Recent advances in silicon core optical fibers: from fabrication to applications

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Abstract: Recent advances in the fabrication and application of silicon core fibers will be reviewed. Focus will be placed on process developments directed towards achieving low-loss transmission and device designs benefiting from the unique fiber geometry.

1. Introduction

The past two decades have seen significant advances in the fabrication and application of silicon core fibers (SCFs). Compared to their planar counterparts, this new class of waveguide retains many advantageous properties of the fiber geometry and, as such, can offer low transmission losses and robust integration with existing fiber infrastructures. In this paper, I review efforts regarding the design, fabrication and optimization of SCFs. Capitalizing on the excellent material quality and the broad wavelength coverage offered by the silicon cores, a wide range of applications have been demonstrated in areas spanning solar harvesting [1], wearable sensors [2], and nonlinear signal processing [3].

2. Fabrication and Post-Processing

The molten core drawing (MCD) method is now the primary fabrication approach for SCFs as it allows for the rapid production of long lengths of fiber [4]. In the MCD procedure, a preform of millimeter dimensions is heated before being drawn down to micrometer fiber sizes, with the softened silica cladding acting as a crucible for the molten silicon core, as illustrated in Fig, 1(a). Recently, there have been several developments in the drawing methods that are helping to improve the silicon core materials. The first approach involves replacing the traditional induction furnace with a laser heating method, allowing for more accurate control of the drawing, resulting in as-drawn SCFs with smaller cores and lower losses (see Fig, 1(b) [5]). The second advance has involved developing a detailed thermomechanical analysis to suppress structural defects in the core, resulting in the production of SCFs with single crystal grain lengths on the order of meters [2]. To complement the fiber drawing, several post-processing techniques have also been developed that can be employed to further improve the core quality, increasing production yields and enhancing device performance [3]. In particular, fiber tapering, as shown in Fig. 1(c), has proven to be particularly useful as the melting and stretching not only helps to improve the core crystallinity to reduce the losses, but it also allows for tailoring of the core dimensions, important for dispersion engineering [6]. Significantly, through the various fabrication and post-processing methods, SCFs are now being regularly produced with transmission losses $\lesssim 1\,\mathrm{dB/cm}$ for core sizes ranging from sub-micron ($\sim 700\,\mathrm{nm}$) up to a few microns in diameter, facilitating their use in different wavelength regions.

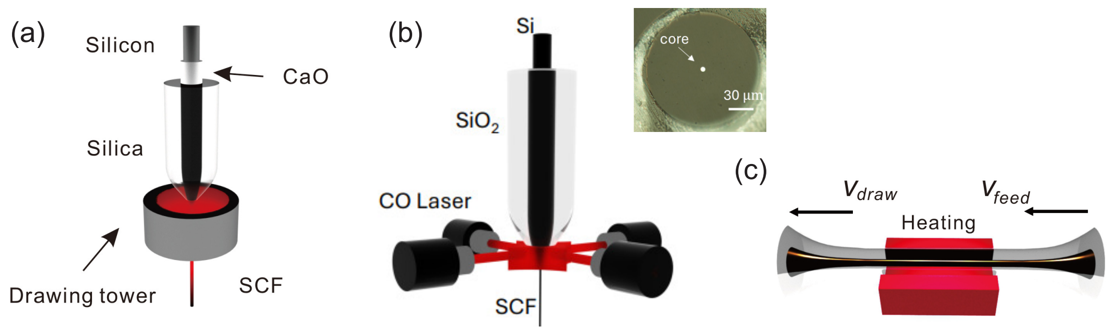

Fig. 1. (a) Schematic of the MCD fiber fabrication process. (b) Schematic illustrating the use of laser heating within the drawing process. Inset shows a cross-section of a laser-drawn SCF. (c) Schematic of the tapering process to control the crystallinity and longitudinal dimensions of the silicon core.

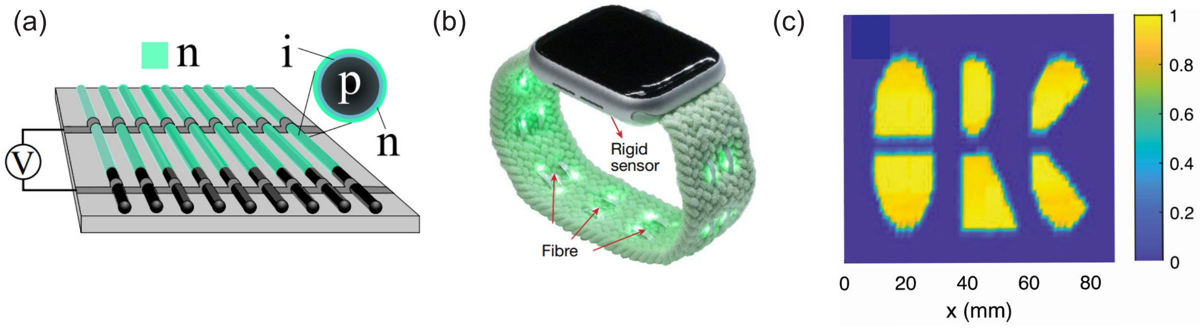

Fig. 2. (a) Fabrication of solar cells using SCF wires [1]. (b) Wearable sensor with a SCF woven into the fabric strap [2]. (c) Demonstration of amplitude imaging using undetected photons generated via a FWM process.

3. Results and Discussion

Figure 2 shows a selection of results that highlight the versatility of the SCF platform. Fig. 2(a) illustrates the potential to exploit the long SCF lengths for light harvesting in solar cells [1]. The horizontal wire design has several advantages over flat substrates as they are cheap to produce, flexible, and can absorb light over a wide range of angles. Fig. 2(b) presents another example where the optoelectronic properties of the silicon core can be exploited, this time for use in wearable sensors [2]. Here the SCFs are woven into the fabric of the strap so that the sensor conforms to the body shape, increasing the contact area and sensitivity. Finally, Fig. 2(c) demonstrates the use of SCFs for all-optical processing and imaging systems [7]. The image presented here has been generated based on undetected photon imaging, where a four-wave mixing (FWM) process has been used to produce a pair of photons such that one photon is used to probe the object and the second photon is used for the detection. This procedure is especially useful when the imaging wavelength is in a region where there is a lack of efficient detectors. However, a wide range of additional applications have also been demonstrated, particularly those that draw on the excellent nonlinear optical properties of the core, of interest for use in areas such as optical communications [8], sensing [9] and quantum information [10].

4. Conclusion

The fabrication and optimization of the unique silicon core fiber platform has been reviewed. Thanks to several recent advancements, the fibers are showing great potential for use in wide ranging applications that can draw on their optical and optoelectronic properties.
Acknowledgments: This work was supported by EPSRC.

References

1. A. C Peacock et al., et al., "Silicon optical fibres–past, present, and future," Adv. Phys. X. **1**, 114 (2016).
2. Z. Wang et al., "High-quality semiconductor fibres via mechanical design," Nature. **626**, 72 (2024).
3. M. Huang et al., "Semiconductor core fibres: a scalable platform for nonlinear photonics," npj Nanophoton. **1**, 21 (2024).
4. J. Ballato and A. C. Peacock, "Perspective: Molten core optical fiber fabrication—A route to new materials and applications," APL Photon. **3**, 120903 (2018).
5. C. M. Harvey et al. "Specialty optical fiber fabrication: fiber draw tower based on a CO laser furnace," J. Opt. Soc. Am. B **38**, F122 (2021).
6. D. Wu et al., "Net optical parametric gain in a submicron silicon core fiber pumped in the telecom band," APL Photonics **4**, 086102 (2019).
7. M. Huang et al., "Classical imaging with undetected photons using four-wave mixing in silicon core fibers," Photon. Research **11**, 137 (2023).
8. R. Sohanpal et al., "All-fibre heterogeneously-integrated frequency comb generation using silicon core fibre," Nat. Commun. **13**, 3992 (2022).
9. M. Huang et al., "Raman amplification at 2.2 μm in silicon core fibers with prospects for extended mid-infrared source generation," Light: Sci & Appl. **12**, 209 (2023).
10. D. Rizzotti et al., "Silicon core fibers: A new platform for quantum light generation," APL Photon. **9**, 091301 (2024).