Midinfrared supercontinuum generation from 2-6 μm in a silicon nanowire: supplementary material

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1. DEVICE FABRICATION

The nanowire was optimally designed for anomalous dispersion in the pump regime by calculating the effective index of the nanowire using the sellmeier equation for bulk silicon [1]:

$$n^2 = \epsilon + \frac{A}{\lambda_1^2} + \frac{B\lambda^2}{(\lambda^2 - \lambda_1^2)} \quad (1)$$

where, $\lambda_1 = 1.1071$, $\epsilon = 11.6858$, $A = 0.939816$ and $B = 8.10461 \times 10^{-3}$.

and, for the sapphire under cladding [2]:

$$n^2 = 1 + \frac{A_1\lambda^2}{\lambda^2 - \lambda_1^2} + \frac{A_2\lambda^2}{\lambda^2 - \lambda_2^2} + \frac{A_3\lambda^2}{\lambda^2 - \lambda_3^2} \quad (2)$$

where, $\lambda_1 = 0.06144821$, $\lambda_2 = 0.1106997$, $\lambda_3 = 17.92656$, $A_1 = 1.023798$, $A_2 = 1.058264$ and $A_3 = 5.280792$. The nanowire was then fabricated by epitaxially growing 500 nm of silicon on a sapphire substrate, which was then patterned using a 248 nm step and scan system and etched in a transformer coupled plasma etcher with an appropriate mix of Cl_2 , HBr and He diluting gases. Further post-processing by repeated chemical

oxidation in piranha (5:1 $\text{H}_2\text{SO}_4:\text{H}_2\text{O}_2$) and oxide stripping in HF was performed four times to controllably smoothen the surface of the nanowire to minimize the surface scattering losses [3–5]. However, the RMS surface roughness for the silicon layer and the sapphire layer on the SOS samples were measured to be 2 nm and 0.17 nm, respectively, using a Veeco optical profiler. This suggests an improvement in the silicon deposition technique would be critical in order to reduce the surface roughness for an optimal SCG. Note in the dispersion modelling a 2.35/0.485 μm waveguide was used instead of the measured 2.4/0.48 μm for optimal dispersion, shown in Fig. 1. This uncertainty could be due to variation in the dimensions along the length of the waveguide and limitation in the measurement technique.

2. PROPAGATION LOSS MEASUREMENT

A QCL at 4 μm was coupled into the nanowire from which the scattered light along the propagation length was captured for analysis [6] with a highly sensitive mid-IR camera (FLIR -

x6540sc) with an InSb detector with noise equivalent temperature difference (NETD) < 25mK and 14 bit dynamic range. In this method, a 2D image of the scattering nanowire was evaluated by defining a region of interest (ROI) of two halves such that one half contains the scattering streak entirely. The column sum of pixels values of one half was subtracted from the column sum of the other half, point by point all along the nanowire (to remove the background effects) and a fit is plotted on a logarithmic scale. We measured a loss of 1 ± 0.3 dB/cm around $4 \mu\text{m}$, which was used to calibrate the transmission measured between $2.9 - 4.1 \mu\text{m}$ using the OPA at low power in order to avoid nonlinear effects. The errors (in Fig. 2) takes into account the calculated uncertainties in streak analysis, detector response and coupling coefficient which was 12 - 6% with respect to centre wavelength, $3.7 \mu\text{m}$, over the measured range from $2.8 - 4.1 \mu\text{m}$.

3. SC MEASUREMENT

For the SC experiment, the OPA source was based on a mode-locked Newport/High-Q femtosecond-Yb laser (1041 nm) pumping a 10 mm long PPLN crystal, which was seeded with a CW 1448 nm light from a tunable semiconductor laser, Santec-TLS510 (more information can be found in [7]). This produced an idler beam at $3.7 \mu\text{m}$ that was coupled into the dispersion engineered nanowire through a high NA (0.85) moulded chalcogenide lens. The lens focused the beam down to a spot size < $4 \mu\text{m}$, resulting in a coupled peak power of up to 2.5 kW. An achromatic reflective microscope objective (Newport-50102) was used to collimate and direct the output to the monochromator, which had a PbSe (< $5 \mu\text{m}$) and MCT (> $5 \mu\text{m}$) detector. To achieve high sensitivity, a lock-in-amplifier (1 sec integration time) was employed, while a InSb camera was used to assist in the alignment.

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