All-fiber Optoelectronics

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Abstract: The combination of insulating, semiconducting, and metallic elements in well-defined geometries with intimate interfaces is essential to achieve all-fiber optoelectronics. Here, we present the development of optoelectronic fibers, from the fundamentals to in-fiber device demonstration. © 2024 The Author(s)

1. Main Text

Fiber drawing from a preform has traditionally been exploited to produce with high precision and reliability the extended lengths of optical fibers that today span the globe, deliver telecommunications, and enable the internet [1,2]. However, one limitation of the current state of the art is that the current fiber drawing has been limited to drawing a single material and features no smaller than several microns. Recently, fiber-drawing approaches have been extended to a new class of multi-material fibers containing functional structures that enable the development of optoelectronic fibers [3–5]. This new class of fibers centers on a method so-called preform-to-fiber fabrication by thermally drawing a macroscopic solid-state preform into extended lengths of uniform fibers. Unlike the traditional optical fiber fabrication, this method features three key elements in resulting fibers: (1) combining a multiplicity of solid materials with disparate electrical, optical, and mechanical properties into a single fiber, (2) realizing arbitrary nanometer-scale geometries in fibers with low-scattering interfaces, and (3) producing long lengths of fibers through the simple and scalable process of thermal drawing.

Especially, the integration of semiconductor materials into fiber geometries provides a unique route to introduce new optoelectronic functionality into the existing glass fiber technologies [6–10]. Firstly, multi-material fibers made of semiconductor materials such as silicon, germanium, and compound semiconductors are developed, offering unique advantages in materials, geometries, and waveguiding properties. Then, three main fabrication approaches to producing these fibers are summarized, in which the first approach is based on the traditional drawing tower technique, the second approach involves laser processing, and the third approach takes advantage of the in-fiber fluid instability phenomenon. Finally, the prospects and applications of this new class of fibers are discussed.

The concept of optoelectronic fibers enables the unique combination of metals, semiconductors, and insulators in the cross-section of a uniform, potentially kilometer-long flexible fiber. Optoelectronic fibers integrating several semiconductor devices can indeed detect light, but also sense local heating, ultrasound waves, or chemicals. The development of optoelectronic fibers also boosts the next generation of advanced fabrics and textiles. Fabrics that are woven either completely or partially from such integrated fibers can deliver a wide range of real-time, non-traditional functionalities over the full surface area of clothing, powered by electrical energy harvested from the ambient environment. The interplay between materials properties and structure integration in these fibers, alongside fabric-array construction, is just beginning, and promises to be an exciting field for fundamental and applied research.

2. References

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