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Electronic and magnetic fibers

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ABSTRACT

Fibers with electronic, magnetic and piezoelectric core materials were fabricated via a modified melt-draw technique. Materials selected for this study were copper, silver, barium titanate, Metglas® and Terfenol-D with a fused silica cladding. Basic material compatibility and process feasibility were confirmed via compositional and microstructural analysis. Demonstration of fibers with multi-functional materials and the potential integration with current state of the art technologies represents the first steps in providing the building blocks for all-fiber optoelectronics.

1. Introduction

The integration of semiconductor and metal structures into optical fibers has created a paradigm shift in the development of the next generation of optoelectronics [1]. The promise of all-fiber optoelectronics has resulted in the pursuit of improved fabrication techniques and material properties [2]. High pressure chemical vapor deposition was successfully demonstrated as a technique to incorporate semiconductor materials into the hole of photonic crystal fibers [3–5]. Semiconductor materials have also been fabricated via traditional optical fiber drawing and modified melt-draw processes [6–8]. These techniques can produce relatively long lengths of fiber and are an attractive option for the inevitable transition to the manufacturing environment [9–11].

The integration of optical fibers and devices finds it origins in the pioneering research by Payne, et al., at Southampton University that ultimately resulted in the original fiber lasers and amplifiers [12,13]. Inspired by this work, the first semiconductor material, silicon, was successfully incorporated into a random hole fiber by Pickrell, et al. Subsequently, significant progress has been made in the fabrication and understanding of these types of fibers [14,15]. Researchers have fabricated basic devices, such as p – i – n junctions, germanium resistors, and optical switches in fibers [16–20]. The ability to generate, transmit, modulate and detect light within the fiber will inherently simplify and improve the performance of all fiber optic technologies. Unfortunately, performance metrics such as resolution and stability are limited by these post-processing techniques. Incorporation of the magnetostrictive materials in situ with fiber synthesis would both simplify the design and improve reliability and performance.

Furthermore, fiber optic sensing technologies stand to benefit from the pursuit of all-fiber optoelectronics. As for example, magnetic fiber optic sensors typically require the use of a magnetostrictive material such as Metglas® or Terfenol-D that is bonded to an optical fiber or incorporated into a laser ablated micro-slot in the fiber [21–24].

In this study, we attempted to address the need for scale-able processes to fabricate fibers with improved and unique functionality. Copper and silver core fibers are potential components for all-fiber optoelectronics and sensors, as well as potential templates for THz waveguide designs. Fibers with Metglas® and Terfenol-D cores and traditional geometries may provide for simple integration into compact fiber optic sensing elements. Furthermore, fibers with barium titanate cores may have immediate use in energy harvesting and wearable devices. Composition and microstructure analyses of all the fibers were performed to evaluate material and process capabilities of these very unique fibers.

2. Materials and methods

Sample preparation: The copper shot, 99.9% (metals basis), nano-size Barium Titanate (99.9+ %) and silver powder, 99.9% (metals basis) were purchased from Sigma-Aldrich. The Metglas® 2605SA1, a Fe – B-Si amorphous metal alloy, was purchased from Metglas® and the Terfenol-D powder ($TbxDy_1 - xFe_2$ ($x \sim 0.3$)), 0–300 μm particle size, was purchased from Extrema products.

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The metal and alloy core fibers were all prepared by the melt-draw technique following the same general procedure, as shown in Fig. 1, on a glass working lathe, Litton Model HSJ143 [25,26]. The fiber drawing system has two chucks, which are used to clamp the silica preform and can spin together or separately at precisely controlled speeds. The second chuck can also be moved linearly, which draws the fiber from the preform when heated and softened by a hydrogen–oxygen torch over 1600 °C. The maximum achievable fiber lengths were limited by the working distance between the chuck faces (approximately 120 cm), as well as the preform length and drawing rod at the tailstock end. The core and overall fiber diameters were determined by the dimensions of the fused silica tube and the draw speed. It is anticipated that precise control of the draw temperature and profile, as well as the draw speed, will allow for a more consistent and longer fiber.

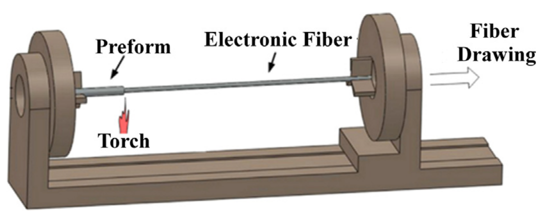

Fig. 1. The fiber drawing system and process utilized to fabricate the metal and alloy core fibers.

First, a fused silica substrate tube (GE214, O.D. = 8 mm, I.D. = 3 mm) was fused to a processing tube (GE214, O.D. = 12.75 mm, I.D. = 10.5 mm). The precursor material was then placed in the processing tube and melted via an oxy-hydrogen flame slightly above their respective melting points. A smaller diameter fused silica rod (GE214, 8 mm) was used to push the precursor melt into the substrate tube forming a preform with a metallic/ceramic core. Finally, the preform was drawn into a fiber via the Taylor process [27].

Characterization: Polished fiber cross sections were characterized with a scanning electron microscope (SEM, LEO 1550) and an optical microscope (Olympus BX51). Energy dispersive spectroscopy (EDS) chemical composition and mapping were performed with an attached IXRF system, Inc. Iridium Microanalysis system at an accelerating voltage of 20.0 kV.

3. Results

The two most common metal conductors, copper and silver, are copper and silver. Although silver is more conductive, copper is often the preferred material for electrical wire and cable

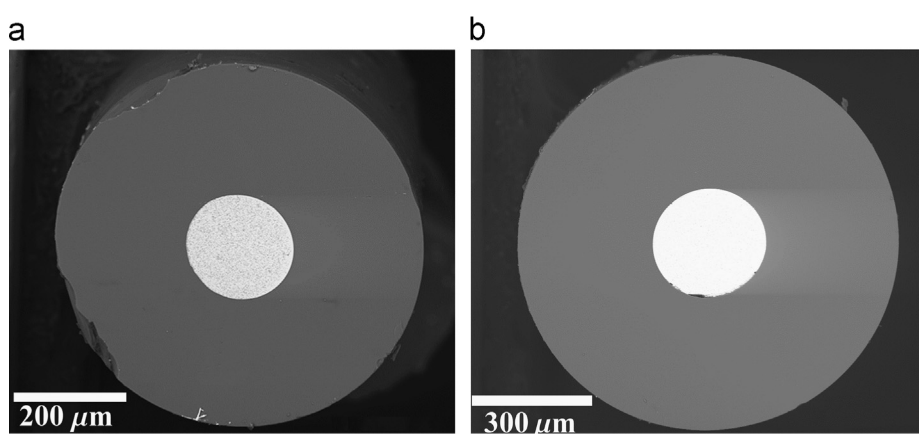

Fig. 2. SEM images of (a) a fiber with a copper core diameter of approximately 200 μm and fused silica cladding of 660 μm and (b) a fiber with silver core diameter of approximately 300 μm and fused silica cladding of 1000 μm.

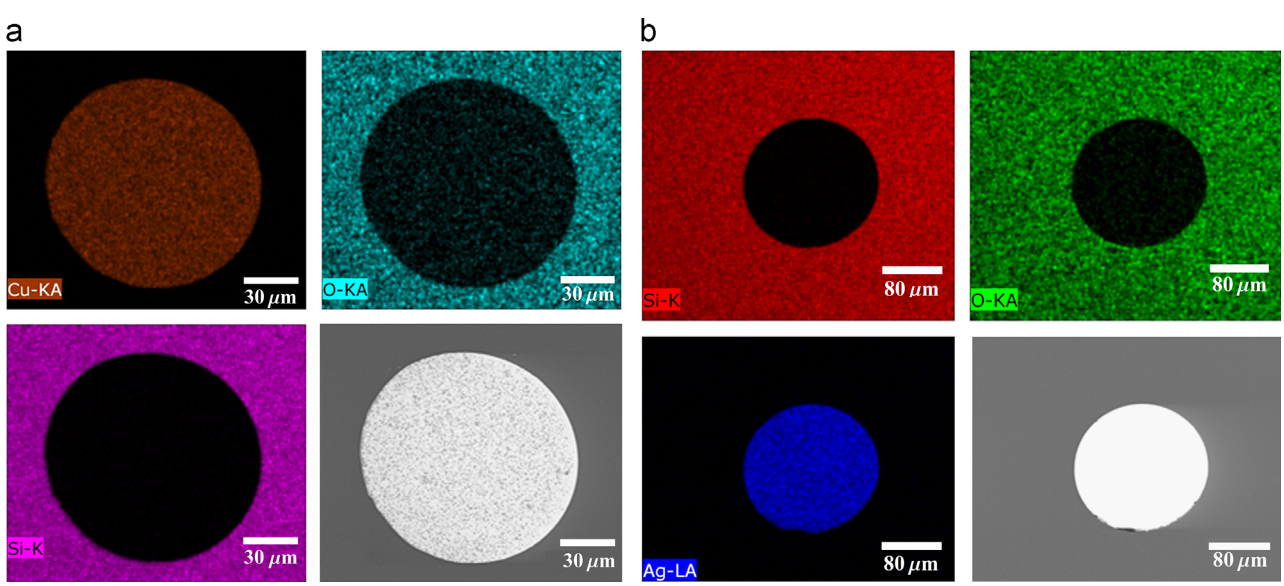

Fig. 3. (a) Copper core fiber: X-ray dot mapping of silicon (turquoise), oxygen (green), and copper (orange). (b) Silver core fiber: X-ray dot mapping of silicon (red), oxygen (green), and silver (blue). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)