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Solid-State Electronics 47 (2003) 1805–1809

SOLID-STATE
ELECTRONICS

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Performance of 850 nm AlGaAs/GaAs implanted VCSELs utilizing silicon implantation induced disordering

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Received 31 January 2003; accepted 27 March 2003

Abstract

In this paper, we report a novel implanted vertical surface emitting lasers (VCSELs) utilizing silicon implantation induced disordering. The VCSELs exhibit kink-free current–light output performance with threshold currents ~ 2.4 mA, and the slope efficiencies ~ 0.45 W/A. The threshold current change with temperature is minimal and the slope efficiency drops less than $\sim 30\%$ when the substrate temperature is raised to 90°C . The eye diagram of VCSEL operating at 2.125 Gb/s with 7 mA bias and 10 dB extinction ratio shows very clean eye with jitter less than 30 ps. We have accumulated life test data up to 5000 h at $100^\circ\text{C}/20$ mA with exceptional reliability and the WHTOL (high temperature and high humidity $85^\circ\text{C}/85$ operating lifetime) biased at 8 mA has passed over 2000 h.

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Keywords: VCSEL; Si implant; Disordering; Kink

1. Introduction

850 nm vertical surface emitting lasers (VCSEL) have become a standard technology for application in local area networks (LANs) [1,2]. The main advantages of VCSELs are the low threshold current, low divergent angle, and circular beam, which lead to simpler packaging and low electrical power consumption. The surface emission from the VCSELs also makes easy the two-dimensional array integration and allows wafer level testing, in turns leading to low fabrication cost. In addition, the VCSEL's small active volume and high efficiency result in an inherently high modulation bandwidth over a wide temperature range [3]. To date, only two types of commercial VCSELs are available: proton implanted VCSEL and oxide-confined VCSEL.

Proton implanted VCSEL has been demonstrated with good reliability and decent modulation speed up to 1.25 Gb/s [1]. However, the kink in current versus light output ($L-I$) has been always an issue in the gain-guided proton implanted VCSEL [4]. The jitter and noise performance of proton implanted VCSEL made it difficult to achieve 2.5 Gb/s (OC-48) requirement. Compared to proton implanted VCSEL, the oxide aperture in oxide confined VCSEL provides precise boundaries near the active region for index-guiding which can give rise to well defined transverse modes at low bias current [2,3]. Therefore, with lower threshold currents and enhanced noise properties, oxide VCSEL can be used for 2.125 Gb/s and above applications. However, there are several manufacturing concerns for the oxide VCSEL. First, it is difficult to control the aperture sizes since the oxidation procedure depend strongly on numerous material and processing parameters which can easily and unpredictably changed. In addition, the strain and defects introduced by the oxide layer could cause potential reliability problem [5]. In this paper, we report a new implant VCSEL design that has the kink-free $L-I$ characteristics

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with an oxide VCSEL-like performance and an implant VCSEL-like reliability.

2. Device structure and fabrication

The VCSEL structure consists of a n-type 35-period- $\text{Al}_{0.15}\text{GaAs}/\text{Al}_{0.9}\text{Ga}_{0.1}\text{As}$ distributed Bragg reflector (DBR), grown on n-GaAs (100) substrate by metal organic chemical vapor deposition (MOCVD) with the growth temperature 750°C . Then, a three-quantum-well active region ($\text{Al}_{0.26}\text{Ga}_{0.74}\text{As}/\text{GaAs}$) was routinely grown, followed by the growth of 3-period $\text{Al}_{0.15}\text{GaAs}/\text{Al}_{0.9}\text{Ga}_{0.1}\text{As}$ p-type DBRs and a 5 nm thin GaAs cap layer (to prevent oxidation of surface before re-growth). Then the $13 \times 13 \mu\text{m}^2$ emitting aperture was defined using silicon implantation. The implantation dose is $5 \times 10^{14} \text{ cm}^{-3}$ with the energy 90 KeV. The whole structure was finished by subsequent MOCVD re-growth of p-type 22-period- $\text{Al}_{0.15}\text{GaAs}/\text{Al}_{0.9}\text{Ga}_{0.1}\text{As}$ DBRs and cap layer. After re-growth, a mirror-like surface as obtained under microscope inspection indicating good re-growth. Then the VCSELs were fabricated utilizing the routine processing—proton implantation to reduce capacitance, Ti/Pt/Au for p-metal and AuGe/Ni/Au for n-metal. The unique technique in this work is that during the MOCVD re-growth, the Si implantation region was annealed and induced disordering. The schematic of the fabricated VCSEL device is shown in Fig. 1.

3. VCSEL performance

Fig. 2 shows the typical Si implanted VCSEL (a) light output, (b) voltage versus current (LIV) curves over temperature. The VCSEL exhibits kink-free current–light output performance with threshold currents about

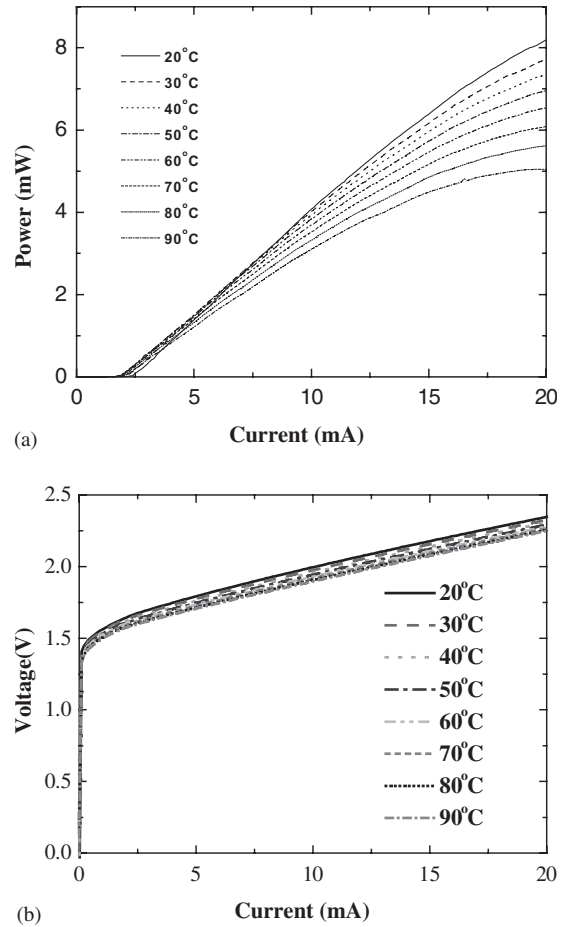


Fig. 2. (a) Power and (b) voltage versus current curves at 20–90 °C. The Si implant VCSELs exhibit kink-free current–light output performance with threshold currents $\sim 2.4 \text{ mA}$, and the slope efficiencies $\sim 0.45 \text{ W/A}$.

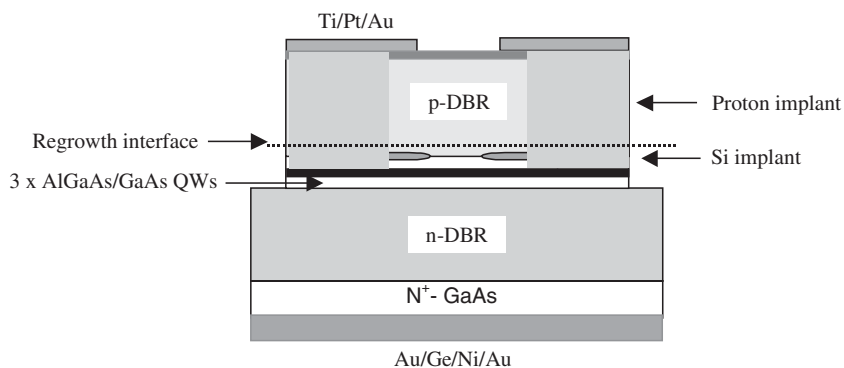


Fig. 1. Schematic structure of a Si implant VCSEL. The Si implant aperture is $13 \times 13 \mu\text{m}^2$ and proton implant aperture is $30 \times 30 \mu\text{m}^2$.

2.4 mA, and the slope efficiencies about 0.45 W/A. The threshold current change with temperature is less than 0.5 mA and the slope efficiency drops less than ~30% when the substrate temperature is raised from 25 to 90 °C. This is superior to the proton-implant VCSEL with similar size and is comparable to that of oxide VCSEL. In addition, More than 90% series resistance of the VCSELs is within 40–45 Ω indicating good re-growth interface.

Fig. 3 shows distributions for threshold current and slope efficiency of our VCSEL's sample test data (1262 chip in total). The sample test data is obtained from one out of 5 × 5 chips. The overall yield across a 3 in. wafer is over 90%. The narrow and normal distributions tell us the production performance of the Si implant VCSEL.

Spectral emission characterization consists of utilizing an optical spectrum analyzer (OSA) and near-field scanning optical microscopy. The output light from the

VCSEL is collimated using a 100× objective. The beam is either redirected to a diffraction grating for near field analysis or coupled using 100× objective to multiple mode fiber and further fed to the OSA. Fig. 4 shows the optical output power spectrum of a Si implant VCSEL driving at 3.5 mA ($1.4 \times I_{th}$). The inset shows the spectrally resolved TEM_{00} , and TEM_{01}^* (donut) intensity pattern. From the near field pattern of Si implant VCSEL, it suggests that silicon implant region does provide the good optical index-guiding. As a result, the Si implanted VCSELs have much better kink characteristics compared to proton implant VCSELs.

Fig. 5(a) shows the typical eye diagram of Si implant VCSEL on TO-46 operating at 2.125 Gb/s with 7 mA bias and 10 dB extinction ratio with $P_{avg} \sim -5.3$ dBm at 25 °C. The wide open eye pattern indicates good performance of our VCSEL. The 2.125 Gb/s Eye-Mask (with 20% margin) is passed with Jitter (p-p) ~ 30 ps.

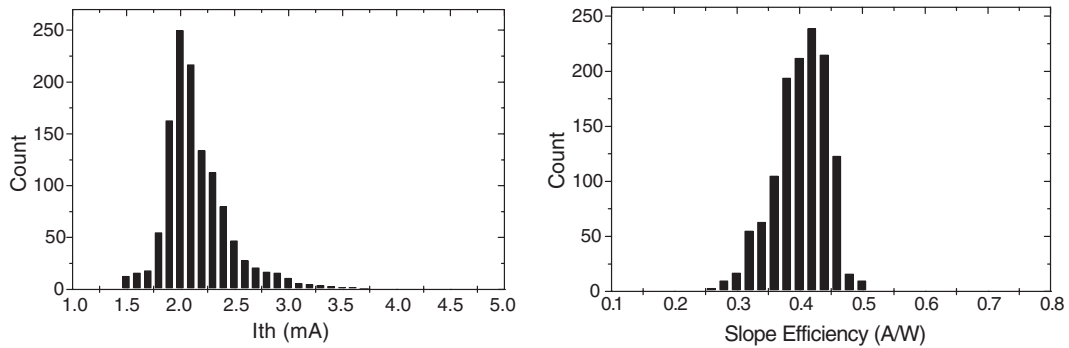


Fig. 3. Distributions plot for threshold current and slope efficiency of Si-implanted VCSEL.

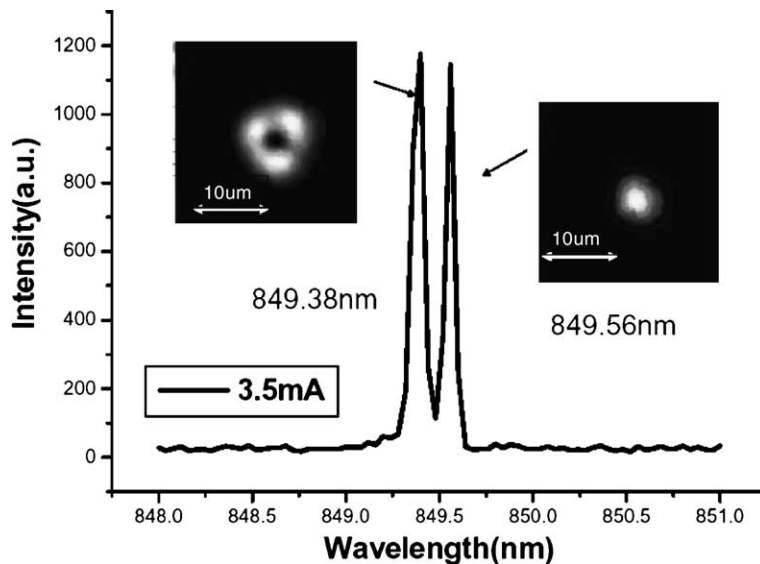
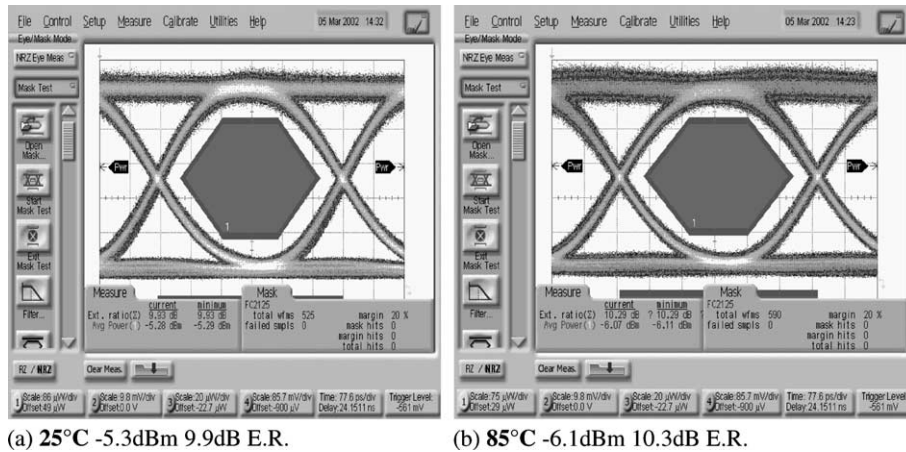


Fig. 4. Optical output power spectrum of a Si implant VCSEL driving at 3.5 mA ($1.45 \times I_{th}$). Inset shows the spectrally resolved intensity pattern.



(a) 25°C -5.3dBm 9.9dB E.R.

(b) 85°C -6.1dBm 10.3dB E.R.

Fig. 5. Typical eye diagram of our VCSEL on TO-46 operating at 2.125 Gb/s (Fiber-Channel mask with 20% margin) with 7 mA bias and 9 dB extinction ratio at (a) 25 °C and (b) 85 °C.

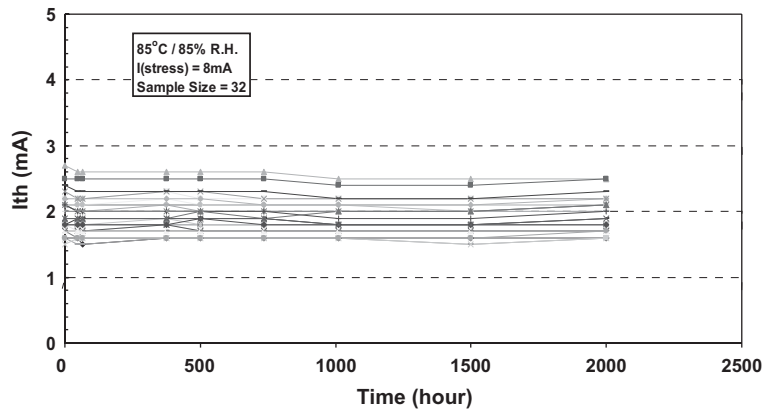


Fig. 6. WHTOL (85 °C/85 humidity) performance of Si implant VCSEL chips.

Our VCSEL also show superior temperature performance. Fig. 5(b) demonstrated the eye-diagrams at 2.125 Gb/s at 85 °C of Si implant VCSEL. The 2.125 Gb/s Eye-Mask (with 20% margin) is passed with only a little noisy signal due to higher temperature operation. This confirms again the superior temperature performance of Si implanted VCSEL.

4. VCSEL reliability

The VCSELs reliability is a very important issue for many practical applications. We have accumulated life test data of our VCSELs up to 5000 h at 100 °C/20 mA with exceptional reliability. In addition, our VCSEL chip is humidity proof and passed 2000-h biased WHTOL (85 °C/85 humidity), a strongly desirable feature for parallel optics applications. As shown in Fig. 6 is the I_{th} versus time scale for VCSEL chips under

WHTOL (85 °C/85 humidity) test, none of them shows the abnormal behavior.

5. Summary

In conclusion, we report a novel implant VCSEL process utilizing silicon implantation induced disordering. The VCSELs show good performance with kink-free $L-I$ characteristics, good temperature and high speed performance with wide open eye pattern. The Si-implant VCSELs should be promise for the optoelectronic and other commercial applications in the coming days.

Acknowledgements

The authors would like to thank Drs. C.P. Kuo, and G. Husnain of LuxNet Corporation for useful discussion and technical support. This work is supported by work was supports by the National Science Council, Republic

of China, under contract NSC-90-2215 -E009-088 and by the Academic Excellence Program of the Ministry of Education of ROC under the contract no. 88-FA06-AB.

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