Silicon Core Fibers for Nonlinear Photonics: Progress and Trends

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

1. Introduction

Over the past two decades, silicon core fibers (SCFs) have undergone significant advancements in their fabrication and optimization 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, can offer low transmission losses and robust 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 versatility of this platform for applications ranging from optical communications to quantum imaging and sensing.

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 [2]. The procedure involves heating the preform, which consists of a silicon rod sleeved in a silica cladding tube, so that it can be drawn down into a fiber using a conventional draw tower, as shown 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, thus increasing the grain sizes, as shown in Fig. 1(b) [3]. As well as reducing the transmission losses to levels that are comparable to or lower than on-chip technologies, this approach has the added advantage of providing a route to tailor the core dimensions, important for optimizing the nonlinear processes through dispersion engineering [4]. Moreover, by adjusting the tapering profile, it is also possible to control the longitudinal dimensions of the fiber, as illustrated in Fig. 1(c), which can be exploited to enhance the optical coupling. 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.

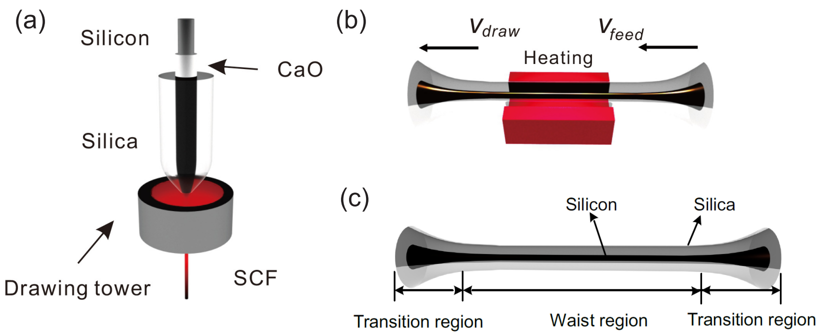

Fig. 1. (a) Schematic of the MCD fiber fabrication process. (b) Schematic of the tapering process to control the crystallinity and dimensions of the silicon core. (c) Schematic showing a tapered fiber design optimised for efficient free space coupling.

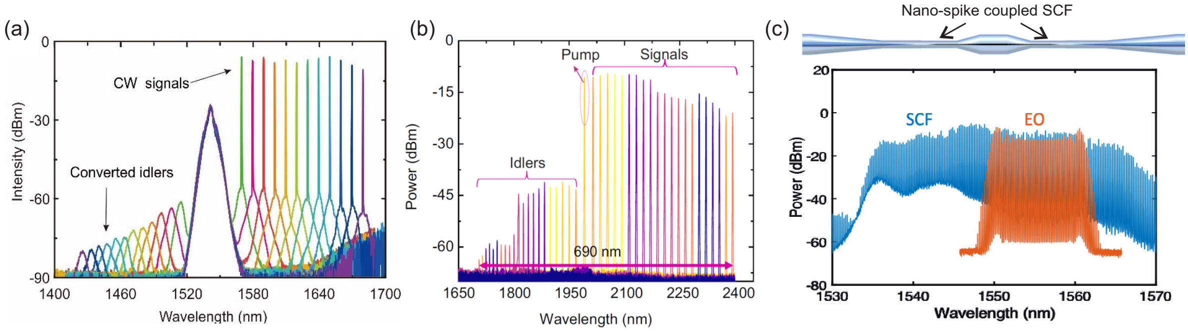

Fig. 2. (a) Characterization of FWM in a SCF in the telecom band. (b) FWM in a SCF designed for pumping at $\sim 2\,\mu$m pump. (c) Spectral broadening of an electro-optic frequency comb (orange) via an all-fibre integrated SCF nonlinear wave-mixer (blue). Inset at top shows a schematic of the integrated SCF device.

3. Results and Discussion

Figure 2 highlights some of our recent results in SCFs that make use of tapered waveguide designs for efficient nonlinear processing. 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. This work was subsequently extended by shifting the pump wavelength to $\sim 2\,\mu$m, as shown in Fig. 2(b), where it is possible to obtain more efficient conversion due to the lower nonlinear absorption [5]. The broad wavelength conversion of ~ 700 nm, possible due to the precise dispersion engineering of the tapered waist, demonstrates the potential for translation between the mid-infrared and telecommunications spectral bands. Finally, Fig. 2(c) demonstrates the use of a SCF to spectrally broaden an electro-optic frequency comb source specially designed to exhibit features such as spectral flatness, narrow tone linewidth, high tone power, and low noise levels required for applications in telecommunications [6]. However, in this instance the SCF was fully integrated into an all-fiber system using nano-spike couplers that were fabricated onto each end of the high index core (as shown in the inset [7]). The resulting system was able to achieve a tripling of the source bandwidth from 10 nm to 30 nm, increasing the number of tone lines whilst preserving all of the key performance features of the original comb. Thus this work paves the way for fully integrated SCF systems that are robust, efficient, and practical.

4. Conclusion

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