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High Power Slow Light VCSEL Amplifier for LiDAR Applications

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Abstract

High power VCSEL photonics for 3D optical sensing will be described. We demonstrate a VCSEL amplifier, which potentially offers high power operations and high-resolution beam steering functions for 3D optical sensing.

1. Introduction

Various applications of VCSELs have been seen including datacom, sensors, optical interconnects, spectroscopy, printers, LiDAR, atomic clock and high power sources [1, 2]. 3D sensing has been attracting much attention for a wide range of applications such as LiDAR for automatic driving cars, distance sensor of robot, face ID in mobile phones, security camera, and motion sensors in virtual reality. 3D sensing has been based on two different schemes of time-of-flight technology and structure light principle [3]. A big market is prospected for 3D depth camera, which was recently installed in iPhone X [4]. An optical beam scanner is a key element for use in various applications such as laser displays, laser sensors and free-space optical communications. A mechanical beam scanner has been widely used, but non-mechanical solid-state scanner is attracting much attention for compact LiDAR applications in recent days. Phased array beam steering devices based on silicon photonics were reported [5, 6], but there still remain critical issues to be solved. We proposed and demonstrated a beam steering device based on a VCSEL structure, showing the record high-resolution beam steering [7]. But it is a passive device and it is a challenge to obtain high output power, which typically needs over 10W for LiDAR applications. In this paper, our recent activities of VCSEL photonics for 3D optical sensing will be reviewed. We demonstrate mm-long VCSEL amplifiers, which show a narrow divergence and a quasi-single mode operation under high power pulsed operations. The power scalability is discussed for use in 3D sensing. In addition, we present a VCSEL amplifier with a folded-path slow-light waveguide layout, which functions as a dot projector without extra optics by scanning a dotted line beam.

2. VCSEL Amplifier

A schematic of the slow light VCSEL amplifier is shown in Fig. 1 [8]. It is similar to our reported beam scanner based on a Bragg reflector waveguide structure [7]. A portion of the propagating light radiated from the amplifier surface which forms a uniform wave fronts. The light decays exponentially due to radiation and absorption loss, but its intensity becomes uniform along the VCSEL amplifier by injecting a current above the lasing threshold of the VCSEL. In this case, the power of the amplified light is proportional to the amplifier length, and the beam divergence is getting smaller and smaller with increasing the length. Figure 2(a) shows the L/I characteristic for a 2 mm long amplifier under pulsed operation [9]. The lasing spectra are also shown in the inset.

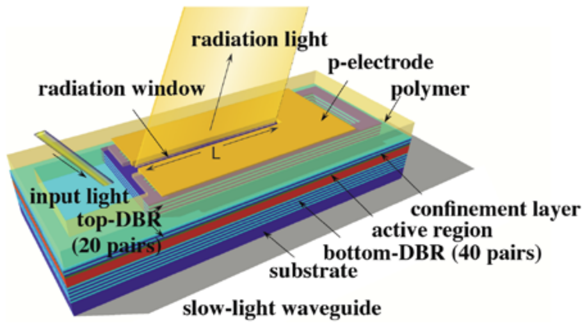


Fig. 1 VCSEL amplifier with beam scanning function.

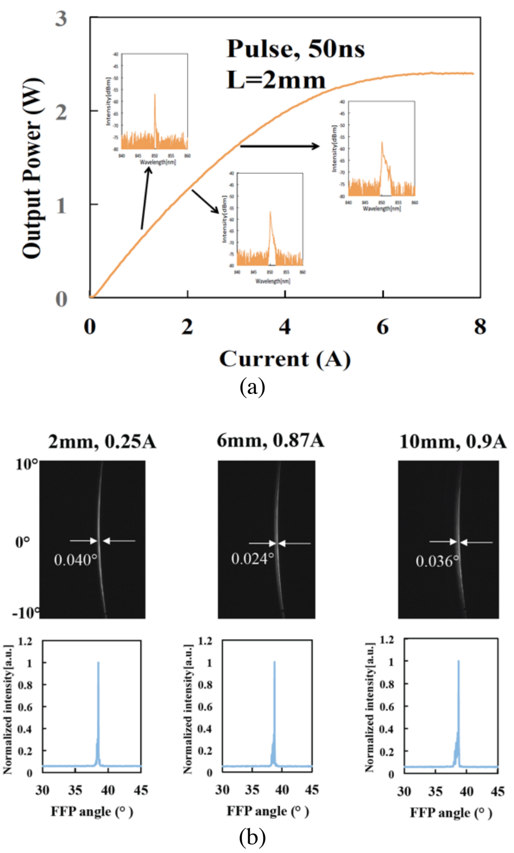
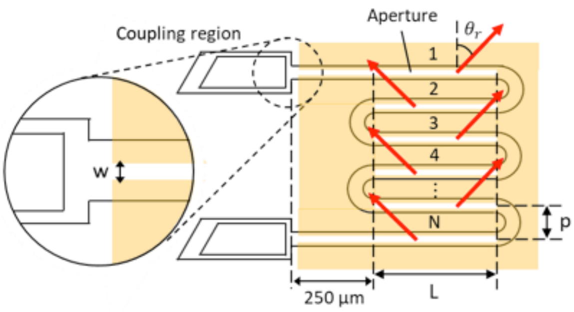


Fig. 2 (a) L/I characteristic and (b) FFPs of VCSEL amplifier.

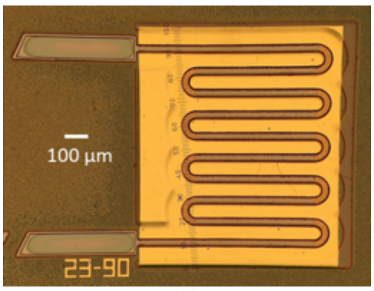
A quasi-single mode operation was realized with pulsed output power of over 1.5 W. The transient thermal chirp and unwanted other slow-light modes deteriorate the single-mode characteristics at higher injection currents. We also measured the far field pattern (FFP) as shown in Fig. 2(b). The device emits a fan-beam. A narrow divergence of 0.024° in the propagation direction was obtained for a 6mm-long device. The scalability and beam steering function will be discussed in the conference.

3. VCSEL Dot Projections

We proposed a VCSEL amplifier with a folded-path slow-light waveguide layout. The device offers the dot projection without extra optics by scanning laser wavelength [10]. Figures 3(a) and (b) show the schematic and photo of the device we fabricated [10]. This device consists of a long VCSEL amplifier with folded waveguide array at a fixed interval. The epi-wafer structure is the same as conventional 980 nm VCSELs. The top electrode covers the turning part so that the output beam is radiated only from the straight part. The oxide confinement enables us to reduce the bent radius of the waveguide to 20 µm and hence the total chip size is sub-mm. Input light from a tunable laser is coupled through a lensed fiber to the amplifier. Light output is radiated in two different directions as illustrated in Fig. 3(a). Because of only one group of the beam can be measured with a camera, we observed the beam emitted from the odd-numbered waveguides.



(a)



(b)

Fig. 3 (a) Schematic and (b) photo of a fabricated VCSEL amplifier dot projector [10].

Dotted line pattern is obtained in a direction perpendicular to the light propagation direction thanks to the interference of beams emitted from odd-numbered waveguides. The dotted line pattern can be swept in the light propagation direction by changing the wavelength, and the scanning angle was about 20°. Figure 4 shows the superimposed images of FFP at different wavelengths. The total number of dots is around 2,850 in a view angle of 20° × 20°. It is noted that the number of dots can be increased in proportion to the device length and total array width, thus the square of the device footprint. It could be scalable up to a few tens thousands dots or much larger without any extra optics such as DOE in mm size devices.

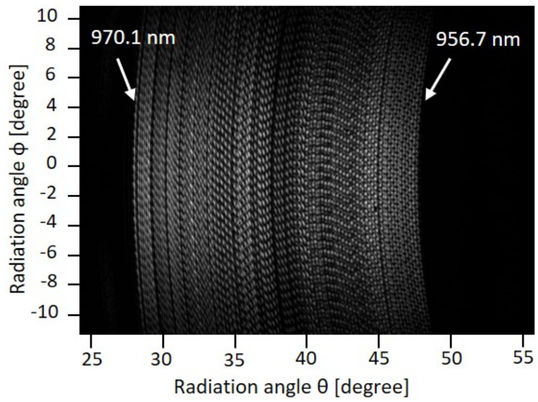


Fig. 4 Superimposed FFPs with scanning the wavelength.

4. Conclusions

A high power VCSEL amplifier was proposed and demonstrated, exhibiting high-power and beam scanning functions. The modeling predicts output of over 100 W for cm-long amplifiers. The output power of over 1W with high beam quality was experimentally presented. A narrow divergence angle of < 0.04°, which is nearly diffraction limited, gaves us a number of resolution-points of over 500. Also, an on-chip amplifier integrated tunable VCSEL was demonstrated, and its electrical beam scanning performance was clarified. The proposed device offers an opportunity of high-beam quality and high-power operations, which will be useful for LiDAR applications and compact structure light sensing systems.

Acknowledgements

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