Demonstration of Pulsed Silicon Raman Laser

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ABSTRACT

We report the demonstration of a pulsed silicon Raman laser. Experimentally, a pulsed Raman laser emission at 1675 nm with 25 MHz repetition rate is demonstrated using a silicon waveguide as the gain medium. The laser has a threshold at 9 W peak pump pulse power and with a slope efficiency of 8.5%.

Keywords: Silicon photonics, Raman lasers, integrated optics, semiconductor lasers, nonlinear optics.

1. INTRODUCTION

The need for low cost photonic devices has stimulated significant amount of research in silicon photonics [1-2]. One approach that has been pursued for light generation and amplification is the utilizing high Raman gain coefficient in silicon [3-5]. However, obtaining net Raman gain in silicon is challenged by the losses induced by free carriers that are generated by the Two Photon Absorption (TPA) process in silicon [6-7]. Reducing the waveguide dimensions and using pulsed pumping can mitigate this problem [7-12]. Using pulsed pumping technique fiber-to-fiber net gain of 11 dB and lasing has recently been reported [11-13].

In this paper, we report the demonstration of a Raman laser in silicon by pulsed pumping technique. A pump laser with 25 MHz repetition rate at 1540 nm and with 30 ps pulses is used to obtain Raman laser in silicon. Lasing is measured at 1675 nm. A clear lasing threshold is observed at 9W peak pulse power along with a slope efficiency of 8.5% above threshold.

2. RESULTS

Figure 1 shows the block diagram of the silicon Raman laser. A mode locked fiber laser operating at 1540 nm with 25 MHz repetition rate is used as a pulsed pump laser. After broadening the pulse width to 30 ps in standard Single Mode Fiber (SMF) and amplifying, the pump is coupled into the laser cavity by a wavelength combiner. The output of the wavelength combiner is coupled to the silicon waveguide which provides the optical gain. The waveguide is approximately 2 cm long with measured 0.8 dB fiber-to-fiber insertion loss and about 5 μm^2 effective area, A_{eff}. At the waveguide output, 95% of the power is looped back to the input wavelength combiner to form the 8 m long laser ring cavity. The total loss at the Stokes wavelength of 1675 nm is measured to be 3.7 dB. The 5% of the waveguide output is used to monitor the output. The efficiency of the laser is controlled by the polarization controllers in the cavity and at the pump path outside the cavity. An autocorrelator, a 40 GHz and an Optical Spectrum Analyzer (OSA) are used to measure the laser characteristics.

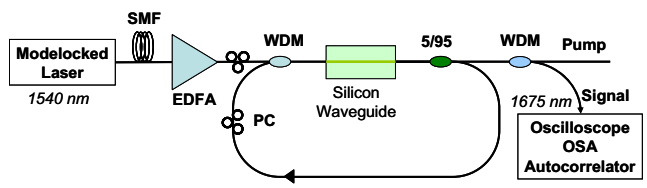

Figure 1. Experimental set up used for silicon Raman laser demonstration. The lasing is obtained at the Stokes wavelength of 1675 nm in ring laser cavity.

The measured laser threshold curve is illustrated in Figure 2. The peak pump power is varied from 0 to 25W to determine the lasing threshold. Lasing, characterized by a sudden increase in emission at the Stokes wavelength of 1675nm, is obtained when the pump peak power level reaches 9 W. This threshold power of 9 W is consistent with the measured cavity loss of 3.7 dB and the measured Raman gain of ~3.9 dB at this power level [11]. After

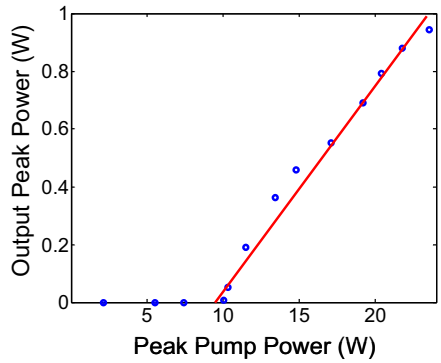

Figure 2. Measured laser output power with respect to peak pump power shows threshold power of 9W with the slope efficiency of~8.5%.

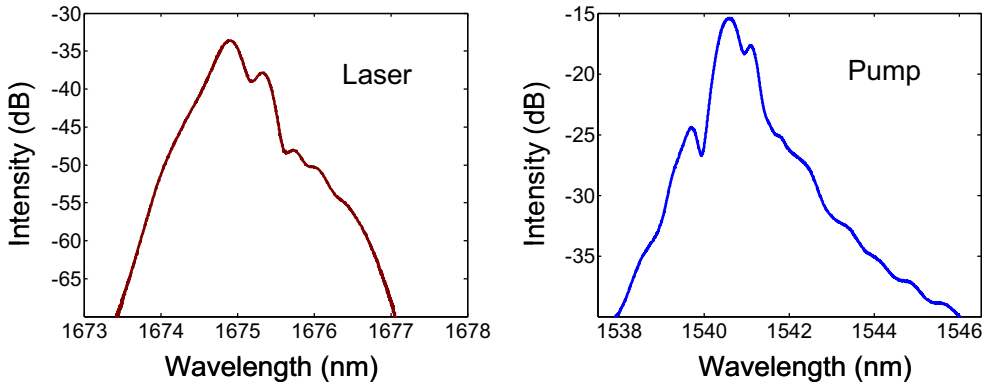

Figure 3. Measured laser and pump spectra. The laser spectrum is located 15.6 THz away from the pump laser. The pump-output separation is precisely the optical phonon frequency in silicon.

exceeding the threshold level the output increases almost linearly with the pump power. Near the threshold power, the laser output power varies more than 20 dB with respect to small variation in the peak pump power level. This can be utilized for demonstration of electronically switched and high extinction ratio Raman lasers. The slope efficiency of the laser, which is defined by the ratio of the output peak power and the input peak pump power, is 8.5%. Additionally, the maximum peak output power of the laser is measured to be about 1 W.

Figure 3 presents the measured laser (3a) and pump (3b) spectrum. The spectral peak of the silicon Raman laser is at 1675 nm, which is precisely the expected location based on the optical phonon frequency (15.6 THz) in silicon [4]. The pump laser, on the other hand, is centered at 1540 nm. Figure 4 shows the measured temporal profile of the laser output, at the Stokes wavelength of 1675 nm, measured using an autocorrelator. The pulse width of the laser is measured to be around 25 ps in the autocorrelator trace. Additionally, the Raman laser results shows that coherent anti-Stokes Raman Scattering starts when the lasing threshold is reached [14]. This indicates the possiblity of dual wavelength lasing with a proper cavity design. In the present configuration the growth of anti-Stokes emission is blocked by the wavelength combiner and the group delay differences between pump, Stokes and the anti-Stokes signals.

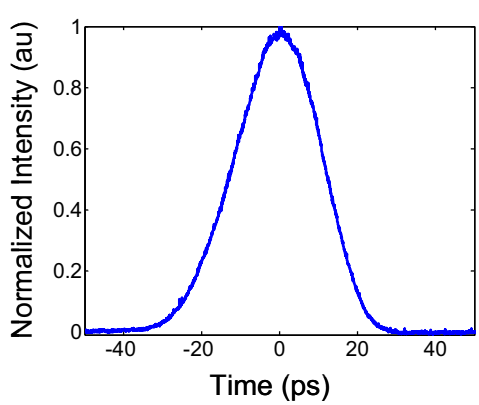

Figure 4. Measured temporal profile of the laser output by an autocorrelator. Pulse width is measured to be 25 ps.

3. SUMMARY

In summary, we have reported the demonstration of a silicon Raman laser simultaneously producing coherent radiation at the Stokes and anti-Stokes wavelength at a threshold value of 9 W. The signal at the Stokes wavelength is due to the lasing at that wavelength whereas the anti-Stokes radiation is due to the parametric Raman coupling between the two signals and the pump. This suggests the possibility of silicon Raman laser with dual wavelength output. With a pump at around 1430nm range, such a laser can simultaneously produce an output in both of the technologically important bands of 1300nm and 1550nm bands. Realization of this device requires a careful cavity design to accommodate both wavelengths. Additionally, the peak laser output power is measured to be about 1W with a slope efficiency of 8.5%.

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