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Heterogeneous Quantum Dots/Silicon Photonics Wavelength Tunable Laser Diode

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Abstract

The hybrid wavelength tunable laser combining quantum dot and silicon photonics technology is proposed. Ultra-compact tunable laser with 8.8 THz frequency tuning range was successfully demonstrated around 1.25 µm wavelength. The hybrid wavelength tunable laser will become breakthrough technology for high capacity data transmission system.

1. Introduction

Recently developed high-capacity optical transmission systems use wavelength-division multiplexing (WDM) mechanisms with dense frequency channels. Because the frequency channels in the conventional band (C-band) at 1530–1565 nm are overcrowded, the frequency utilization efficiency of such WDM systems is saturated. However, extensive and unexploited frequency resources are buried in near infra-red wavelength regions such as the thousand (T) and original (O) bands at 1000–1260 nm and 1260–1360 nm, respectively. Photonic devices used in short-reach data transmission require small footprints and low power consumption; thus, compact, low-power wavelength tunable laser diodes are key devices for use in higher capacity data transmission systems that can utilize these undeveloped frequency bands. A heterogeneous wavelength tunable laser diode consisting of a quantum dot (QD) optical gain medium and a silicon photonics external cavity is one promising candidate for implementing such light sources. QD optical-gain media have various attractive characteristics, including ultra-broad optical gain bandwidths, high-temperature device stability, and small linewidth enhancement factors, and silicon photonic wire waveguides based on silicon-on-insulator structures provide promising platforms for highly integrated photonics devices. We propose a novel wavelength-tunable laser diode combining QD and silicon photonics technologies. Although wide range wavelength tuning operation at wavelengths of around 1250 nm wavelength has been demonstrated using ultra-small foot print devices, to our knowledge the 44 nm wavelength tuning range of our proposed QD and silicon photonics hybrid wavelength tunable laser diode is a world record

2. Device Structure

Figure 1 shows a schematic of the wavelength-tunable laser diode. The tunable laser consists of a quantum-dot

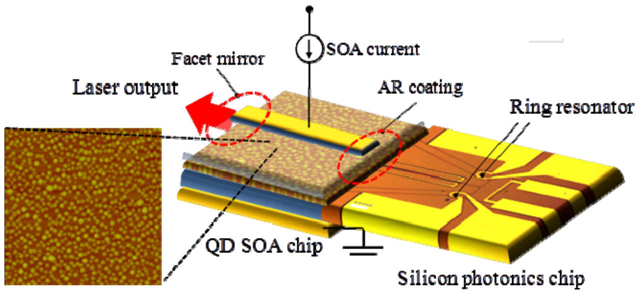

Fig.1 Schematic of heterogeneous QD/Silicon photonics wavelength tunable laser diode.

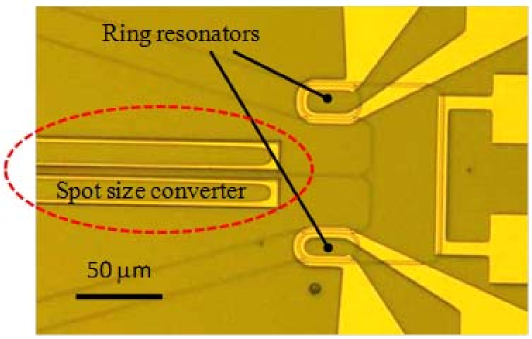

Fig. 2 Microscope image of silicon photonics chip

semiconductor optical amplifier (QD-SOA) chip for providing optical gain and a silicon-photonics chip with ring resonators for selecting the lasing wavelength. The QDs were grown using molecular beam epitaxy on an n-type (001) GaAs substrate. The sandwiched sub-nano separator (SSNS) growth technique was used to obtain high-quality, high-density self-assembled InAs QDs, which are shown in the inset atomic force microscope (AFM) image in Fig. 1 [1]. A 2-mm-long, 5-µm-wide ridge-waveguide SOA containing this ultra-broadband InAs QD gain medium was fabricated, and an anti-refraction (AR) coating was conducted onto one side of the end facet in order to connect the silicon photonic external cavity without reflection. Figure 2 shows a top view of the fabricated silicon-photonics chip. A loop-type wavelength filter with two ring resonators was formed using a 400-nm-wide, 220-nm-high silicon photonic wire waveguide. Light from the QD-SOA is coupled to a silicon waveguide with a high coupling coefficient through a double-core spot size converter. Propagation light is filtered by means of two ring resonators with different free spectral ranges (FSRs); using the Vernier effect between the two ring resonators, specific wavelengths are selected and reflected to the QD-SOA [2]. Based on the designed FSRs of the ring resonators of 675 and 734 GHz, respectively, the wavelength tuning range of the double ring wavelength filter would be expected to be 45 nm. The lasing wavelength can be tuned with low power consumption by using micro heaters placed on the ring resonators to induce the strong thermo-optical effect in silicon. The longitudinal mode in the laser cavity is controlled by a phase control heater placed on the bus-waveguide. The footprint of the silicon photonics external cavity containing the electrode pads is less than 600 μm × 800 μm.

3. Measurements

The QD-SOA and silicon photonic external cavity were butt-jointed using stepping-motor-controlled stages. The laser output from the cleaved facet of the QD-SOA was measured using a lensed fiber. The QD-SOA injection current dependence of the optical output power is shown in Fig. 3. The threshold current of laser oscillation was 220 mA and the maximum fiber-coupled output power was 0.47 mW when the QD-SOA injection current was 500 mA. Figure 4 shows the lasing spectrum around a wavelength of 1230 nm at an SOA injection current of 500 mA. A clear single-mode laser oscillation with a 53 dB side-mode suppression ratio (SMSR) is seen. Figure 5 shows the superimposed lasing spectra obtained when the lasing wavelength was tuned using a micro-heater with 2.1 mW/nm power consumption; the relationship between the heater input power and the lasing wavelength is shown in the upper part of the figure. It is seen that the heater input power linearly tuned the lasing wavelength and a 44.0-nm wavelength tuning range was obtained with a 37-dB SMSR between ring resonator's modes. The obtained tuning range around 1230 nm corresponds to 8.8 THz in the frequency domain, which is far larger than the 4.4 THz available in the C-band.

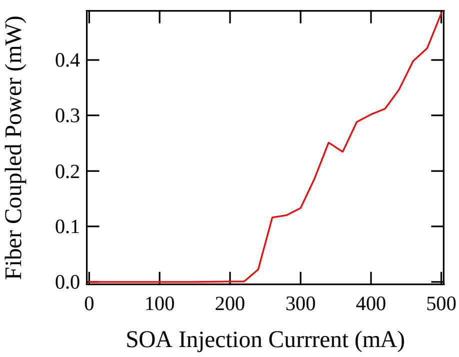

Fig. 3 QD-SOA injection current dependence of Laser output power

4. Conclusion

A heterogeneous wavelength tunable laser diode with an InAs QD optical amplifier and a silicon photonic external

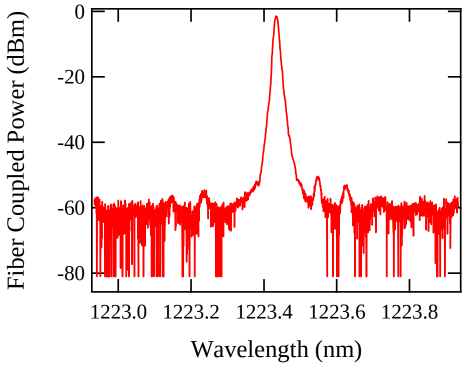

Fig. 4. Lasing wavelength spectrum

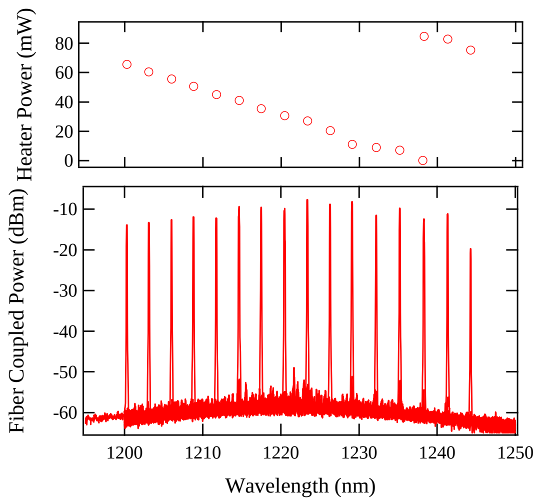

Fig.5. Superimposed lasing spectra with various heater power

cavity was successfully tested, producing clear single-mode lasing operation with a wide wavelength tuning range of 44.0 nm. We expect that this combination of the QD technique and silicon photonics will represent a breakthrough technology in the development of effective and compact light source.

Acknowledgements

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