In-fiber Nonlinear Silicon Photonics

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Abstract: This paper reviews recent advances in the application of silicon core fibers for nonlinear photonics. Particular focus will be placed on novel device designs that benefit from the fiber geometry.

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1. Introduction

Over the past decade, silicon core fiber technologies have undergone significant advancement such that they are now established platforms for nonlinear optical applications [1]. Compared to their planar counterparts, this new class of waveguide retains many of the advantageous properties of the fiber geometry and, as such, is more immediately suitable for integration with existing fiber infrastructures. In this paper I review our efforts regarding the development and optimization of silicon core fibers for nonlinear applications. Results will be presented over a range of wavelengths extending from the telecom band up to the mid-infrared, highlighting the potential versatility of this platform for applications spanning communications to sensing and healthcare.

2. Fabrication

In recent years, the molten core drawing technique has become the primary fabrication method for the production of silicon core fibers [2]. The procedure starts by sleeving a silicon rod inside a glass tube that has been coated with a CaO interface modifier layer to create a millimeter sized preform, which is then heated and drawn down into a fiber with micrometer dimensions, as depicted in Fig. 1(a). The role of the interface layer is to reduce oxide contaminations from the core during the high temperature drawing and also to reduce the effective expansion mismatch between the materials that can lead to cracking. To improve the transmission of the as-drawn fibers, a post-process tapering prodecure is applied to melt and re-grow the crystalline core to increase the grain size, as shown in Fig. 1(b). As well as reducing the transmission losses down to levels that are comparable with on-chip technologies, this approach has the added advantage of providing a route to tailor the core dimensions, as illustrated in Fig. 1(c), which is important for enhancing the nonlinear processes via dispersion engineering [3, 4].

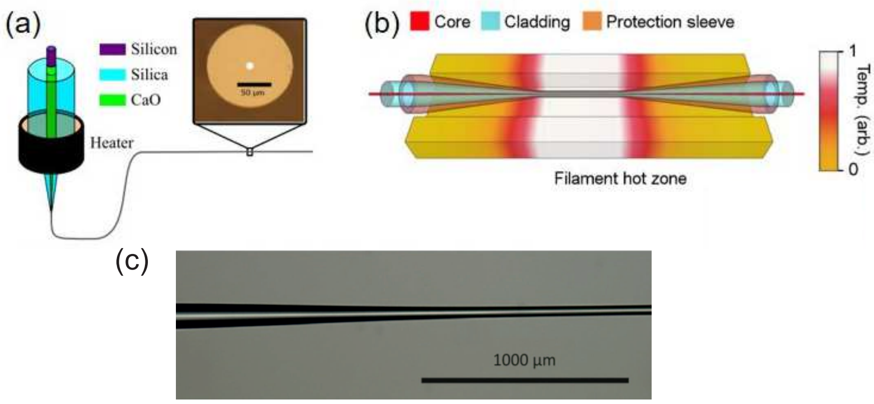

Fig. 1. (a) Schematic of the molten core drawing fabrication process, with a microscope image of a silicon fiber cross-section. (b) Schematic of the tapering process. (c) Microscope image showing the longitudinal profile of a tapered silicon core fiber.

3. Results and Discussion

Figure 2 highlights some of our latest results in nonlinear processing obtained for the silicon core fibers. Fig. 2(a) shows the first demonstration of parametric amplification via four-wave mixing (FWM) in a silicon fiber that was tapered to have a sub-micrometer core size to facilitate phase-matching [4]. Significantly, this result reported the first observation of a net optical gain obtained in a silicon waveguide in the telecom band, where two-photon absorption is normally a barrier to high performance, which we attributed to the low transmission losses and high coupling efficiency of our taper designs. Subsequently, high efficiency FWM wavelength conversion of a 20−Gb/s bitrate telecom signal was realized using a similar low loss tapered silicon core fiber as shown in Fig. 2(b) [5]. However, this time the silicon fiber was directly integrated into an all-fiber system using a nano-spike coupler that was formed in the high index core, as shown in the inset [6]. Finally, Fig. 2(c) shows the generation of a high-brightness supercontinuum spectrum spanning almost two octaves, from the near infrared into the mid-IR, that was obtained using an asymmetric taper profile [7]. Specifically, the taper was designed with a short output coupling section to minimise the interaction of the long wavelength light with the lossy silica cladding, which enabled the red edge of the spectrum to be extended well beyond the previous results obtained in silica clad, silicon waveguides (by around 2 μm).

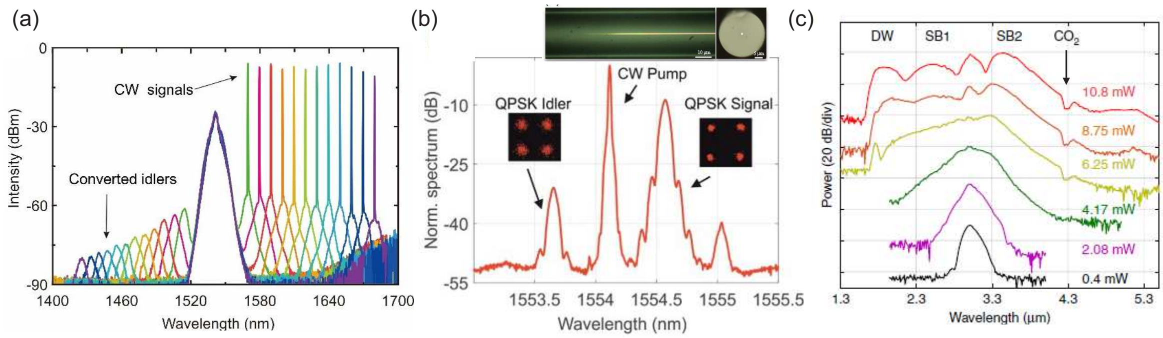

Fig. 2. (a) FWM amplification in a silicon fiber as the signal wavelength is tuned. (b) Wavelength conversion of a QPSK data signal, with the signal and idler constellation diagrams shown as insets. Top inset shows the silicon nano-spike coupler for integration with a standard fiber. (c) Supercontinuum generation into the mid-IR using a specially designed taper. The wavelength converted peaks associated with FWM (SB1 and SB2) and dispersive wave emission are labelled. The black arrow shows the CO2 absorption dip.

4. Conclusion

The nonlinear performance of silicon core fibres has been demonstrated across a broad wavelength region, highlighting their potential for use in practical all-fiber systems across a variety applications.

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