Nonlinear Optics in Silicon Core Fibers: Progress and Trends

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Abstract: Recent advances in the development and application of silicon core fibers for nonlinear photonics is reviewed. Focus will be placed on novel device designs that benefit from the fiber geometry and integration with existing components.

1. Introduction

Over the past two decades, silicon core fibers (SCFs) 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 design and optimization of SCFs for use in all-fiber nonlinear optical applications. Results will be presented over a range of wavelengths, starting from the telecom band before extending up to the mid-infrared region, highlighting the potential versatility of this platform for applications spanning communications to sensing and healthcare.

2. Fabrication and Post-Processing

The molten core drawing (MCD) method is now the primary SCF fabrication approach as it allows for the rapid production of long fiber lengths [2]. The procedure begins by sleeving a silicon rod inside a glass tube to create a preform. The preform is then heated and drawn down into a fiber using a conventional draw tower, as depicted in Fig. 1(a). To improve the transmission of the as-drawn fibers, a tapering procedure has been developed to melt and re-grow the crystalline core to increase the grain sizes, as shown in Fig. 1(b) [3]. 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 [4]. Moreover, by adjusting the tapering profile, it is also possible to control the longitudinal dimensions of the fiber, which can be exploited to enhance the coupling regions as illustrated in Fig. 1(d). Significantly, using these tapering methods, SCFs can now be 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 [5].

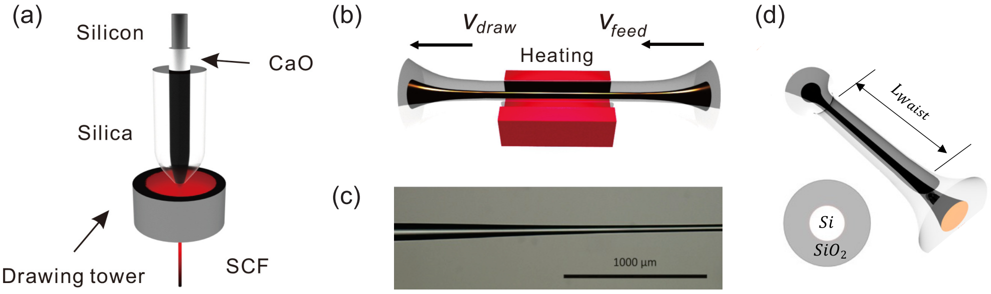

Fig. 1. (a) Schematic of the MCD fabrication process. (b) Schematic of the tapering process to control the crystallinity and dimensions of the silicon core. (c) Microscope image showing the longitudinal profile of a tapered SCF. (d) Schematic showing a tapered fiber design optimised for efficient free space coupling.

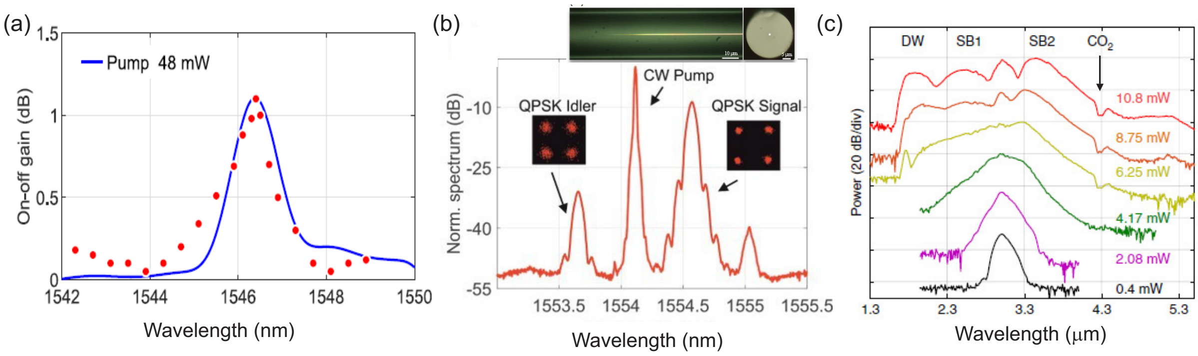

Fig. 2. (a) Characterization of Raman gain in a silicon fiber. (b) Wavelength conversion of a QPSK data signal, with constellation diagrams shown as insets. Top inset shows the silicon nano-spike coupler for integration with a standard fiber. (c) Supercontinuum generation into the mid-infrared using a specially designed taper. The wavelength converted peaks associated with FWM (SB1 and SB2), dispersive wave (DW) emission, and CO_2 absorption are labelled.

3. Results and Discussion

Figure 2 highlights some of our latest results in nonlinear processing obtained for the silicon fibers. Fig. 2(a) shows the first demonstration of Raman amplification in a SCF that was tapered to obtain a loss of only ~ 1 dB/cm, over a length of ~ 1.5 cm in a sub-micrometer sized core [5]. Significantly, the Raman gain is slightly higher than previous results in planar silicon waveguides using similar CW pump powers, which we attributed to the combination of low loss and longer lengths of our tapered fibers. This result has recently been extended using an even longer ~ 6 cm SCF to wavelengths $> 2\,\mu$m, demonstrating the potential for mid-IR source generation [6]. Fig. 2(b) then shows high efficiency four-wave mixing (FWM) wavelength conversion of a 20−Gb/s bitrate telecom signal, which was realized using a similar low loss tapered SCF [7]. 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 [8]. Finally, Fig. 2(c) shows the generation of a high-brightness supercontinuum spectrum spanning almost two octaves, covering near- to mid-infrared wavelengths, that was obtained using an asymmetric taper profile [9]. Specifically, the taper was designed with a short output coupling section to minimize 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 silicon waveguides that are clad in silica, by around $2\,\mu$m.

4. Conclusion

The nonlinear performance of silicon core fibers 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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