Output Polarization Dependence of Asymmetric Current Injection VCSELs on Crystalline Direction and Ion Implantation

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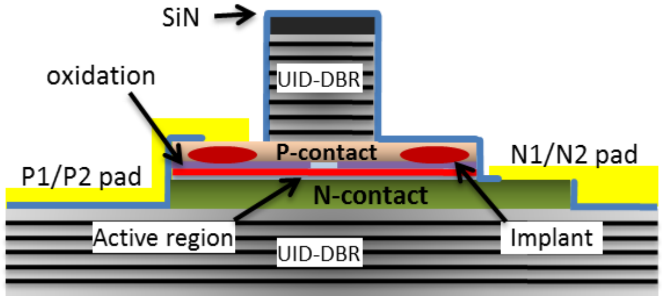
Vertical-cavity surface-emitting lasers (VCSELs) have emerged as a valuable platform because of their reliability, high-speed characteristics, and ability for on-chip integration [1]. Recent work has also demonstrated the possibility of output polarization control [2]. By leveraging the advantages of the VCSEL platform, innovative solutions in imaging, sensing and military applications are possible. We demonstrate control between two orthogonal polarization states via asymmetric current injection (ACI) utilizing a novel dual intracavity contacted circular mesa design. Modulation doping is used in the contact layer to reduce optical loss. Deuterium (D^+) isolation implantation in the p-contact layer was also investigated to reduce lateral current spreading.

Devices were grown using molecular beam epitaxy (MBE) on undoped (001) GaAs starting with 18 periods of GaAs/AlAs for the bottom DBR mirror 420nm of Si doped GaAs for the n-contact layer. The p- and n-contact layers were grown close together to increase current directionality. The active region consists of three 8nm thick $In_{0.2}G_{0.8}As$ quantum wells separated by 8nm GaAs barriers surrounded by a $Al_{0.3}Ga_{0.7}As$ separate confinement heterostructure (SCH). Due to the large optical field in the p-contact region, only the standing wave nulls were doped to reduce free carrier absorption. Carbon was used in this modulation doping scheme because of its low diffusivity. The top mirror consists of 32 periods of 85% AlGaAs/GaAs. A wedding cake structure is created using standard lithographic procedures and an oxide aperture is created through a wet oxidation process. Metal contacts are laid out in a cross pattern to separately inject current in two orthogonal directions. The whole cross layout is also rotated relative to the crystal axis to investigate its effect on output polarization. Deuterium was also implanted into the p-contact layer in areas that straddle current injection paths to reduce lateral current spreading.

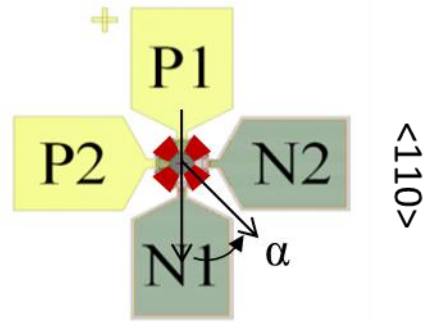
Light output (LI) first passes through a focusing lens/rotating polarizer combination and is then measured by a Si photodetector. Each arm of the diode is biased separately and the output polarization is measured. A measured phase difference of 90° means that the two outputs are orthogonally polarized relative to each other. By rotating the current injection directions relative to the crystal axes it was found that the amount of splitting between the two polarization states follows a $\cos^2(\alpha)$ dependence. The largest offsets between polarization states occurred every 90° with respect to the <110> axis. Minimal polarization phase offsets were found to occur when current was aligned to the <010> and <100> directions. For one device that did not display polarization splitting from ACI as grown, after D^+ implantation the output polarization showed a polarization phase offset of approximately 90°, demonstrating the ability to suppress crosstalk between polarization paths with ion implantation.

References

[1] Y.-C. Chang and L.A. Coldren, *Appl. Phys. A*, **95**(4), pp.1033-1037, June 2009.
[2] L. M. Augustin, E. Smalbrugge, K.D. Choquette, F. Karouta, R. C. Strijbos, G. Verschaffelt, E.-J. Geluk, T. G. van de Roer and H. Thienpont, *IEEE Photon. Technol. Lett.*, **16**(3), pp. 708–710, Mar. 2004.



(a)



(b)

Fig. 1 a) Polarization switching VCSEL schematic. b) Top view showing contact pads relative to <110>. Ion implant locations shown in red.

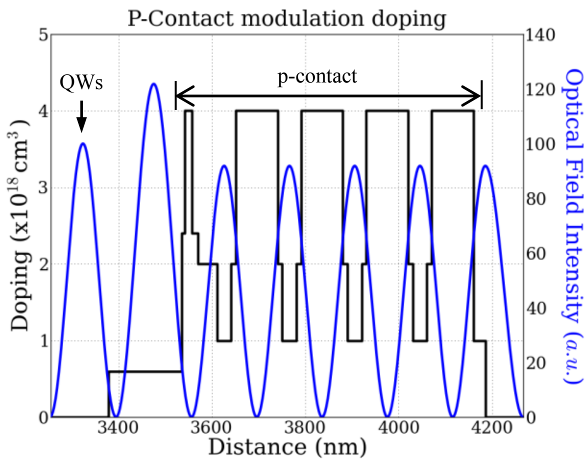


Fig. 2 Low optical loss modulation Carbon-doping of the p-contact region overlaid with optical standing wave in the laser cavity.

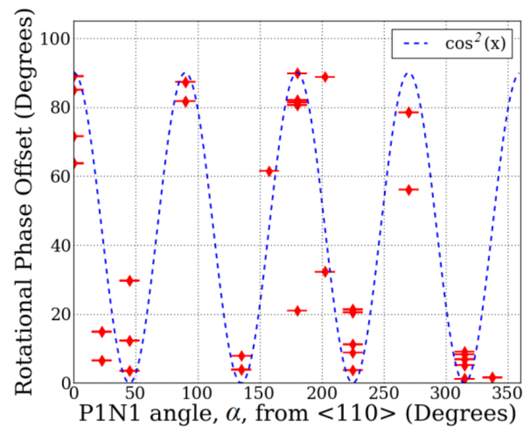
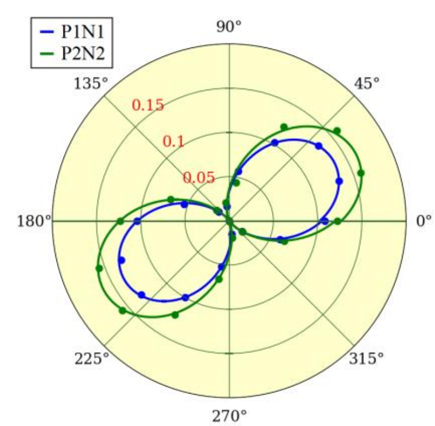
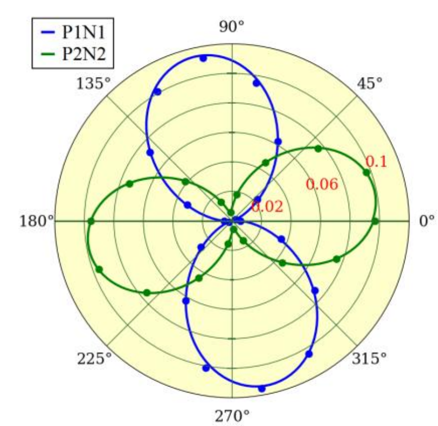


Fig. 3 Phase offsets between two polarization states measured as the current injection angle, *α*, is rotated.



(a)



(b)

Fig. 4 Output power (radii-a.u.) and polarizer angle for the P1N1 and P2N2 current directions of a device a) before D^+ implantation and b) after D^+ implant. The 0° horizontal axis is aligned to the crystalline <1$\bar{1}$0> axis.