



The effect of indium tin oxide as an ohmic contact for the 850 nm GaAs oxide-confined VCSELs

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Abstract

In this article, we report the effect of indium tin oxide (ITO) as a p-type ohmic contact for the 850 nm GaAs oxide-confined vertical-cavity surface-emitting lasers (VCSELs). The VCSELs with ITO contact have a threshold current of 0.96 mA, a full-width-at-half-maximum angle of beam divergence of 27° and an ellipticity of 103.8% for the far-field pattern at a 10-mA driving current, which are the same as those of the conventional VCSELs with Au/Zn/Au or Ti/Pt/Au ohmic contacts. In addition, the VCSELs with ITO contact exhibit a light output power of 1.27 times in magnitude higher than those of the conventional VCSELs.

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Keywords: Vertical-cavity surface-emitting lasers; Indium tin oxide

1. Introduction

Vertical-cavity surface-emitting lasers (VCSELs) are interesting light sources for the optoelectronic industry, because they offer potentially low fabrication and packaging cost. They have a high potential for various applications in optical communication, optical computing, optical interconnects, and optical storage. Over the past few years the excellent performance of oxide-confined VCSELs has been reported in the literatures in terms of low threshold current [1], high wallplug efficiency [2,3], and others [4]. A VCSEL is normally pumped electrically through the top and bottom mirrors and the light is extracted either from the top or through the substrate. Since the conventional p-type ohmic contact uses Au/Zn/Au or Ti/Pt/Au, the opaque property of these metal materials must obstruct the lasing light

output and thus reduce the light power. Previous workers have investigated the use of indium tin oxide (ITO) films because of their high-electrical conductivity and high-optical transparency [5]. ITO films have a widespread use as transparent electrodes not only for liquid crystal flat panel displays [6], but also for optical devices such as light-emitting diodes [7] and laser diodes [8–10]. In this article, we report the effect of ITO film as a p-type ohmic contact for the VCSELs on the characteristics of threshold current, light output power, and beam divergence and ellipticity of far-field pattern.

2. Device structure

The VCSEL epitaxial layers were grown on an n-type GaAs substrate by organometallic vapor phase epitaxy. The bottom Bragg reflector consists of 23 n-type Si-doped $\text{Al}_{0.9}\text{Ga}_{0.1}\text{As}/\text{Al}_{0.15}\text{Ga}_{0.85}\text{As}$ pairs with quarter-wavelength-thick layers. The active region contained four GaAs– $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$ quantum wells designed for 850 nm peak gain wavelength. The p-type top Bragg reflector

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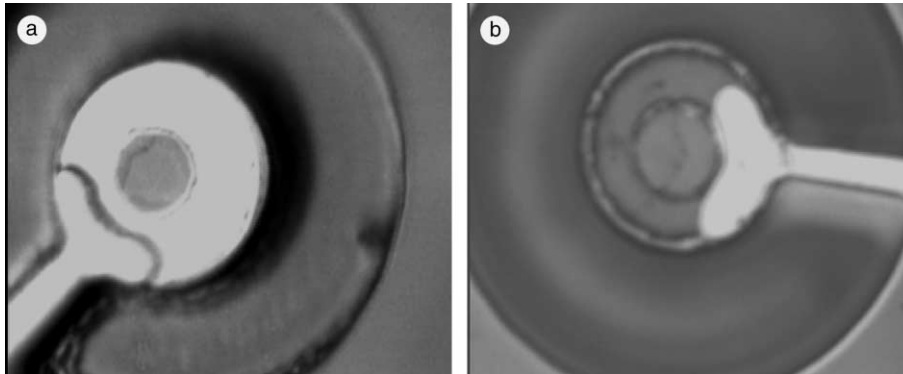


Fig. 1. The schematic top views of the fabricated oxide-confined GaAs VCSELs with (a) Ti/Au and (b) ITO ohmic contacts.

consists of 34 C-doped $\text{Al}_{0.9}\text{Ga}_{0.1}\text{As}/\text{Al}_{0.15}\text{Ga}_{0.85}\text{As}$ pairs. A 20 nm $\text{Al}_{0.98}\text{Ga}_{0.02}\text{As}$ layer used for the subsequently selective oxidation was placed in the first quarter-wavelength layers above the cavity region. As reported previously, this layer is shifted towards a node of the standing-wave pattern to reduce the built-in effective index guiding and the optical losses [11]. Using a thick SiN_x film as mask, a 5 μm -depth trench linking a letter “C” was formed by dry etching. The 3 μm -width bridge, which was not formed as the trench on the p-side surface, can prevent the connecting metal of ohmic contact and bonding pad from being broken since the metal has to cross the 5 μm -depth ring trench. Then the wafer was oxidized in a $\text{N}_2/\text{H}_2\text{O}$ atmosphere at a temperature of 425 $^\circ\text{C}$ for about 58 min to get a 10 μm -diameter aperture. After coating a thin SiO_2 passivation layer on the wafer, a p-type ring contact deposited on the top of the 22 μm -width mesa and a Ge/Ni/Au broad-area contact on the lapped n-type GaAs substrate side, both of which were annealed. There are two p-type contact materials were used in this study. One is the conventional metal Ti (100 \AA)/Au (2000 \AA) and the other is ITO film (1650 \AA), both were coated by E-beam evaporation. In order to form a good ohmic contact, the conventional Ti/Au metal needs a rapid thermal annealing at 500 $^\circ\text{C}$. However, the ITO film coated by E-beam evaporator can be a good ohmic contact without annealing. This can prevent the oxidized layer from being cracked. The device process was completed by depositing a TiAu bonding pad on the wafer. Fig. 1 shows the schematic top views of the fabricated GaAs oxide-confined VCSELs with (a) Ti/Au and (b) ITO ohmic contacts.

3. Results and discussion

Fig. 2 shows the reflectivity as a function of wavelength for the thickness of 1230, 1400, and 1650 \AA of the

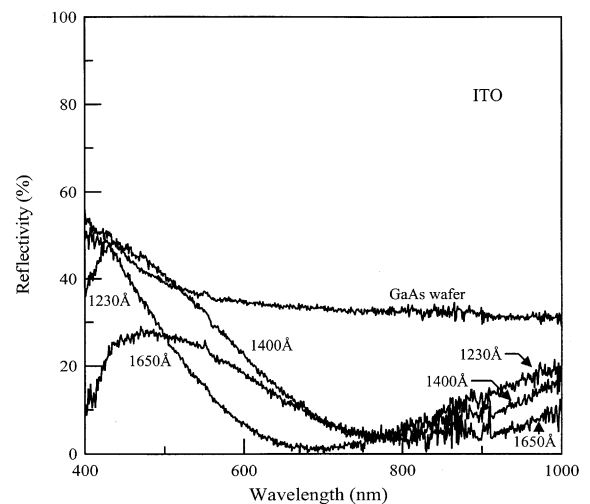


Fig. 2. The reflectivity as a function of wavelength for the thickness of 1230, 1400, and 1650 \AA of the ITO films coated by E-beam evaporator.

ITO films coated by E-beam evaporator. At 850 nm wavelength, the 1650- \AA ITO film exhibits the lowest reflectivity, which is the optimum condition to extract the light output from the VCSELs. Fig. 3(a) and (b) shows the light output power and voltage as a function of injected current (L - I and V - I) for the VCSELs with ITO and Ti/Au contacts, respectively. It can be observed that both the two devices typically have a nearly same threshold current of 0.96 mA (for L - I characteristic) and threshold voltage of 1.62 V (for V - I characteristic) while the VCSEL with ITO contact exhibits a maximum output power of about 6 mW at 12 mA, which is higher than that of 4.7 mW for the device with conventional contact. Since the oxide aperture and the contact aperture have a similar diameter of about 10 μm , the ratio is in agreement with our calculation. The little difference may come from the alignment of the ring contact and

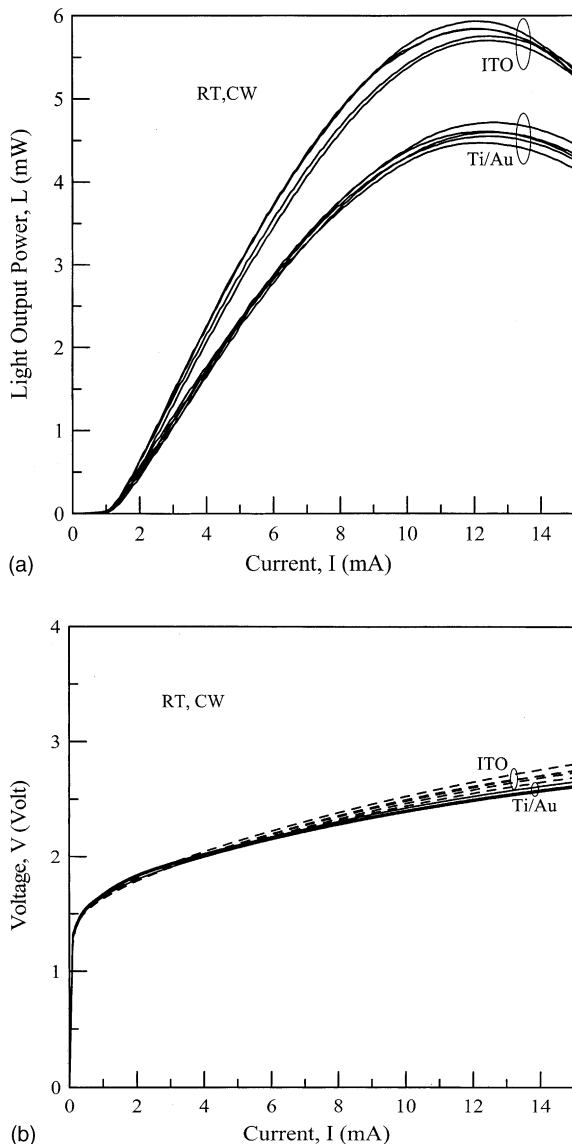


Fig. 3. (a) CW light output power and (b) voltage as a function of injected current (L - I and V - I characteristics) for the oxide-confined VCSELs with ITO and Ti/Au contacts for the 10 μm -current-confined aperture.

the oxide aperture. As shown in Fig. 3(b), the device with ITO contact has a series resistance of 62 Ω , which is slightly higher than that of 57 Ω for the conventional device. This result is consistent to the work reported by Chua et al. [10]. Nevertheless, the ITO film was not annealed; it still exhibits a high-optical transparency and high-electrical conductivity to be suitable for use as a transparent electrode for VCSELs.

Fig. 4 displays the lasing spectra at a driving current 0.96 mA for both devices. The device with Ti/Au contact

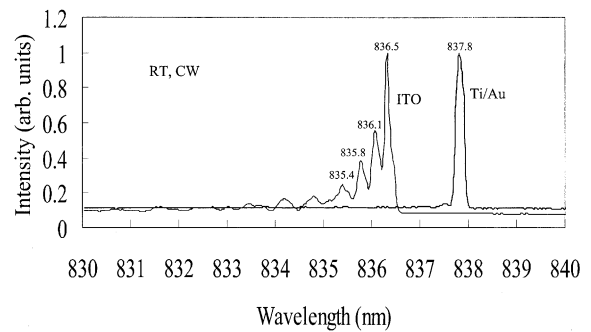


Fig. 4. The lasing spectra at a driving current 0.96 mA for the two devices.

shows a nearly single mode spectrum and a lasing peak at 837.8 nm. On the other hand, the device with ITO contact has other transverse modes and a main lasing peak at 836.5 nm. The wavelength difference between these devices maybe comes from the non-uniformity of quantum well in the epi-wafer during epitaxial growth.

Fig. 5 shows the measured far-field pattern for the two devices at a driving current of 10 mA. Both the two VCSELs have a full-width-at-half-maximum (FWHM) angle of beam divergence of about 27°. Unlike the edge-emitting laser, these VCSELs give a smaller ellipticity of 103.8%. Fig. 6 displays the far-field pattern for the VCSEL with Ti/Au contact, which the metal contact aperture is not aligned to the oxidized aperture. The FWHM angle of beam divergence is more than 30° and its lasing peak will shift to 839.0 nm because of its longer vertical cavity. This problem can be overcome by using the ITO contact in the VCSELs.

4. Conclusions

We have demonstrated the effect of ITO as a p-type ohmic contact for the 850 nm GaAs oxide-confined VCSELs. The ITO film can be formed as a good ohmic contact without any annealing and exhibits a high-optical transparency and high-electrical conductivity. As compared to the VCSELs with conventional Ti/Au contact, the VCSELs with ITO contact have a nearly low threshold current of 0.96 mA and a threshold voltage of 1.62 V. On the other hand, the VCSELs with ITO contact have a maximum output power of 6 mW, which is 1.27 times in magnitude higher than the VCSELs with Ti/Au contact. For the measured far-field pattern at a driving current of 10 mA, both the devices have an FWHM angle of beam divergence of 27°. From above description, the oxide-confined VCSELs with ITO contact can be fabricated in a much simple photolithographic process and are more suitable to the fiber connection than the edge-emitting laser.

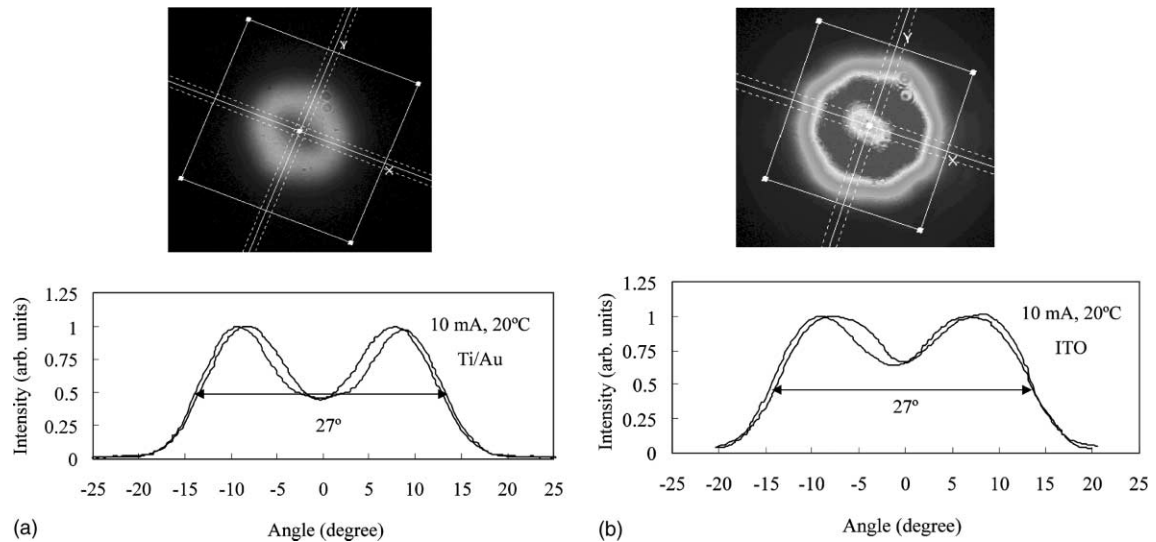


Fig. 5. The measured far-field pattern for the two devices with (a) Ti/Au and (b) ITO contacts at a driving current of 10 mA.

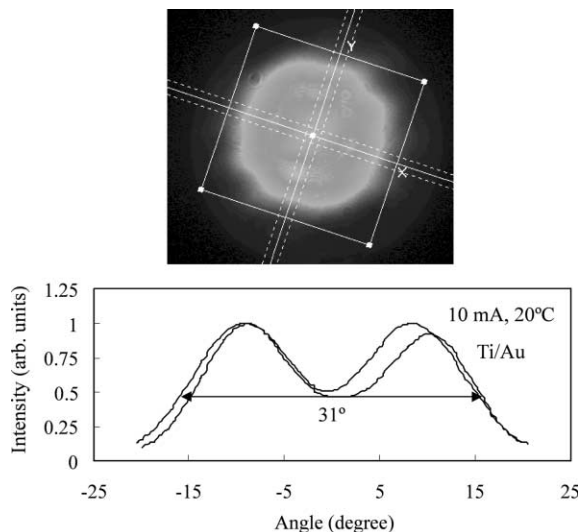


Fig. 6. The far-field pattern for the VCSEL with Ti/Au contact. The metal contact aperture is not aligned to the oxidized aperture.

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