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Frequency modulated external cavity laser with photonic crystal resonator and microheater

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ABSTRACT

We demonstrate frequency modulation (FM) in an external cavity III-V/Silicon laser, comprising a Reflective Semiconductor Optical Amplifier (RSOA) and an SU8 polymer waveguide vertically coupled to a 2D Silicon Photonic Crystal (PhC) cavity. Laser FM was achieved by local heating of the PhC using a resistive element of Ni-Cr metal as a microheater to change the refractive index in the cavity hence changing the lasing frequency. Presented is a thermal study of the laser dynamics and observations of the shift in lasing frequency.

Keywords: Semiconductor lasers, photonic crystal, frequency modulation, silicon thermo-optic effect

1. INTRODUCTION

The importance of frequency modulated lasers is evident in their role in a wide range of applications such as: bio-medical imaging[1], LIDAR[2], sensing and fast transmission communications[3]. Various frequency modulated lasers have been demonstrated with many using direct modulation of the laser injection current which modulates the laser intensity and frequency simultaneously[4]. The use of an external modulator has also been explored with multi-section lasers[5].

Several configurations for an external cavity laser using silicon-based resonant reflectors have been previously demonstrated. Some of these configurations employ as a silicon reflector a microdisk[6], racetrack resonator[7,8] and ring resonator devices[9,10,11]. Previous research has addressed the requirement for a large extinction ratio to modulate the output power for data bit transmission by switching between on and off states at resonance with the least power consumption. By employing a continuous frequency scan rather than switching this can be ideally suited for sensing applications.

Here we utilize an external cavity laser with a RSOA and a PhC cavity resonant reflector as per the configuration in[12]. Previous research has seen electro-optical modulation of the Si-reflector as a means of tuning the reflectance wavelength. This work focuses on the thermo-optical effects in silicon to achieve modulation of the lasing frequency. Modulation of the current to a microheater on the Si-reflector of the external cavity laser will change the refractive index which will tune the reflectance wavelength and hence modulate the lasing frequency required to regain phase matching. PhC cavities are smaller in area than a typical ring resonator and have larger free spectral range that results in less mode competition effects.

2. LASER CONCEPT

The laser cavity consists of a III-V optical amplifier with one facet of highly reflective coating and the other of anti-reflective coating. The optical output of this RSOA is butt-coupled to the SU8 waveguide which is vertically coupled to the silicon PhC cavity. On resonance, light couples to the PhC cavity and is back-reflected. Butt-coupling of the gain and

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PhC reflector elements ensure a small cavity laser which is effective to achieve single-mode lasing as the narrowband reflectance peak of the PhC overlaps with only one longitudinal mode of the laser cavity.

Figure 1 shows the laser setup. The output is collected via a lensed fiber. A trench around the PhC is intended for better thermal isolation around the PhC. The microheater is a Ni-Cr resistive element and current is applied through the metal contacts shown in Figure 1. When current is applied to the resistor, the PhC heats locally causing a refractive index change in the silicon. This change effectively modulates the lasing frequency.

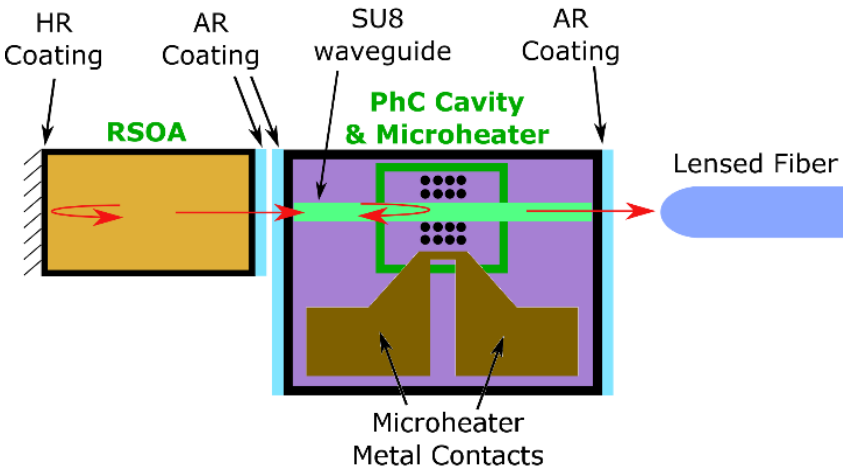


Figure 1. Laser configuration schematic

3. EXPERIMENTAL RESULTS

The system temperature was maintained using peltier controllers on both the RSOA and PhC. At an operating temperature of 20°C, the injection current to the RSOA was increased and a red-shift in the lasing wavelength was observed (Figure 2. (a)). At ~30 mA, another PhC resonance mode appears and above 70 mA, a few longitudinal modes start to appear. The corresponding LI curve was also recorded (Figure 2. (b)) and the jumps in the output power match the where the extra resonance mode and longitudinal modes form. There is stable linear laser operation from ~35 mA to 70 mA with output power of ~0.3 mW and a lasing threshold of 15 mA was achieved.

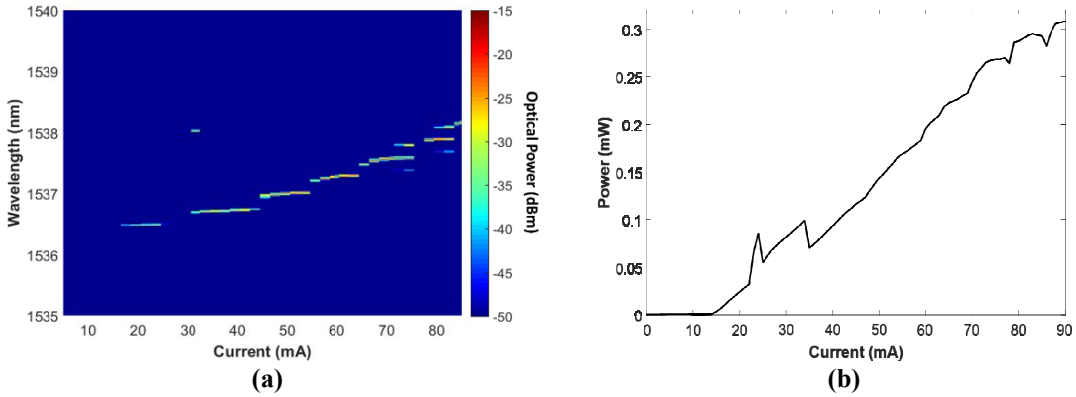


Figure 2. (a) Characterization of laser tuning by current injection. (b) Laser LI curve

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Single mode operation was achieved at 1532.5nm with SMSR of ~50 dB. Figure 3 shows the single mode lasing peak red-shift with increasing temperature. The laser injection current was set to 40 mA and the overall system i.e. the RSOA and PhC temperature was increased. A shift of an average of 0.08 nm/°C can be seen.

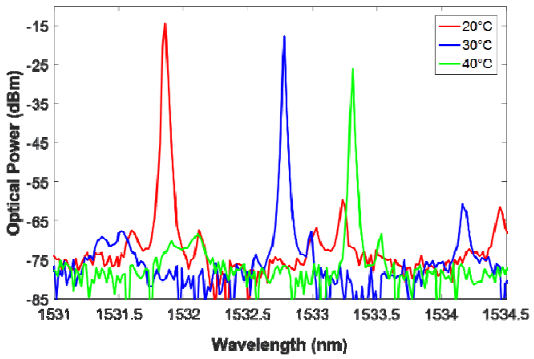


Figure 3. Single mode lasing peak shift with temperature

The next step in the experiment involved maintaining laser injection current at 40 mA and maintaining system temperature at 20°C then applying current to the microheater pads and observing the optical spectrum. The resistor was found to have a value of 1 kΩ then with the application of 4 V i.e. 4 mA to the microheater, the single mode peak can be seen to red shift as expected (Figure 4). The shift observed was ~13 pm at 4 mA equating to a heating power of 16 mW for this shift.

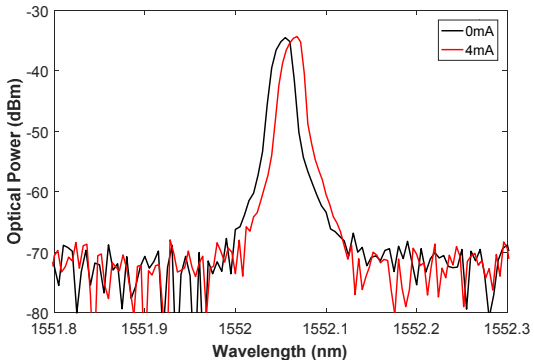


Figure 4. Lasing wavelength shift with increasing current to microheater

Once the lasing peak shift was confirmed on application of current to the microheater, a modulation signal could then be implemented. Current to the microheater was driven by a sine wave signal between 3-5 V (3-5 mA). Due to the fast

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changing dynamics of the laser frequency, a heterodyne measurement method was used to detect the laser FM. The heterodyne measurement was implemented as shown in Figure 5. The output of the laser collected via the lensed fiber was mixed with a tunable laser source (TLS) signal set close to the lasing wavelength. Both signals were passed by a 3x3 splitter and then directed to a power meter, optical spectrum analyzer and oscilloscope.

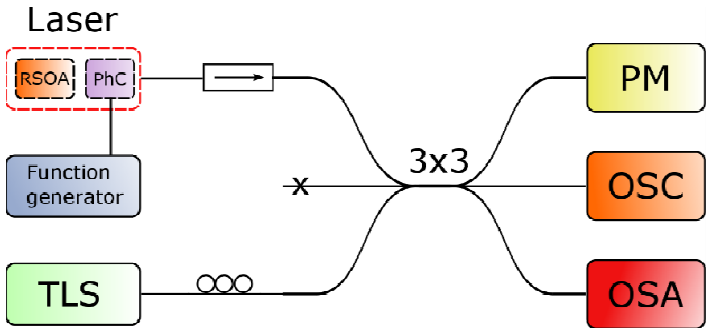


Figure 5. Experimental setup for heterodyne measurement

The heterodyne beating signal was captured on the oscilloscope. A Fast Fourier Transform of the time trace signal and subsequent processing produced the frequency shift colour maps shown in Figure 6. (a) and (b). The frequency on the vertical axis corresponds to the heterodyne beating frequency of both the laser and TLS hence a noticeable frequency shift can be seen. Modulation frequencies of 1 kHz and 100 kHz were applied and a modulation depth Δf of 1.5 GHz and 0.5 GHz respectively can be seen. Δf reduces with increasing modulation frequency i.e. the temperature difference between the two modulation states reduces.

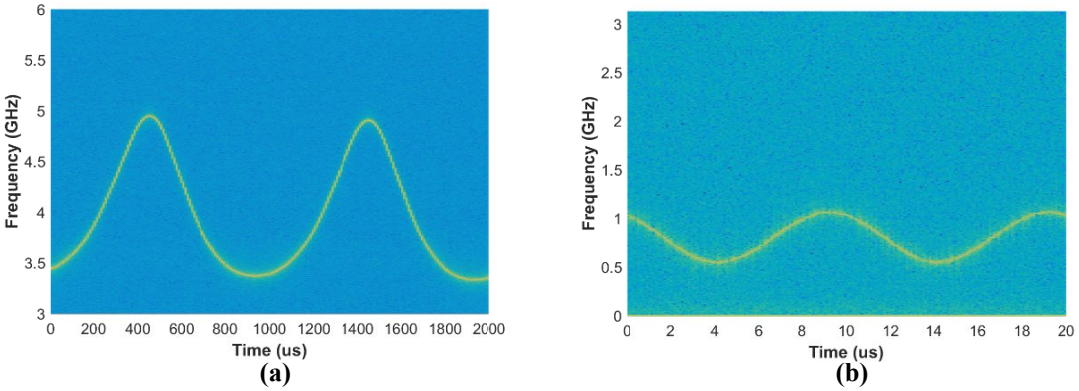


Figure 6. Heterodyne beating frequency at (a) 1 kHz and (b) 100 kHz modulation frequencies

4. CONCLUSION

We have presented a low threshold PhC laser capable of stable single mode operation. Demonstrated in this work we have shown that local heating of a PhC cavity acting as the resonant reflector of the laser can achieve laser frequency modulation. The shift of 13 pm with a heating power of 16 mW can be much further improved upon with optimized design and sufficient thermal isolation trenches. The output power was also not as high as expected as there were significant coupling losses but again, these can be improved in further experiments. Further work will involve improving

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these efficiencies with further study of the PhC heating for frequency modulation. These can provide compact low-power consumption devices ideally suited for the application of sensing technology.

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