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Citation: Deng, D.S., Orf, N., Abouraddy, A.F., and Fink, Y. (2009). "Novel fabrication and enhanced photosensitivity of selenium filament arrays by optical-fiber thermal drawing." Conference on Lasers and Electro-Optics, 2009 and 2009 Conference on Quantum Electronics and Laser Science Conference (Piscataway, N.J.: IEEE): 1-2. © 2009 IEEE.

As Published: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5224453

Publisher: Institute of Electrical and Electronics Engineers

Persistent URL: <http://hdl.handle.net/1721.1/58987>

Version: Final published version: final published article, as it appeared in a journal, conference proceedings, or other formally published context

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Novel Fabrication and Enhanced Photosensitivity of Selenium Filament Arrays by Optical-Fiber Thermal Drawing

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Abstract: We report break-up of cylindrical shell into well-ordered filament arrays by optical-fiber thermal drawing. Enhanced photosensitivity of centimeter-long crystalline-Se nano-filaments is observed and the mechanism is discussed. This work paves a way to in-fiber nanodevices.
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OCIS codes: (160.2290) Fiber materials; (250.0040) Detectors

1. Introduction

Optical-fiber thermal drawing from a viscous macroscopic preform is a well-established process for producing kilometer-long silica fibers with uniform dimensions in the telecommunication industry. In the last decade, microstructured fibers incorporating air enclaves have been created with these methods, resulting in novel fiber designs. All these fibers, however, consist of a single material with the possible addition of air cavities. The fact that these fibers consist of a single dielectric material limits their usage to optical-transport related applications.

An altogether different class of fibers incorporating multiple materials (e.g., semiconductors, insulators, and metals) thermally drawn from a macroscopic preform has recently emerged [1]. These fibers, by virtue of their novel designs and material combinations, are enabling unique applications in sensing and flexible electronics. However, nothing is known about the extent to which a feature size (such as film thickness) can be reduced in a multimaterial fiber.

2. Novel fabrication

Our approach to achieve extended nanofilaments is illustrated in Fig. 1a. A macroscopic preform is composed of a thin cylindrical semiconductor selenium shell encapsulated in a polymer matrix (Fig. 1b). During thermal drawing, the preform is heated at elevated temperature into a viscous fluid and controllably stretched by the application of axial tension into an extended fiber (Fig. 1c). Upon reaching a characteristic thickness, a shell undergoing a scaling process evolves into an ordered array of filaments with breakup in the cross-section while maintaining uniformity in the axial direction [2].

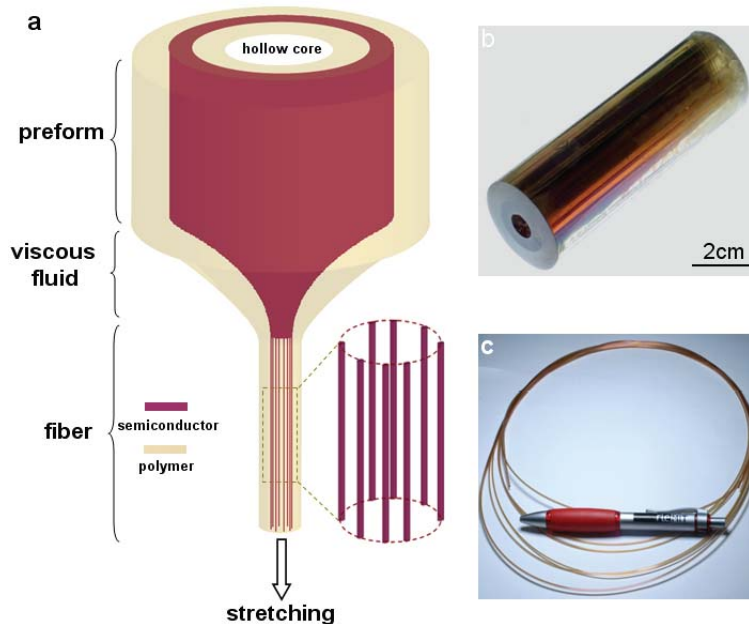


Fig. 1 Novel fabrication of filament arrays by optical-fiber thermal drawing. a) Schematic diagram of break-up of a thin cylindrical shell into filament arrays; b) Photograph of centimeter-long preform; c) Photograph of meter-long section of fiber.

Several intriguing features are offered by this new approach. Filaments are produced in a high-throughput fashion with unprecedented length. Filaments are hermetically sealed in a protective polymer matrix, thus avoiding problems associated with the mechanical fragility of these nanostructures. Additionally, the methods should be compatible with other materials such as metals and other semiconductors.

3. Enhanced photosensitivity

Filament arrays were found to exhibit enhanced photosensitivity compared to the film. The photosensitivity performance here is defined by the current ratio $\Gamma = I_{\text{light}} / I_{\text{dark}}$ at the same applied voltage, where I_{dark} and I_{light} denote the current in darkness and illumination, respectively. From Fig. 2, photosensitivity performance Γ is about 2 and 50 for film and filaments, respectively. Enhanced sensitivity was observed in several fiber segments between 0.5 cm to 3 cm in length by more samples of in-fiber Se 300-nm film and in-fiber filaments from 100-nm layer breakup. Thus the photosensitivity performance of Se filaments is enhanced by one order of magnitude compared to that of Se film.

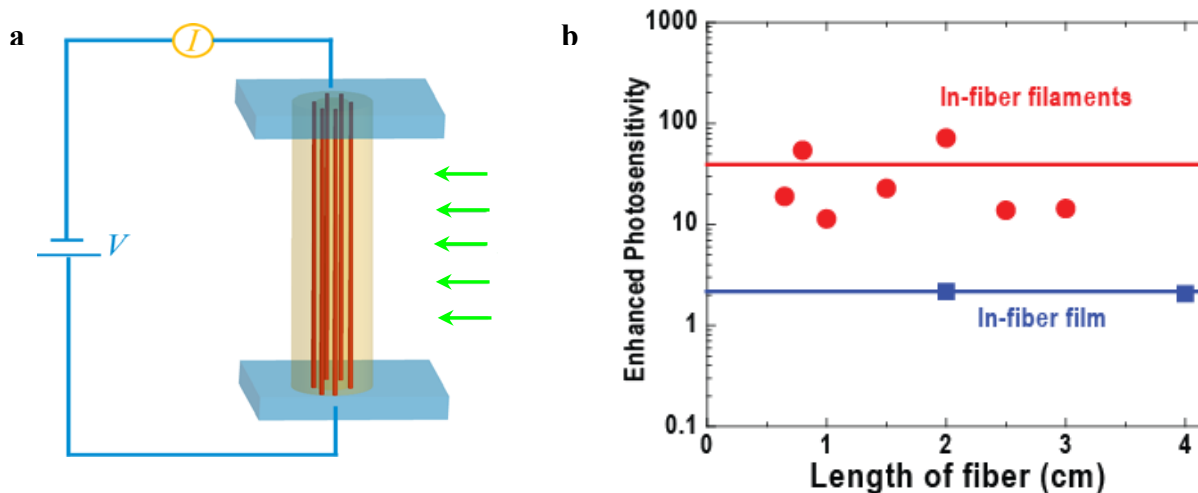


Fig. 2 a) Sketch of photosensitivity setup; b) Enhanced photosensitivity of in-fiber filaments compared with that of in-fiber film under the same illumination.

The mechanism of enhanced photosensitivity performance of Se filaments may be attributed to the nanoscale dimensions of filaments. First, larger surface-to-volume ratio of filament arrays compared with that of thin film efficiently improves the performance of photosensitivity. Second, the shorter radial dimension of filaments comparable to diffusion length might reduce the bulk recombination rate of carriers and extend carrier lifetime. Third, surface states due to the dangling bonds of filaments might preferentially trap one of carriers over the other, and unpaired carriers have longer lifetime by reducing electron-hole recombination. Detailed analyses of these processes in filaments are needed in future work.

4. Outlook

This top-down methodology is a unique approach to producing nanofilaments with several attractive features. These filaments may be produced in a high-throughput and low-cost fashion. The arrays are well-ordered with parallel alignment. Furthermore, these filaments are encapsulated in a protective polymer matrix, which lends itself to manual manipulation until the need to extract filaments arises. We thus bypass the fragility of these nanostructures during handling that plagues other approaches. Most importantly, the nanofilaments are produced with exceptionally long lengths. Nanofilament bundles of these or other materials may be potentially useful in enabling large-area applications including renewable energy and bioengineering. Directions for future work include producing high-density filament bundles using a multiplicity of layers in the fiber preform, and assembling metal and semiconductor structures in the same fiber.

5. References

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