Towards in-fiber silicon photonics

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Abstract: We review the recent advancements in the fabrication and application of silicon optical fibers. Particular focus is placed on novel materials and device designs for use in optical signal processing systems.

OCIS codes: 060.2270, 060.2290, 060.4370, 160.6000.

1. Introduction

The nascent field of silicon core fibers is attracting increased interest as a means to exploit the optoelectronic functionality of the semiconductor material directly within the fiber geometry [**?**]. Compared to their planar counterparts, this new class of waveguide retains many of the advantageous properties of the robust and flexible fiber platforms. In this paper we review our efforts regarding the fabrication and application of silicon core optical fibers. Results of transmission measurements will be presented for fibers with both amorphous and polycrystalline core materials, covering a wavelength range that extends from the telecoms band up to the mid-infrared [**?**, **?**]. In addition, we will also present some of our more recent results where we have shown that it is possible modify the optoelectronic properties of the core material using a laser processing procedure [**?**]. Our work in this area has shown that this new fiber technology has great potential for the development of a wide range of devices including broadband sources, modulators, amplifiers and even photodetectors.

2. Fabrication

There are two main approaches to fabricating silicon optical fibers. The first makes use of a high pressure chemical vapour deposition (HPCVD) method in which the silicon is deposited inside micrometer sized pores of pre-fabricated capillaries. The second approach is based on a conventional fiber drawing method whereby a silicon rod is sleeved inside a glass tube to create a millimeter sized preform, which is then heated and drawn down into a fiber with micrometer dimensions. These two methods offer different advantages and disadvantages in terms of the materials and fibre dimensions that they can access, thus our work makes use of both fiber types [?]. Fig. **??** shows a selection of silicon fibers, highlighting the variation in geometries. In particular, the fibers displayed in Fig. **??**(b) and (c) demonstrate the capability to tailor the waveguide design far beyond what is achievable on-chip, of particular use for nonlinear applications [**?**].

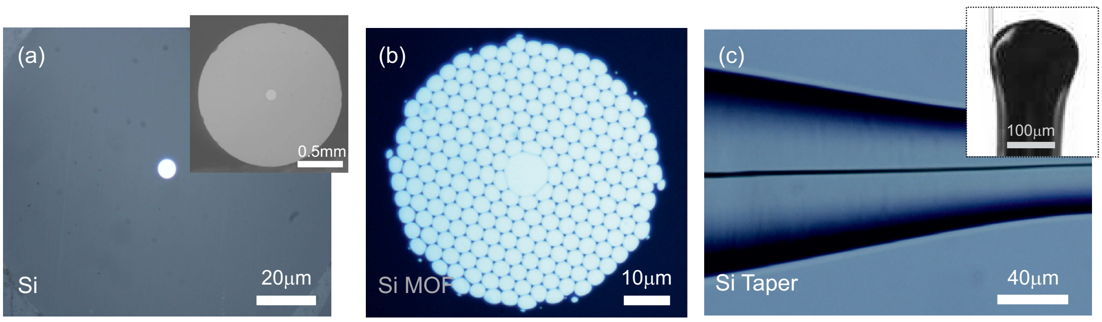

Fig. 1. (a) HPCVD step-index silicon core fiber (inset: drawn silicon core fiber), (b) silicon microstructured optical fiber, and (c) tapered silicon core fiber (inset: silicon microspherical resonator).

3. Results and Discussion

Figure **??** highlights some of our latest results obtained for the silicon core fibers. Fig. **??**(a) shows all-optical modulation of a $\lambda \sim 1.55\,\mu$m signal that is circulating in a silicon fiber-based resonator, similar to what is shown in the inset of Fig. **??**(c). The on/off switching is induced by an ultrafast Kerr nonlinear index modulation when the silicon core is pumped with 720 fs pulse source [**?**]. This modulated signal was obtained for an average pump power of 10 mW, for which we obtained an extinction ratio of ~ 6 dB. Fig. **??**(b) shows broadband supercontinuum generated via a cascaded four-wave mixing process in a small core ($D \sim 2\,\mu$m) silicon fiber, recorded for two different pump wavelengths [**?**]. For the longer pump wavelength we have obtained a continuum spanning more than an octave, which we attribute to the lower linear and nonlinear losses of the silicon material in this region, thus motivating a shift to investigate the use of these fibers within the mid-infrared region. Finally, Fig. **??**(c) shows the results of photoconductivity measurements to determine the electronic band-gap shift of a silicon core fiber that has been modified via a laser processing procedure. From this we see that it is possible to induce a large reduction in the band-gap energy of the fiber core, down to 0.59 eV compared to 1.05 eV for the silicon reference sample [?]. Significantly, this shifts the absorption edge out to $\sim 2.1\,\mu$m which opens up the possibility to develop in-fiber silicon detectors that can operate across the entire telecommunications band.

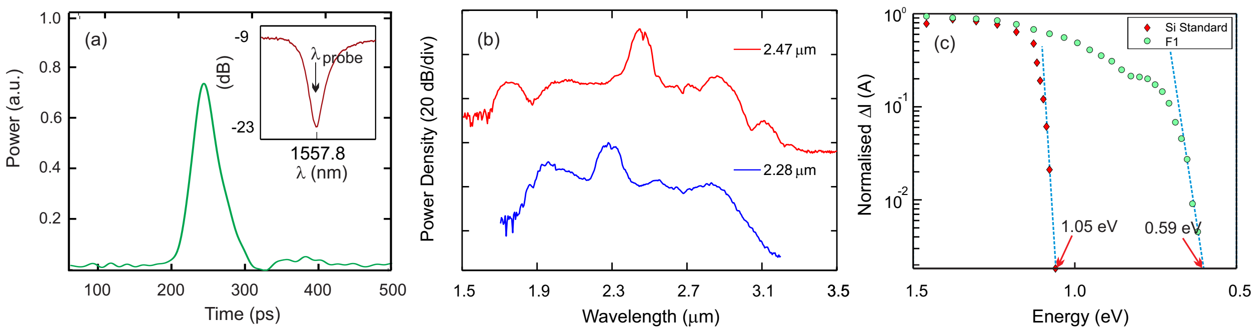

Fig. 2. Silicon fibers for optical processing. (a) All-optical switching of a CW probe circulating in a silicon fiber-based resonator, induced by a pulsed pump. Inset: the CW probe position with respect to cold cavity resonance dip. (b) Supercontinuum spectra generated in a silicon fiber when pumped in the anomalous dispersion regime; pump wavelengths as labeled. (c) Band-gap shift in a laser-processed silicon core fiber (F1), compared to a standard single crystal reference.

4. Conclusion

The transmission properties of various silicon core fibre devices have been characterized and demonstrated for use in signal processing applications extending from the telecoms band up to the mid-infrared.

Acknowledgements: This work was supported by EPSRC (EP/J004863/1 and EP/M022757/1) and the Norwegian Discovery Fund. We thank Dr K. Ignatyev and Diamond Light Source for access to beamline I18 (SP13025).

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