Hollow Silica Waveguides for Mid-Infrared Power Transmission and Spectroscopy

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Abstract

Applications in the Mid-Infrared often require a flexible conduit for transmitting light from source to destination. Hollow Silica Waveguides with an internal Ag/AgI dielectric reflective layer optimized for maximum transmission between 2.5µm and 15µm have been used successfully for applications such as Erbium YAG and CO_2 laser power transmission for industrial and medical applications. In addition the waveguides are used as long path flow cells for IR spectroscopy. In the following paper, the physical structure of the waveguides is detailed. Guidelines for handling and optical coupling are discussed. Typical spectral attenuation is shown for example waveguides.

Introduction

Many applications in the Mid-Infrared require a flexible conduit for transmitting light from source to destination. Because typical silica-based fibers heavily absorb light with wavelengths longer than 2.1 microns, a different technology is required. The Hollow Silica Waveguide is a good solution for mid to far infrared applications, such as power delivery for CO_2 and Erbium YAG lasers, and spectroscopy making use of the unique hollow structure.

Structure

The waveguides consist of a fused silica capillary tube with an optically reflective internal dielectric silver/ silver halide coating. Figure 1 below shows a schematic view of an example HSW. For protection, the capillary tube is coated with an external protective polymer buffer layer, which improves the strength and flexibility of the waveguide. The standard HSW comes with an acrylate buffer. It is also available as shown below where the buffer is a thermoplastic Tefzel layer for added protection.

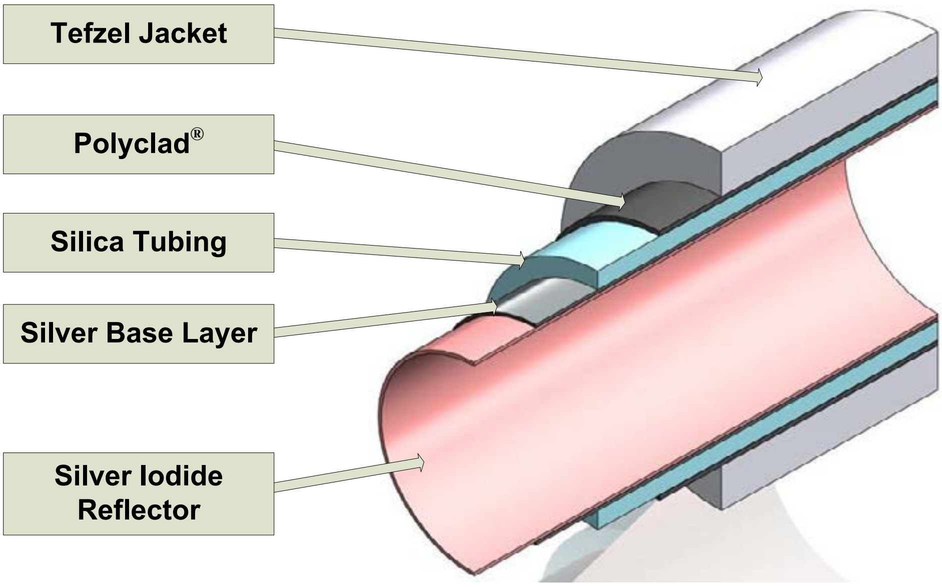

Figure 1. Schematic of example Hollow Silica Waveguide structure

The internal dielectric layer has been optimized for low optical power loss operation at either CO_2 (10.6 µm) or Er:YAG (2.94 µm) laser wavelengths, although relatively low loss operation is possible in the intervening wavelength band. Figure 2 below shows the attenuation of the two 1000µm bore HSW types as a function of the operating wavelength. The CO_2 laser optimized waveguide is designated by HWC while the Er:YAG optimized waveguide is designated by HWE in the figure. The attenuation is in units of dB loss per meter of waveguide.

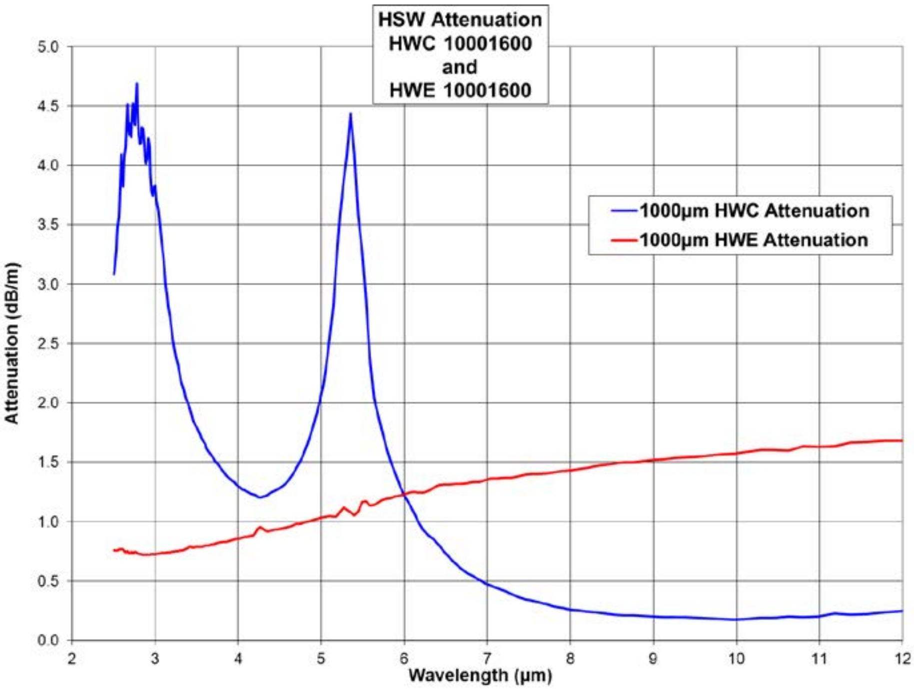

Figure 2. HSW attenuation versus operational wavelength

The waveguides are available with standard internal bore sizes of 300, 500, 750, and 1000 microns. Configurations with alternative bore sizes, buffer materials and target wavelengths can be fabricated on a custom basis, if needed.

While these waveguides have similarities with normal optical fibers, significant differences exist which require different handling and operation techniques. The most significant are discussed below.

Handling

Because of the hollow structure, the waveguides should be handled with reasonable care. The outer jacket will protect the capillary tube from normal handling damage, but can only do so much with stress caused by tight bends or compression on the sides of the tubing. Because of the stiffness of the larger diameter HSWs, one should not subject them to small bend diameters which have a potential for breaking the glass and destroying the waveguide.

In addition, care must be taken to avoid any contamination entering the bore of the waveguide during termination and handling. The contaminant will act as a scattering point for the transmitted laser power which might lead to internal burning and premature failure. Also, particles traveling inside the waveguide bore have the potential to physically scratch the inside of the capillary silica surface leading to dramatically increased fragility.

Optical Considerations

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 the user needs to keep in mind. The coupling of power into the HSW is heavily dependent on the input beam characteristics. In high power applications care must be taken to avoid hitting the annular end surface of the silica tubing (the silica heavily absorbs the Mid-IR light potentially leading to thermal damage).

When coupling laser power into the HSW, the goal is to minimize the input numeric aperture, while keeping the spot size smaller than the waveguide bore diameter. Since the reflective internal layer is a low loss dielectric reflector and not based on total internal reflection, the goal is to minimize the number of reflections down the waveguide by keeping the input NA low. A good rule of thumb is to target a focused beam diameter approximately 70% of the waveguide bore.

Attenuation of the waveguide is affected by several factors beyond the input coupling efficiency. The length of the waveguide drives overall optical system loss due to attenuation losses as shown in Figure 2. The bore size affects the loss per unit length as well, with smaller diameter waveguides having higher attenuation than larger bore waveguides. Larger bore sizes can transmit higher optical powers. Also, bends in the waveguide will lead to some added loss with tighter bends potentially having higher losses.

Exit Divergence

Theoretically, the divergence angle of the beam out of 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. This is complicated by the fact that each reflection at the dielectric layer has a small amount of attenuation, causing higher order modes to attenuate more over longer lengths of waveguide.

Assemblies and Connectorization

To avoid unstable launch conditions and potential damage due to beam wander, the waveguide should be securely fixtured during launch. This can be accomplished in several ways, including permanent fiber connectors. One alternative handy solution is the Polylok^{TM} connector available from Polymicro Technologies. This reusable connector fitting is used for prototyping and testing the waveguides, and is available in SMA, STII and FC configurations.

The waveguides can be built into permanent assemblies using standard connector types. In addition, various protective outer jackets can be used in the assembly design to protect the waveguide from exterior handling damage. Stainless steel armored jackets are often used to reduce the risk of damage to equipment and personnel in high power industrial applications.

Applications- Laser Power Transmission

For laser power transmission applications, the HSW can be used to replace high cost, heavy, rigid articulated arms for CO_2 and Er:YAG lasers. Delivered power has been demonstrated up to 100W, with higher powers possible with cooling jackets. Some potential applications include the following:

- Medical
- Dental
- Industrial cutting of wood panels, textiles, natural leather, plastics
- Laser printing and marking

Applications- Spectroscopy

The capability of the HSW for optimized transmission between 2.5µm and 5.0µm is extremely useful for spectroscopy, and can be used as an analytical cell for FT-IR spectroscopy. The hollow bore structure allows the waveguide to act as a long path flow cell for gas analysis. Path lengths of several meters are possible in straight or coiled configurations, leading to high sensitivity for detection of low level concentrations of target compounds. The operating spectral range facilitates qualitative and quantitative analysis of many organic and inorganic compounds, both in gas and solid phase.

Summary

Hollow Silica Waveguides act as flexible optical fibers for Mid-Infrared optical systems. While the HSW can be used in a manner similar to silica optical fibers, minor differences require additional care in alignment and handling. They can be used to replace complex and expensive articulated arms for CO_2 and Er:YAG laser systems in industrial and medical applications. The waveguides have also been used as long path flow cells for FT-IR gas sensing.