Broadband MIR wavelength conversion in a tapered silicon core fiber

D. WU[1], T. S. SAINI[1], S. SUN[1], L. SHEN[2], M. HUANG[1], T. HAWKINS[3], J. BALLATO[3], and A. C. PEACOCK[1]

1. Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, UK

2. Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan 430074, Hubei, China

3. COMSET, Department of Materials Science and Engineering, Clemson University, Clemson, SC 29634, USA

Silicon core fibers (SCFs) fabricated via the molten core drawing method (MCD) have emerged as a new platform for efficient four wave mixing (FWM) based wavelength conversion of optical data signals [1]. Thanks to the high nonlinearity of the core and the strong dispersion tailoring that is facilitated by the high core/cladding index contrast, both high gain [2] and broadband conversion [3] have been demonstrated in the telecoms band, despite the nonlinear absorption (two-photon and free carrier effects) that occurs in this spectral region. Here we build on this work to investigate FWM that extends into the mid-infrared (MIR), where the optical losses (both linear and nonlinear) of the SCFs are lower [4], and thus where the conversion efficiency (CE) and bandwidth are expected to improve. Specifically, we make use of a SCF that has been tapered to have a longitudinal profile that maximises the nonlinear conversion, but yet still offers low loss to the mid-infrared signal beams.

The as-drawn SCF was fabricated with a core diameter of 10 μm and a cladding diameter of 125 μm. To engineer the dispersion of the SCF for efficient FWM, a tapering method is applied to tailor the zero-dispersion wavelength near the 2.0 μm pump. The tapered SCF is produced with a waist core diameter of 1.6 μm over a length of 4 cm. A section of the taper transition region is kept at each end so that the core size at the coupling facets is 4.3 μm, which helps to reduce the total insertion loss and results in a total fibre length of 4.5 cm. The insertion loss at 2 μm is measured to be 12 dB, from which we estimate a linear loss of 0.5 dB/cm (assuming a total coupling loss of 10 dB). Fig.1(a) shows the experimental setup for the FWM. A thulium fiber laser with a pulse duration of 100 ps was employed as the pump source, which operates at 1992 nm with a 10 MHz repetition rate. A CW ZnSe laser was used as the signal wave, tuning from 2.0 to 2.4 μm. The pump and signal beams are then combined using a 75:25 optical coupler (OC), before coupling into and out from the tapered SCF using two tapered lensed fibers (TLF). Two polarization controllers (PC) are used to adjust the polarization of the two waves for optimizing the conversion efficiency. Finally, the spectrum was recorded using an optical spectrum analyzer.

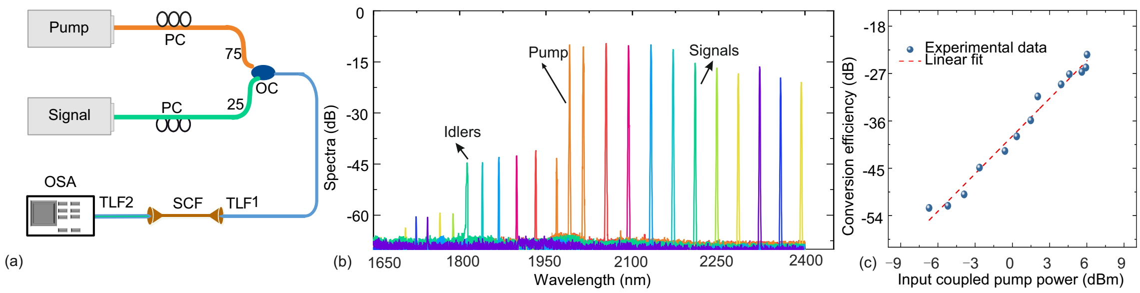

Figure 1: (a) Schematic of the experimental setup for FWM in a tapered SCF fiber. (b) Measured transmission spectra from the SCF output as the signal wavelength is tuned from 2 to 2.4 nm, pumping at 2 μm. (c) The measured CE as a function of the coupled input pump power.

The spectra illustrating wavelength conversion extending from the near to the mid-infrared region is plotted in Fig.1(b), where the input coupled pump power was 6 dBm and the signal power was 6 dBm. A broad conversion bandwidth of 690 nm was obtained when the signal is tuned to the longest wavelength of 2395 nm, corresponding to a converted idler of 1705 nm. We note that the tuning range is only limited by the signal wavelength available from the ZnSe source, and simulations indicate that conversion could be achieved over a bandwidth of 1500 nm. Fig.1(c) plots the CE as a function of the coupled input pump power, where the input signal wavelength is kept at 2010 nm and the power at 6 dBm. The CE grows from -52 dB to -23 dB linearly as the pump power increases with a slope of 2, as indicated in simulation results. As there is no observed saturation of CE so far, this could be increased further with a higher input pump power. According to our simulations, we find that the CE eventually starts to saturate when the pump power reaches 11 dBm, which corresponds to a CE of -15 dB. Thus, we expect these tapered SCFs will find extensive use in applications such as gas detection and free space communications that require efficient wavelength conversion bridging the near to mid-infrared regimes [5].

References

[1] J. Ballato et al., "Silicon optical fiber," Optical Express **16**(23), 18675-18683 (2008).

[2] D. Wu et al.," Net optical parametric gain in a submicron silicon core fiber pumped in the telecom band," APL Photonics **4**(8), 1-5 (2019).

[3] D. Wu et al., "Four-Wave Mixing-Based Wavelength Conversion and Parametric Amplification in Submicron Silicon Core Fibers," IEEE J. Sel. Topics Quant. Electron **27**(2), 4300111 (2021).

[4]H. Ren et al., "Nonlinear optical properties of polycrystalline silicon core fibers from telecom wavelengths into the mid-infrared spectral region," Opt. Mater. Express **9**(3), 1271-1279 (2019).

[5]S. Zlatanovic et al., " Mid-infrared wavelength conversion in silicon waveguides pumped by silica-fiber-based source," IEEE J. Sel. Topics Quant. Electron **18**(2), 612-620 (2012)