

Improvement of kink characteristic of proton implanted VCSEL with ITO overcoating

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ABSTRACT

Proton implanted VCSEL has been demonstrated with good reliability and decent modulation speed up to 1.25 Gb/s. However, kinks in current vs light output (L-I) has been always an issue in the gain-guided proton implant VCSEL. The kink related jitter and noise performance made it difficult to meet 2.5 Gb/s (OC-48) requirement. The kinks in L-I curve can be attributed to non-uniform carrier distribution induced non-uniform gain distribution within emission area. In this paper, the effects of a Ti/ITO transparent over-coating on the proton-implanted AlGaAs/GaAs VCSELs (15 μ m diameter aperture) are investigated. The kinks distribution in L-I characteristics from a 2 inch wafer is greatly improved compared to conventional process. These VCSELs exhibit nearly kink-free L-I output performance with threshold currents \sim 3 mA, and the slope efficiencies \sim 0.25 W/A. The near-field emission patterns suggest the Ti/ITO over-coating facilitates the current spreading and uniform carrier distribution of the top VCSEL contact thus enhancing the laser performance. Finally, we performed high speed modulation measurement. The eye diagram of proton-implanted VCSELs with Ti/ITO transparent over-coating operating at 2.125 Gb/s with 10mA bias and 9dB extinction ratio shows very clean eye with jitter less than 35 ps.

KEYWORDS: VCSEL, Proton implant, ITO, Kink, kink improvement, High-speed operation, uniform carrier distribution

1. INTRODUCTION

The vertical cavity surface emitting lasers (VCSELs) have generated research and commercial interests worldwide, because VCSELs possess several unique features over the edge emitting lasers. The VCSELs emit circular emission beam with low divergence, making optical fiber coupling efficient and easier than the edge

emitting Lasers. The VCSELs can be tested on wafer level before packaging, and can be easily fabricated into dense 2-dimensional laser arrays. Currently, there are two main categories of VCSELs namely oxide-confined VCSELs and proton implanted VCSELs. The oxide confined VCSELs have an oxidized boundary surrounding the emitting aperture for index-guiding and current confinement resulting well defined transverse modes at low bias current [1, 2]. However, the oxide VCSELs have a few technical issues. The oxidation procedure depends strongly on materials and processing parameters which could change during the process making control of the aperture size relatively difficult. In addition, the strain and defects introduced by the oxidation process have shown to cause reliability problem [3]. Compared to the oxide-confined VCSELs, the proton implanted VCSELs have a relatively simple fabrication process and have been demonstrated with good reliability [4]. However, due to the gain-guided nature of the proton implanted VCSELs, the kink in light output power versus current (L-I) has been an issue [5], and the laser power output jitter and noise also tend to limit the modulated speed around 1.25 Gb/s [4] that hardly meets the 2.5 Gb/s (OC-48) requirement. Earlier reports on edge emitting lasers related kinks in L-I curve to the spatial hole-burning [6], mode hopping [7] and mode jumps due to an increase in the injection current [8]. Therefore, the frequency of lasing mode could be affected by the fluctuation and non-uniformity in both junction temperature and injected carrier density [9]. For the VCSELs, the reports also indicated the transverse mode structures depend on the drive current,[10] and the injection current from the periphery of the top contact aperture into the active region tends to cause current crowding and non-uniform current spreading [11-14]. Such non-uniform current spreading might lead to the kinks in L-I curve. Therefore the improvement of current spreading and reduction of current in VCSELs could reduce the kinks and thus improve the device modulation speed.

Recently there were reports using of transparent indium-tin-oxide (ITO) to replacing regular Ti/Au or Ti/Pt/Au p-contact of the VCSELs and showed that the ITO has good ohmic contact similar to the regular contact and increase contact transparency. These include the use of ITO [15, 16], Au-plated ITO [17] as the top contact and ITO as top ring contact [18]. However, the effect of these new contact scheme on the VCSEL performance such as kink characteristics of L-I curve, and modulation response were not clearly mentioned. In this paper, we report results of incorporation of a new p-contact scheme using Ti and ITO transparent overcoating on the regular p-contact of the implanted VCSEL that show substantial improvement in the kink characteristics in L-I curve, and the modulation response of the VCSEL.

2. EXPERIMENT

The GaAs VCSEL wafer structure was grown on the n⁺-GaAs substrate by a metal organic chemical vapor deposition system. The bottom DBR consists of a 30.5-period n-doped quarter-wave stack of Al_{0.12}Ga_{0.88}As/AlAs and the top DBR consists of 19.5-period p-doped Al_{0.12}Ga_{0.88}As/AlAs. The graded-index separate-confinement heterostructure active region has an undoped three-quantum-well (3QWs) GaAs/Al_{0.3}Ga_{0.7}As, a lower

linearly-graded undoped $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($x = 0.6 \rightarrow 0.3$) waveguide layer and an upper linearly-graded undoped- $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($x = 0.3 \rightarrow 0.6$) waveguide layer. A heavily C-doped p-type GaAs cap layer was grown to facilitate p-ohmic contact. The VCSELs were fabricated using a planar process. First, the VCSEL wafer was cleaned by acetone, isopropyl alcohol and D.I. water. Then a regular p-contact metallization of Ti (200 Å) / Au (1500 Å) were deposited by E-beam evaporator with 15µm diameter emission aperture and a contact pad size of 350×350 µm². Then a Ge (200 Å) / Au (400 Å) / Ni (140 Å) / Au (1500 Å) layer was deposited as the n-ohmic contact. The device was annealed in a rapid thermal annealing system at 380 oC under N₂ ambient for 30sec. The device was then subjected to the proton implantation with an energy of 200 KeV and a dosage of $1 \times 10^{15} \text{ cm}^{-2}$ with an aperture of 20µm diameter. All the VCSELs were tested prior to the overcoating. The tested VCSELs were then overcoated with Ti/ITO transparent film on top of the regular Ti/Au p-contact by RF sputtering. The thickness of Ti is 40 Å and the thickness of ITO (In₂O₃-SnO₂) is 3200 Å. The thin Ti film was chosen because of its high transparency (~ 92% at 850nm), low annealing temperature and good adhesive property and ohmic contact with GaAs. Subsequently, the device was annealed at 380oC under N₂ ambient for 30sec to form ohmic contact. The dimension of the transparent overcoating is 300×300 µm² slightly smaller than the regular p-contact pad size for easy probing. The schematic of the fabricated VCSEL device is shown in Fig. 1.

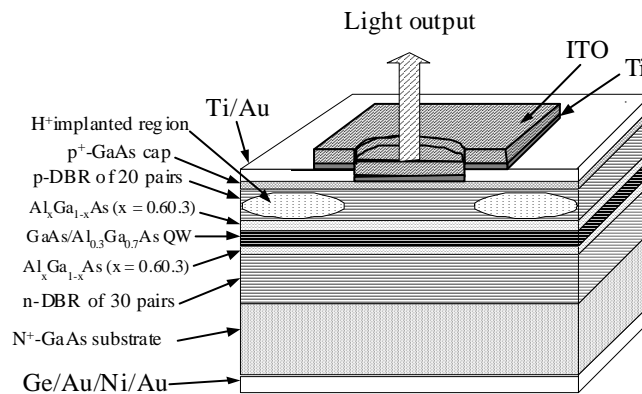


Figure 1. The schematic of the overcoated VCSEL device.

3. RESULTS AND DISCUSSION

Figs. 2(a), 2(b), and 2(c) show the comparisons of the L-I-V characteristics of three adjacent VCSELs before and after the Ti/ITO overcoating. The output power of VCSELs show almost the same after transparent overcoating, and all VCSELs only have slightly change in series resistance from 33Ω to 38Ω after Ti/ITO overcoating which

consist with the previous reports [16,18]. The L-I curves of the overcoated VCSELs show a substantial improvement in the kinks compared with the uncoated VCSELs. To quantify the kink characteristics in L-I curve, we define a Derivative Kink Factor (DKF) which measure the mean square deviation of the local slope from the average slope, normalized to the average slope of the L-I cure as show below:

$$Derivative\ Kink\ Factor = \frac{\left\langle \left(\frac{\partial L}{\partial I} - \left\langle \frac{\partial L}{\partial I} \right\rangle \right)^2 \right\rangle^{1/2}}{\left\langle \frac{\partial L}{\partial I} \right\rangle} \Bigg|_{L_{I_{th}}}^{L_{max}/2}$$

Where L is the light output power, I is the driving current, Lmax is the maximum light output power, and Lth is the light output power at the threshold. To minimize the effect of thermal rollover at higher power output, the DKF is only evaluated from threshold to Lmax/2. Table 1 shows the calculated values of DKF of these three devices for current range from the threshold to 15mA. The data indicate the DKF values of all these devices with overcoating reduce. In particular, the device1 and device3 show 3 to 6 time reduction while the device 2 also shows 24% reduction in DKF value. From the L-I curves and the estimated DKF values, the Ti/ITO overcoating clearly improves the kink characteristics of the implanted VCSEL.

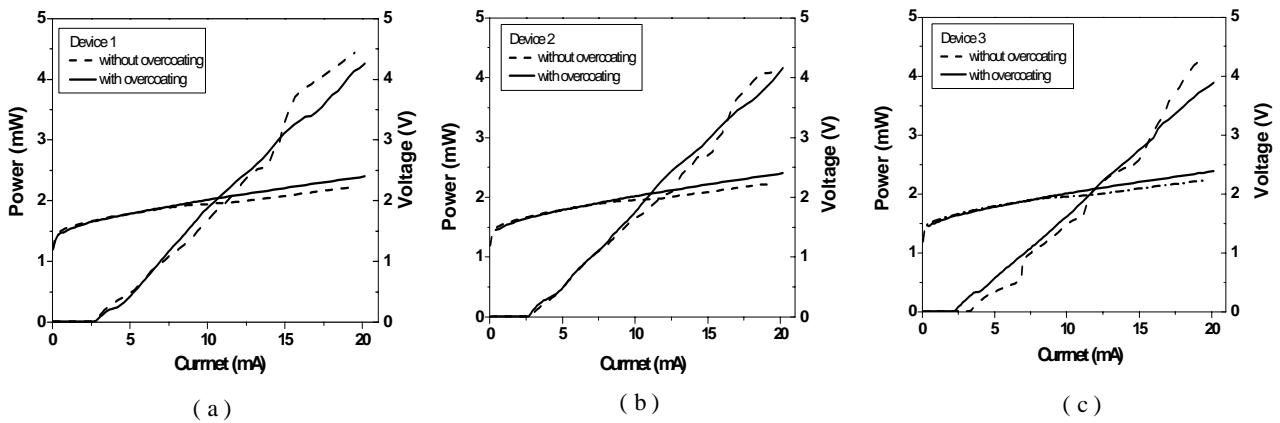


Figure 2. The L-I-V characteristics of the VCSELs with and without Ti/ITO transparent overcoating : (a) device1, (b) device2 and (c) device3.

Table 1. The derivative kink factors of three devices with and without Ti/ITO transparent overcoating.

	Device 1	Device 2	Device 3
Without Ti/ITO	0.62	0.26	1.05
With Ti/ITO	0.23	0.21	0.17

The device3 then was measured the eye diagram before and after Ti/ITO overcoating respectively operating at 2.125Gb/s with 10mA bias and 9dB extinction ratio. The uncoated VCSEL failed to pass the 2.125 Gb/s Eye-Mask and has a large jitter over 40ps. While the overcoated VCSEL showed a wide open eye pattern, and easily passed the 2.125 Gb/s with a jitter of less than 35ps. The result indicates the Ti/ITO overcoated VCSEL with lower DKF values has substantially improved in the high-speed performance characteristic.

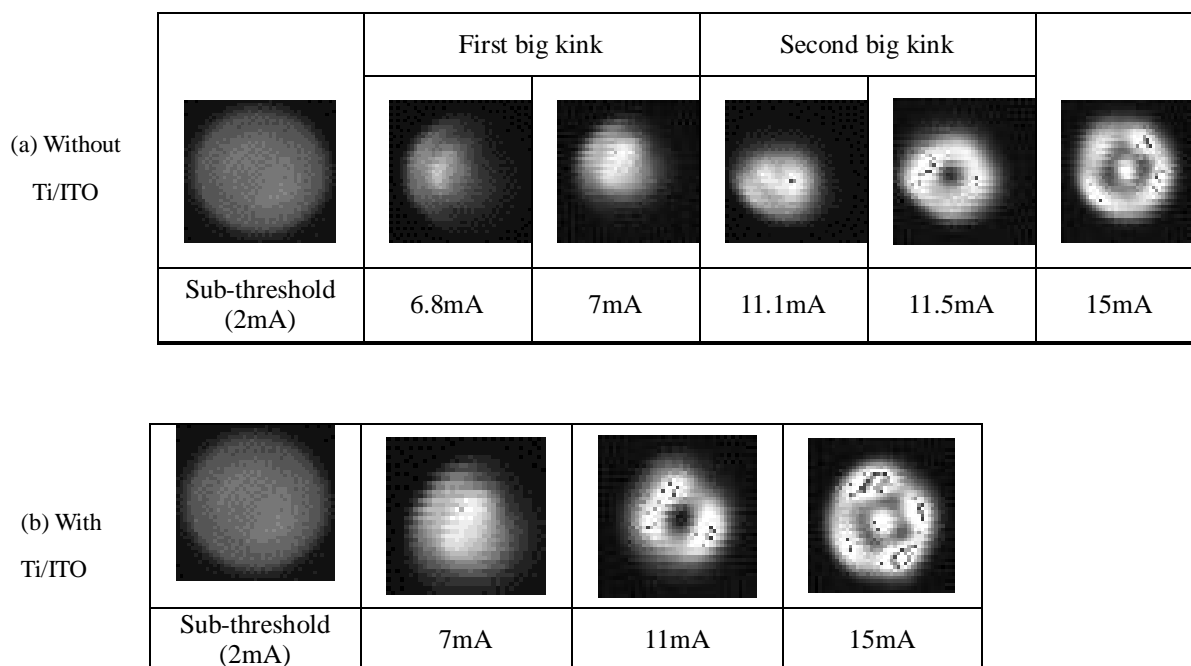


Figure 3. The near-field emission patterns of the VCSEL device 3 (a) without and (b) with Ti/ITO transparent overcoating at different injecting currents

The improvement in the kink characteristics and modulation response of the Ti/ITO overcoated implanted VCSEL maybe the result of better current injection and spread induced by the overcoating. Since the change of light

emission pattern correspond to the change of current injection density [6] into the VCSELs, Fig. 3(a) and 3(b) compare the near-field optical microscope images of the emission patterns of the VCSEL before and after overcoating in the currents which the kinks take place. Fig 3(a) clearly shows different lasing mode patterns when kink takes place in L-I curve, and Fig 3(b) shows that the overcoated VCSELs have more uniform and stable emission patterns at the same current level than the uncoated devices. The results seem to suggest that the overcoated VCSELs allow better uniform current injection than the uncoated devices resulting in better emission mode stability which could lead to the improvement in the kink characteristics and high speed response.

4. CONCLUSION

In summary, we demonstrated the enhancement in the performance of proton-implanted VCSEL by using a Ti/ITO overcoating on the regular p-contact. The kink characteristics of the VCSEL with the Ti/ITO overcoating show substantial improvement with as large as six fold reduction in the derivative kink factor. The high-speed response of the overcoated device shows better performance than the uncoated devices with clear eye with 35ps jitter operating at 2.125Gb/s with 10mA bias and 9dB extinction ratio. These improvements in the implanted VCSEL performance would be due to the better current spreading and uniformity induced by the overcoating. This overcoating technique should be applicable to the other types of VCSELs.

5. ACKNOWLEDGEMENT

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