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High power stable single-fundamental mode vertical cavity surface-emitting lasers with a zinc diffused absorber

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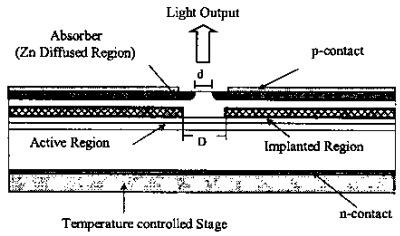
1. Introduction

Vertical-cavity surface-emitting lasers (VCSELs) have emerged as important light sources for the data communication, optical interconnects, and optical storage. Higher output power (> 3 mW) and stable single-fundamental mode operation is very desired for many applications, such as free-space reading/writing in the storage system, and optical link in one- and two-dimensional interconnects. We may define the stable single-fundamental mode operation as a lasing that can maintain single-fundamental mode emission over the entire drive current range above the threshold. Although various device structures have been attempted, including the proton-implant and oxide confined VCSELs, only few can exhibit both high power and stable single-fundamental mode operation.[1,2] To obtain a stable single-fundamental mode operation, usually the active region of the VCSELs required to be less than ~5 μm diameter[1,2] formed by either proton-implant or oxidation. Since the active region of the single mode VCSELs is usually small resulting in a large series resistance and serious ohmic heating, which in turn limits the maximum drive current and the output power of the devices. In this letter, we report that a VCSEL with a ~10 × 10 μm^2 active region confined by proton-implant and a ~5 × 5 μm^2 absorber aperture formed by zinc diffusion exhibited a stable single fundamental mode emission[3] with a maximum power of 3.2 and 4.4 mW at room-temperature and –7°C respectively. The active region with a larger area allowed more current injection resulting a high output power, while the absorber suppressed the higher-order mode and maintained a stable single-fundamental mode operation over the entire drive current range.

2. Device Structure and Fabrication

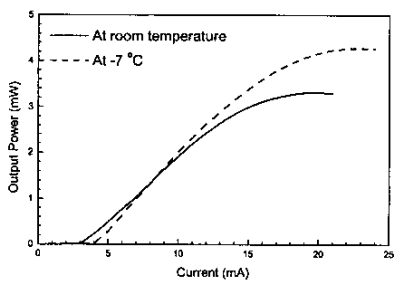
The epilayer used for the device fabrication was a typical implanted VCSEL structure grown by metalorganic chemical vapor deposition (MOCVD), consisted of a heavily carbon doped p-type GaAs cap layer, a 30-pair p-type and a 20-pair n-type $Al_{0.12}Ga_{0.88}As$/AlAs distributed Bragg reflectors with compositional grading at each interface, that sandwiched a three GaAs/AlGaAs multiquantum well (MQW). Fig. 1 shows the device mounted junction up on a copper heat sink with its temperature controlled by a thermalelectric (TE) cooler. The device was fabricated as follows: First, a Si_3N_4 mask with 5 × 5 μm^2 squares was formed photolithographically on the sample, then the masked sample and a Zn_3As_2 source were sealed in a vacuumed quarts ampoule and put into a 650 C furnace for 8–10 min zinc diffusion. A higher-order mode absorber with a shallow zinc diffusion region of ~0.6 μm thickness was formed surrounding the 5 × 5 μm^2 Si_3N_4 masked areas as our previous work.[3] Using a photoresist layer as a mask, a proton implantation was conducted on the zinc diffused sample to form a ~10 × 10 μm^2 cur rent confined active region. A Cr/Au film with an opening window and a Ni/Ge/Au film was deposited on the top and bottom of the sample to form a p- and n-type electrode respectively.



TuW2 Fig. 1. Schematic diagram of the single-fundamental mode VCSEL.

3. Device Characteristics

Fig. 2 shows the light output versus current characteristics at both room temperature at –7°C of a fabricated device with a ~10 × 10 μm^2 active region and an absorber with a ~4 × 4 μm^2 aperture formed by Zn diffusion. The light output power was measured using a calibrated Newport silicon p-i-n photodetector. At room temperature (25°C) a maximum output power of 3.2 mW was obtained at a current of ~20 mA. The corresponding spectra shown in Fig. 3 indicate that a single mode operation with a higher-order mode suppression ratio better than 30 dB started at a current level (5 mA) just above the threshold current (3 mA) and maintained stable up to the maximum drive current where the output power saturated. According the model in our previous work,[3] given a ~0.6 μm thick absorber the higher-order modes will have a threshold gain 3 times larger than that of the fundamental modes. As a consequence, only the fundamental mode can lase and sustain at all the drive current levels, while the higher-order modes will be suppressed. The threshold current at –7°C was slightly higher than that at room temperature., mainly due to the detuning between the gain peak and cavity mode at lower temperature. A maximum power of 4.4 mW was obtained at ~20 mA for low temperature (–7°C) operation, which was 40% larger than that at room temperature. The high output power of single fundamental mode obtained in this device is attributed to a relatively large active region compared to the other single mode devices and an effective higher-order mode absorber that allow a higher drive current, while maintaining a stable single mode operation.



TuW2 Fig. 2. L-I curves for both room temperature and –7°C.

In conclusion, we have demonstrated a stable single-fundamental mode VCSEL with a maximum output power of 3.2 and 4.4 mW at room temperature and –7°C respectively. The single mode operation was obtained using a higher-order mode absorber formed by Zn diffusion with a mode suppression ratio better than 30 dB. With optimization on the device structure a single mode output power larger than 5 mW.

References

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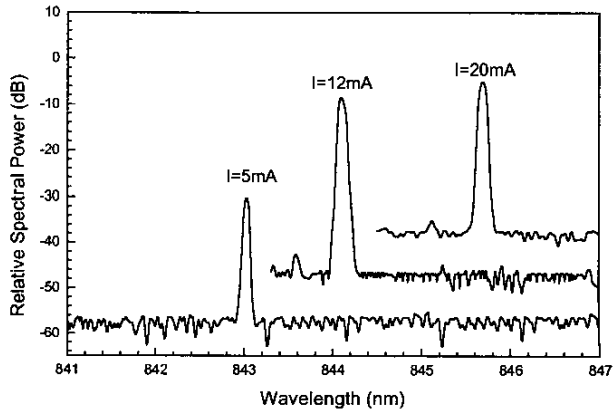

TuW2 Fig. 3. Emission spectrum of the single-fundamental mode VCSEL at different current levels.