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# Surface Grating VCSEL-Integrated Amplifier/Beam Scanner with High Power and Single Mode Operation

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## INTRODUCTION

While the output power of a conventional single mode VCSEL is limited to several mw due to its small aperture size, applications such as laser manufacturing and LiDAR require a high power VCSEL with good beam quality [1]. However, increasing the output power of VCSELs is a critical issue. Although two-dimensional VCSEL arrays can provide kW-class output power, but there still remains difficulties in their poor beam quality [2]. In our group, we proposed and demonstrated the slow light VCSEL amplifier with high output power over 8W [3]. In the amplifier, an external light source is needed as a seed light. We also demonstrated a VCSEL integrated amplifier [4] which is free of an external light source for making the device compact, but the coupling power from the VCSEL side to the amplifier side is below 1mW, which limits the amplified single mode output power to around 40mW. There still remain challenges in increasing the coupling power in order to further enhance the amplified power. In this paper, we demonstrate a single-mode surface-grating VCSEL-integrated amplifier/beam scanner. Coupling power from the slow-light laser to the amplifier can be enhanced due to the larger power of the seed laser itself, which enables us to largely increase the amplified output power.

## SCHEMATIC STRUCTURE

The schematic structure of our integrated device is illustrated in Fig. 1(a). Proton is implanted between the VCSEL and amplifier section for electrical isolation. The surface of the VCSEL section is periodically wet-etched by 60 nm. Since the effective index of the slow light mode of VCSELs in the etched region is different from that of the un-etched region, lateral Bragg-grating mirrors are formed. A single slow-light mode nearly at the Bragg-wavelength can be selected due to optical feedback which is similar to the situation of a DFB edge emitting laser. 5 pairs of  $\text{SiO}_2/\text{Ta}_2\text{O}_5$  dielectric DBR are deposited on the top of the seed VCSEL to inhibit the emission to the upper side. The top view of a fabricated device is shown in Fig. 1 (b). The oxidized aperture size of the seed laser is  $400\mu\text{m} \times 4\mu\text{m}$  and the length of the amplifier is 1mm. The Bragg-wavelength is designed at 845 nm and the grating pitch is  $3\mu\text{m}$  for 5th-order grating, which was formed by a matured laser lithography.

## EXPERIMENTAL MEASUREMENTS

Figure 2 shows the L/I characteristic when the amplifier is also pumped with and without coupled light from the seed VCSEL. By pumping the amplifier with pulse current with a pulse width of 100 ns, we could avoid the heating effect. With a seed light, the output power increases noticeably, which gives a clear evidence of the amplification of the slow light mode from the seed VCSEL. The amplified power is around 500 mw. Further increase in the single-mode power can be expected.

Figure 3 shows the measured far-field pattern (FFP) with pumping the amplifier section and laser section both, showing a diffraction-limited narrow beam divergence of  $0.06^\circ$  at an angle of around  $40^\circ$ . The lasing wavelength of the seed VCSEL can be tuned continuously through changing current injection thanks to a thermal effect. We could continuously steer the beam deflection angle while fixing the amplifier current at 200mA. The total steering range is around  $1.5^\circ$  with a number of resolution point of around 25.

## CONCLUSIONS

We demonstrate a surface-grating VCSEL-integrated amplifier/beam scanner with an output power of over 500mW under pulsed operation. Also we realized continuous fan beam steering of  $1.5^\circ$  and a diffraction-limited narrow beam divergence of  $0.06^\circ$ . The output power can be boosted by increasing the amplifier length. Further increases in the single mode power toward W-class operation can be expected.

## ACKNOWLEDGEMENT

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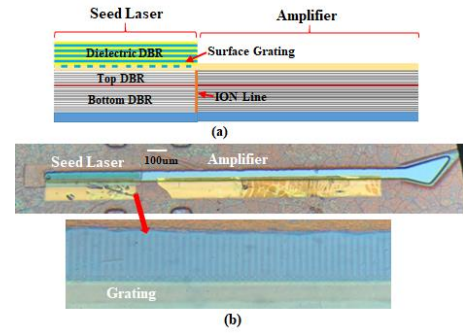


Fig. 1 (a) Side view of the schematic structure (b) Top view of a fabricated device

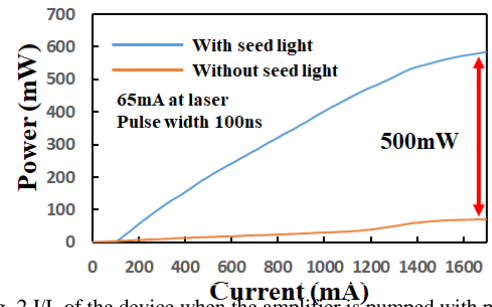


Fig. 2 L/I of the device when the amplifier is pumped with pulse current with and without seed light

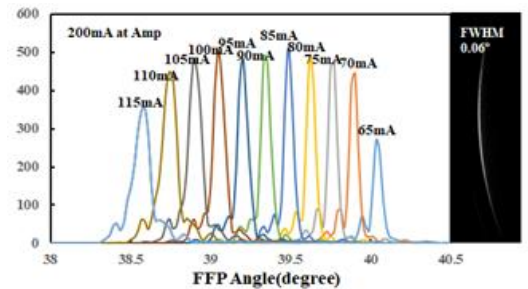


Fig. 3 L/I of the device with a seed light from the VCSEL