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Working with Hollow Silica Waveguides

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Introduction

Applications in the infrared region (2.9 to 20µm) have suffered from the lack of a reliable, cost effective means of guiding optical power in an optical fiber or other flexible waveguide. Many systems still depend on direct line of sight, lensing/mirrors, or cumbersome articulated arms. This severely limits the scope of potential applications, particularly remote spectroscopy, minimally invasive surgical procedures, and CO_2 laser material processing and printing. Flexible hollow silica waveguides (HSW) offer an excellent solution in many cases; however, one must appropriately handle the waveguides and design/control launch optics in order to maximize their performance.

Waveguide Structure

The HSW consists of a hollow silica tube with inner diameter of typically 300 to 1000µm. The inner surface of the tube is coated with a silver mirror finish followed by a silver halide, thereby creating an efficient infrared dielectric reflector. The reflector can be optimized for the desired wavelength region. An acrylate buffer is applied over the silica tube to provide protection from mechanical abrasion.

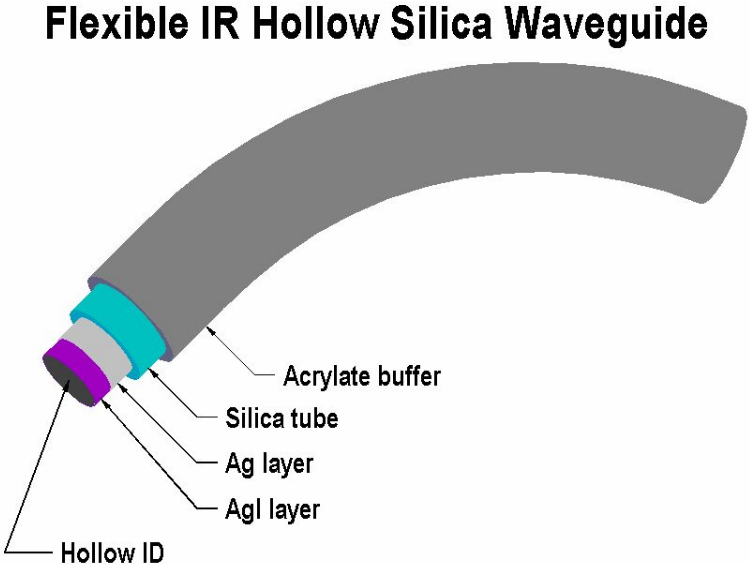

Figure 1: Hollow Silica Waveguide Structure

Handling

The HSWs are in general much stronger than other solid core IR waveguides. However, because of the hollow structure, the waveguides should be handled with reasonable care. The outer acrylate jacket will protect the capillary tube during normal handling, but does not eliminate the stress incurred from tight bends or compression on the sides of the device. Because of the stiffness of the larger diameter HSWs, they should not be subjected to bend diameters less than 30 cm. Tighter bends have a potential for breaking the glass and destroying the waveguide.

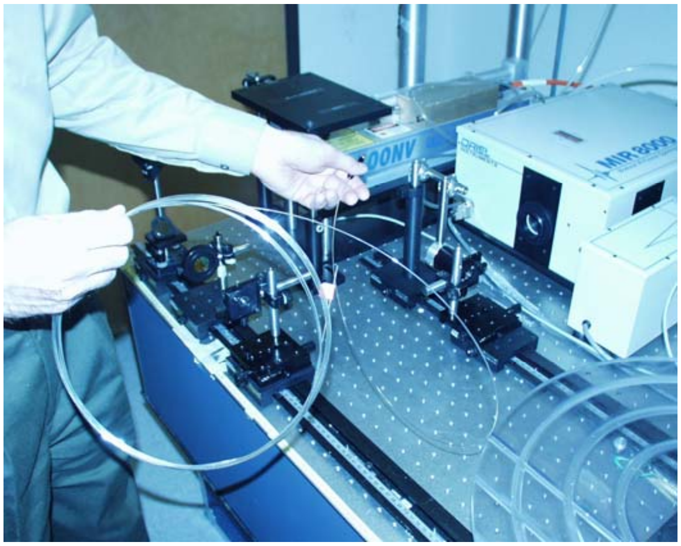

Figure 2: Hollow Silica Waveguide In Use

Cleaving

To terminate the waveguide the end should be cleaved to a clean flat end face, not polished. The cleaving process is accomplished by cutting through the outer acrylate coating and lightly scribing the glass tubing within using a diamond scribe tool.

With this tool one can cut directly through the acrylate until the blade contacts the glass, then pull the end off straight (without bending). It is important that no particles fall into the waveguide that could cause scattering and potential damage. Any jacket or silica tubing material left in the bore of the waveguide will affect light propagation, and at higher laser powers will cause catastrophic damage to the waveguide.

Launching Light

The process for launching light into a Hollow Silica Waveguide in general is very similar to launching into a standard optical fiber, with a few differences that should be kept in mind.

- Fill Factor. To minimize the optical loss, the focused input beam should have a beam diameter at the entry to the waveguide at around 65% to 70% of the waveguide bore size. When reasonably well centered, this leads to the best transmission characteristics. Also, this avoids the beam hitting the front edge of the waveguide, a situation that easily causes damage at higher powers (since the silica tube itself is highly absorptive at IR wavelengths).
- Minimize Entry Angle/NA. In order to minimize the loss at the launch through the waveguide, the numerical aperture of the focused laser beam needs to be kept very low. Higher input angles are less likely to propagate down the HSW, being absorbed and causing localized heating, often burning up the waveguide. Therefore, the lowest beam input NA which correctly fills the waveguide bore is desired. Lenses with f numbers of >20 are typically used for this reason.
- Exit Divergence. Theoretically, the divergence angle of the beam exiting the waveguide will match that of the input. In reality, there will be some broadening caused by mode mixing when the waveguide is bent, along with some small broadening caused by microscopic roughness or non-uniformities in the silver halide coating on the inside of the waveguide.
- Alignments should be performed at low power. The power may be increased once the alignment is optimized.
- Standard connectors (SMA, ST, FC) are often used but the end faces are cleaved instead of polished.

Optical Performance

The HSWs can transmit infrared power in the 2.9 to 20µm wavelength region and can be optimized for 9-11µm CO_2 or 2.9µm Er:YAG lasers. Typical attenuation at 10.6µm (CO_2) for a 1000µm ID waveguide is <0.5 dB/m. The waveguides can handle up to 100W at CO_2 wavelengths without external cooling, and ≥1000W with external cooling.

Summary

The benefits of the HSW are its strength and flexibility (as compared to solid core IR fibers), wide wavelength range (2.9 to 20µm), high power capability (>1000W CO_2), low insertion loss (no fresnel reflection), low beam divergence, and low weight/bulkiness/cost (as compared to articulated or lensed arm systems).

While these waveguides have similarities to normal optical fibers, significant differences exist which require different handling and operation techniques. Give proper care in the handling as well as alignment of the waveguides, excellent optical transmission characteristics can be achieved.