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Stable single-mode 850 nm VCSELs with a higher-order mode absorber formed by shallow Zn diffusion

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Abstract: We report that an 850 nm VCSEL with a planar higher-order mode absorber formed by shallow Zn diffusion (< 0.3 μm deep) operated at stable single-mode. A 5 μm square device showed single-mode emission with a ~ 0.8 mA threshold, a 2.2mW maximum output power, and a mode suppression ratio of 40 dB.

In recent years the 850 nm VCSEL has been adopted in gigabit-Ethernet for local area network (LAN). It has been realized that the modulation bandwidth can be maximized by maintaining the VCSEL in stable single-mode operation [1]. Various VCSEL structures are fabricated, but only few devices exhibited stable single-mode emission [2]. In this letter we report that a VCSEL with a higher-order mode absorber formed by shallow Zn diffusion operated at stable single-mode over the entire drive current range with a minimum threshold current of ~0.8 mA, a maximum power of 2.2mW, and a maximum mode suppression ratio of 40 dB. The Zn diffused region was formed selectively outside the 5 μm square masked area with a very shallow diffusion depth (< 0.3 μm deep) corresponding to less than 2 DBR pairs, which minimized the optical loss due to the free carrier absorption for the fundamental mode [3,4], while still preserved the strong absorption and formed an effective absorber of the higher-order modes.

The completed device shown in Fig. 1 was fabricated on a wafer with a MQW active layer sandwiched by 20 pairs p-DBR and 30 pairs n-DBR as a typical oxide confined VCSELs, except that the sample with a Si_3N_4 squares mask was conducted < 8 min short time Zn diffusion to have a shallow diffusion depth (0.2-0.8 μm deep) outside the Si_3N_4 masked area to form the higher-order mode absorber. The devices with the absorber (Zn diffused region) apertures of 5 and 10 μm squares and the oxide confined active regions of 5, 10, and 15 μm squares were fabricated to investigate the aperture and active region size effects on the mode selection respectively. It was consistently shown that near 100 % devices with a 5 μm absorber aperture exhibited stable single-mode operation, while the device with a 10 μm absorber aperture showed multimode emission. The results also showed that mode behavior was independent of the conducted oxide confined size (5, 10, and 15 μm), which indicated that the mode behavior of this VCSEL can be fully determined by the size of absorber aperture.

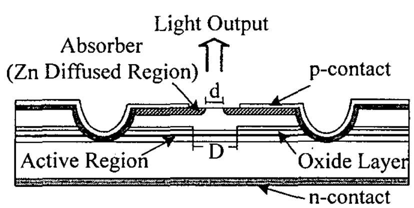
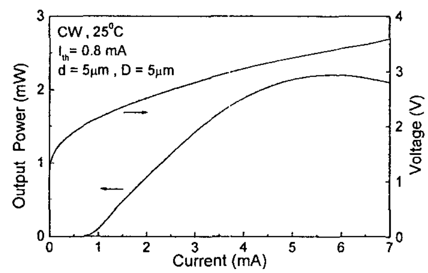
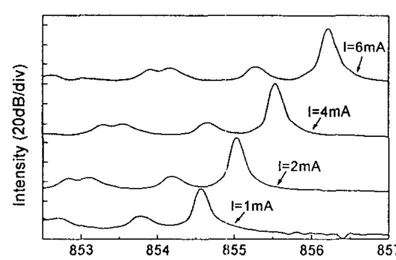


Fig. 1. Schematic diagram of a VCSEL with a higher-order mode absorber formed by shallow Zn diffusion.



(a)



(b)

Fig. 2. (a) The typical light output and voltage versus current characteristics of a VCSEL with a 5 μm square absorber aperture and a 5 μm square oxide confined active region. (b) The emission spectra at different current levels.

Fig. 2(a) shows the light output and voltage versus current characteristics of a VCSEL with a 5 μm absorber aperture and a 5μm oxide confined active region. Fig. 2(b) shows the corresponding emission spectra of the device at different current levels, indicating the device operated at single-mode with a higher-order mode suppression ratio of better than 40 dB up to the maximum drive current where the output power saturated. The Zn diffusion depth of this device was only ~ 0.25 μm. The performance with a threshold current of ~ 0.8 mA and an output power of ~ 2.2 mW on this device was obtained, which was much better than that of the VCSEL with zinc diffusion through the entire top DBR [3]. The laser with a 5 μm absorber aperture was also in contrast to the previous work [4], in which the device with a < 7 μm absorber aperture could not lase due to the optical loss in the Zn diffused region. These results indicated that the optical loss of the fundamental mode has been minimized in this VCSEL by shallow Zn diffusion.

To study the effect of the Zn diffusion depth on the single-mode control, the Zn diffusion was conducted on the wafer with a 5 μm squares mask for1, 3, 5, and 8 min, resulting in the diffusion depths of <0.1, 0.25, 0.5 and 0.8 μm respectively. The results showed that all the devices but the one with < 0.1 μm diffusion depth exhibited stable single-mode emission. The threshold gain versus the diffusion depth is calculated on the VCSEL using a transmission matrix model. The calculated results show that the required threshold gain for the higher-order mode will increase monotonically with the diffusion depth and be at least two times larger than that of the fundamental mode as long as the diffusion depth is over ~ 0.1 μm, which agrees well with the experimental results. These results lead to a simple and reliable process for the fabrication of single fundamental mode VCSELs.

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