials typically used include vinyl, neoprene, Hypalon, polyethylene, polyurethane, thermoplastics, nylon, Kynar, Teflon FEP, Tefzel, and polyolefins.

Configurations. Fiberoptics systems are configured either as single fibers or as fiber bundles, in which groups of fibers are variously arranged (Figure 3). Depending on its function, the single-fiber configuration may consist of *step-index* fibers, in which the core and cladding materials have distinctly different indexes of refraction; *graded-index* fibers, in which the core and cladding materials exhibit a decreasing index of refraction radially outward; and *polarization-preserving* fibers, which are manufactured with birefringent cores to maintain a specific level of linear polarization.

Fiber bundles can be configured randomly or in an arranged pattern. In a random configuration, groups of fibers are used primarily for raw power delivery when image- or signal-restoration is not a requirement. Arranged patterns are designed to keep some aspect of the detection and analysis section the same throughout the system or provide a unique function. For example, a random bundle may provide image gathering, light gathering, or light emission. An arranged bundle may provide image and illumination (in the same bundle) or photo-

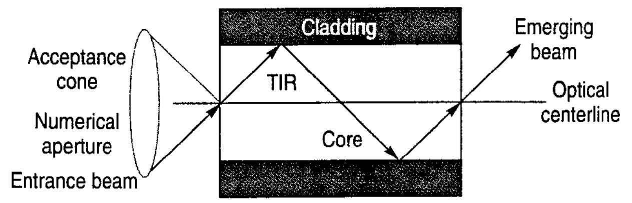

Figure 1. Light propagation though fiberoptics.

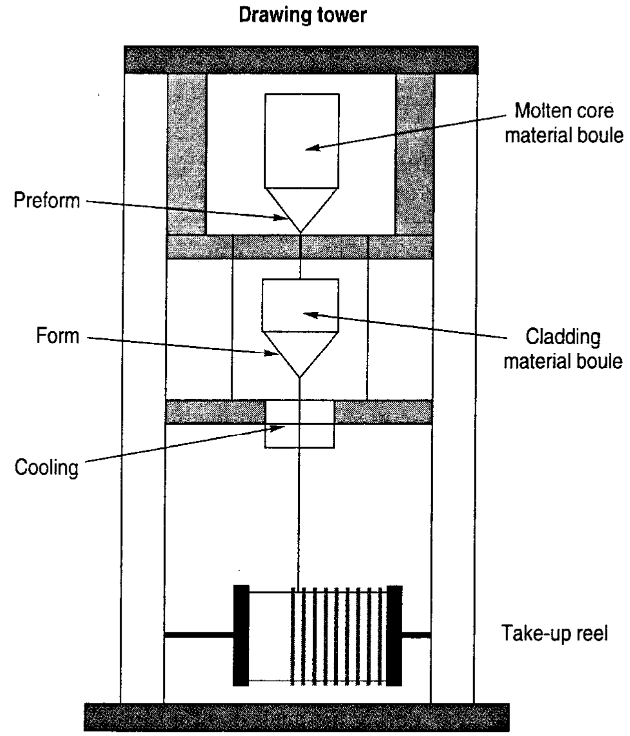

Figure 2. Fiberoptics construction process and equipment.

chemometrics (chemical reaction in the presence of light).

Design. Fiberoptics are designed with some important characteristics in mind. The *numerical aperture* is the "light-gathering" number; the larger it is, the higher the light-gathering capability.

The *normalized frequency parameter,* or *V* number, is a dimensionless quantity that describes fiber parameters including the core diameter, wavelength, and refractive index.

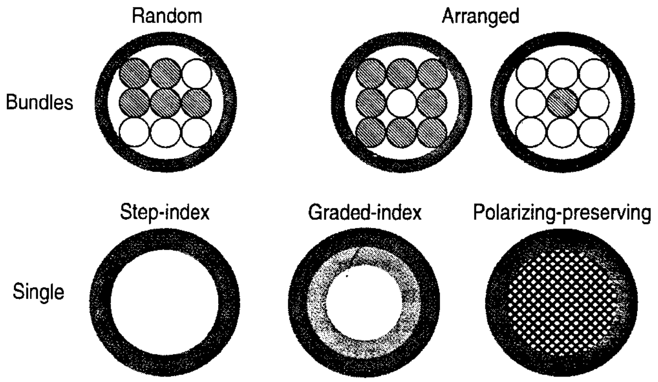

Figure 3. Fiberoptics configurations.

The highest rate for which information can be transmitted with acceptable resolution is limited by the *bandwidth,* which can be further separated into three types of limitations caused by dispersion. *Modal* dispersion is caused when multiple modes in a fiberoptic system interfere with a signal or even modify its characteristics (for example, pulse lengthening). *Material* dispersion is caused by the material of which the fiber is manufactured (especially core material), which creates dynamic changes such as shifting interfaces and static changes due to impurities in the core.

Attenuation, which describes loss, is the most important factor to consider in designing a system because it can occur in so many different ways, including the following:

- Absorption. If materials, interfaces, and so on are not properly packaged, the surrounding environment can affect absorptive losses by changing the material. For example, when exposed to humid conditions, some optic, electro-optic, and acousto-optic materials will exhibit slight hygroscopic characteristics.
- Scattering. Loss by scattering occurs when an interface surface is broken by an abrupt discontinuity such as a crack, scratch, or reflective contaminant.
- Microbending. Losses of this type occur when a normally propagating beam follows a path that is not entirely linear, trapping light.
- Mode scrambling. Multiple modes can create interferences that limit power.
- Polarization scrambling. The light signal may lose its original polarization orientation, again limiting power.
- Environmental. Performance can be adversely affected by temperature, pressure, mechanical stress, radioactivity, light irradiation, or chemicals.
- Nonlinear effects. New frequencies, "hot spots," and varying spatial and temporal problems can occur from putting too much power (overdriving) into the fiberoptic system.
- Surface preparation. Losses can occur if proper cleaning, polishing, and splicing procedures are not followed.
- Feedback. This is caused when an unexpected abrupt interface, such as microbending, appears in the optical path.

A properly designed fiberoptic system — one that addresses the factors above — can reduce space, cost, weight, and need for operator attention, and at the same time increase performance, repeatability, reliability, and applicability for any system to which it is applied.

Fiberoptics has influenced the field of spectroscopy in many ways, from helping make finicky instruments easier to operate, to introducing entirely new applications in new fields. It has brought us from the use of fragile optical breadboards to the development of spectroscopic "engines" able to work in remote locations.

Today we have not only accepted fiberoptics as the technology of the future in most areas of society, but are spending a great deal of effort developing material and systems to take us well into the next century.

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