Silicon-based photonics has become a very active field of study. The extension of silicon planar waveguides to optical fiber waveguides would significantly enhance this emerging field and open the door to new applications. Silicon exhibits high thermal conductivity, a high optical damage threshold, and low loss transmission out to about 7 µm. This article reports on the production of glass-clad fibers possessing a highly crystalline silicon core. Perhaps most important, these fibers were fabricated using conventional fiber draw techniques that would permit relatively high-volume manufacturing.

Optical fibers with silicon-containing cores have been synthesized using chemical vapor deposition techniques. While this approach is an important step forward, it is not readily scalable. An industrially proven, well-established process would be preferable. For optical fiber-based structures, a draw tower is the ideal fabrication tool. Crystalline materials, which melt and do not soften, cannot themselves be drawn into fibers. The production process we describe uses a glass cladding tube essentially as a crucible to confine a core material that melts at the temperature at which the cladding is soft enough to draw. The generalized approach of interest is to sleeve the silicon core inside a silica (glass) cladding (see Figure 1). At the temperature at which the silica cladding softens and draws into fiber, the silicon core is molten. This molten core draws with the cladding and solidifies as the fiber cools.

Silica-clad, silicon-core fibers were drawn at approximately 1950°C using an industry-grade optical fiber draw tower at Clemson University. X-ray diffraction analysis of the silicon core clearly shows that the core is silicon with no other phases apparent. Further, the narrowness of the peak width implies a high degree of crystallinity within the silicon. A Raman spectrum of the core shows that the silicon optical fiber is only slightly blue-shifted and broadened in comparison to silicon taken directly from a single crystal boule. Accordingly, the silicon core is very similar to the starting boule despite having been melted in immediate contact with a soft cladding glass and quickly quenched. The measured transmission at both 1306 and 1532nm was ~2.7dB/cm. Transmission measurements at ~3µm yielded an attenuation of 4.3dB/m after taking into account the 48.8% Fresnel reflection losses of silicon (n=3.436 at 3µm).

Elemental analysis did show that the silicon core contained between 10 and 17 atom percent oxygen, which likely diffused in from the soft silica glass cladding during the draw. Although the x-ray and Raman analysis did not show any oxide precipitates present, this level of oxygen in the silicon would presumably lead to some nanocrystals of silicon dioxide. Based on the measured transmission losses, such nanocrystals would have to be only about 20 unit cells in size and likely not observable against the strong x-ray and Raman signals of the silicon. Efforts are underway to identify the nature of the oxygen and develop a special cladding glass that would lessen the oxygen intake.
To the best of my knowledge, this was the first optical fiber containing a silicon core to be fabricated using high-speed, high-volume industrial fiber draw techniques. Such fibers have considerable potential for Raman and other nonlinear optical fiber-based devices of interest for mid-wave infrared sensing and power delivery as well as terahertz guided-wave structures. The silicon core was found by x-ray diffraction and Raman spectroscopy to be highly crystalline. The attenuation at 3\(\mu\)m was about 4dB/m in these proof-of-concept fibers. Continued optimization, particularly of cladding materials, is expected to yield next-generation fibers of lower attenuation.

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