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Infrared Fibers for Sensors

At NRL, we are involved in the research and development of specialty infrared optical fibers, glasses, ceramics, and thin films. We have built world class state-of-the-art facilities for making high purity chemicals and unique optical materials of unequaled quality, which are being exploited in optical devices and systems for Navy and DoD applications. One of the core scientific areas that we have pioneered is based primarily on infrared (IR) transmitting glasses and fibers. The IR transmitting glasses are based on chalcogenide materials (S, Se, Te, and their alloys and compounds). One of our major accomplishments has been the purification of these elements and materials to levels well beyond the previous state-of-the-art. This has enabled us to reduce the absorption losses in these materials for both the mid-wave and long wave IR spectral regions. In addition to their use in bulk optics such as windows, we are the international leader in developing these materials for optical fibers and their applications. The fibers and their applications can be split into two main groups, namely passive and active. In the case of passive fibers, they merely act as a light pipe, transferring infrared energy from one location to another. In the case of active fibers, they actually change the wavelength of light exiting the fiber. Some examples of both are highlighted below.

Passive Fiber Applications

Chemical sensing or remote detection and identification of most molecular species due to their infrared vibrational absorption "fingerprints" can be achieved by using chalcogenide fibers in fiberoptic chemical-sensor systems. For example, an optical-fiber-based reflectance probe was developed at NRL to detect contaminants in soil (see Fig. 1). The detection was accomplished with the probe deployed in a cone penetrometer system and tested in the field. Detection limits of 130 ppm of marine diesel fuel (DFM) in sea sand have been demonstrated. In the medical area, a chalcogenide fiber probe has been used to show the spectral differences between various tissues and organs in biomedical samples from chickens, sheep, and mice. The fibers have also shown utility for tissue evaluation and early detection of cancer. In contrast to conventional medical techniques in which large portions of tissue are cut out of the body and sliced into sections before a process such as Fourier transform IR (FTIR) spectroscopic analysis is used, a flexible optical fiber imaging approach is minimally invasive. We have also demonstrated feasibility of mid-IR imaging bundles for remoting of focal plane arrays as well as a compact IR fiber based FTIR spectrometer. The fibers also have the potential for detecting and identifying chemical and biological agents based on their characteristic IR absorption bands.

Active Fiber Applications

Chalcogenide fibers can be used to create lasers or bright sources in the infrared by either rare earth doping or using non-linear optical processes. Unlike in silica glass, whose high phonon energy limits fluorescence emission from rare earth ions to a wavelength of only 2 μm, the low phonon energy of chalcogenide glasses leads to strong infrared fluorescence emission from the rare earth ions. Figure 2 shows the measured infrared fluorescence emissions in the 2-5 μm atmospheric window, which are characterized by high efficiencies (>80%), as well as an emission at around 8 μm which represents the longest wavelength emission seen from any glass system. It should be possible to create efficient high power infrared fiber lasers using these rare earth dopants and suitable pump lasers with singlemode fibers. However, to-date only multimode fibers have been developed. In one example, a Pr^{3+} doped multimode fiber pumped by a 1.95 μm diode has been used to create a bright source in the 3-5 μm wavelength region which simulates a blackbody source at 2400K but is actually >100x brighter. This device has been used as a scene simulator in hardware-in-the-loop systems. A similar fiber was also used to demonstrate chemical sensing by detecting and identifying a contaminant based on its characteristic absorption spectrum in the 3-5 µm wavelength region. Depending upon composition, chalcogenide fibers also exhibit optical non-linearities that are up to 1000x higher than for silica glass. Consequently, they can be used to demonstrate broadband supercontinuum sources in the infrared (figure 3) when pumped with suitable lasers. They can also be used for creating compact Raman fiber laser sources in the infrared as well as tunable lasers using 4-wave mixing processes. Preliminary feasibility for these has been demonstrated, but design and fabrication of photonic crystal fibers (figure 4) with the correct geometry will lead to compact and efficient broadband and tunable fiber laser sources for the 2-12 µm wavelength region, suitable for remote spectroscopy.

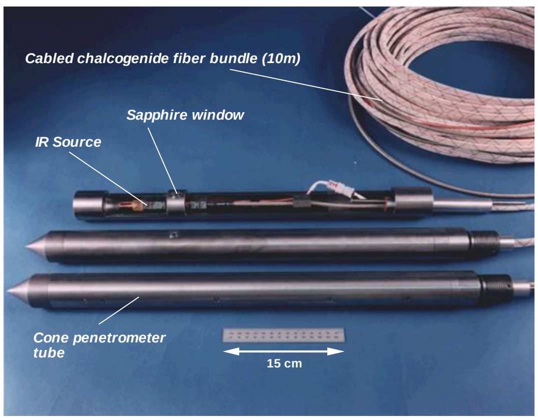

Figure 1. Infrared conepenetrometer system for remote detection of contaminants in the ground

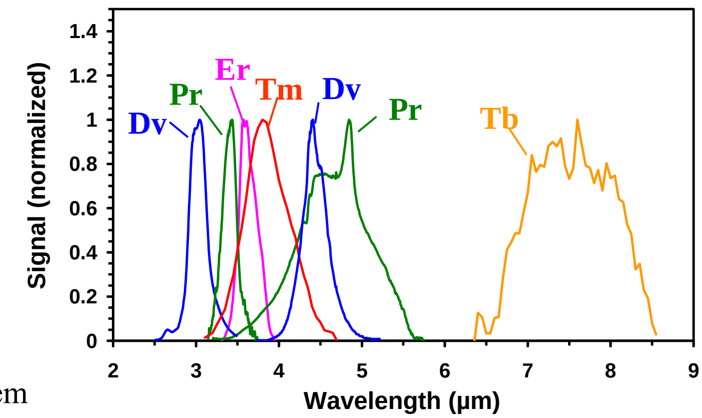

Figure 2. The infrared fluorescence emissions from rare earth doped chalcogenide glasses.

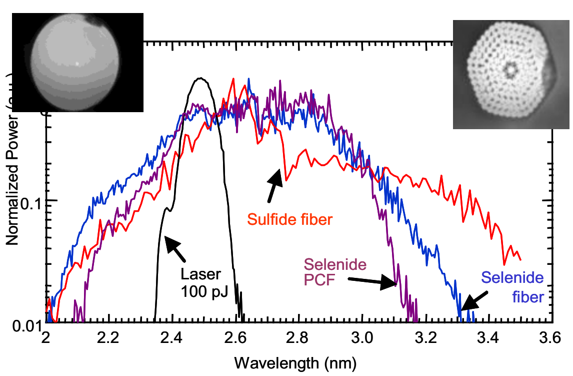

Figure 3. The supercontinuum emission from preliminary IR fibers.

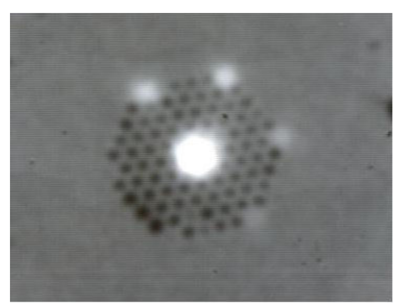
Figure 4. Chalcogenide glass based photonic crystal fibers (PCF) for non-linear IR sources.