TuC5 (Contributed)
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Ultrafast Electrical Polarization Modulation in VCSEL with Asymmetric Current Injection

Ajit V. Barve[1], Alok Mehta[2], Anis Husain[2] and Larry Coldren[1]
[1]Department of Electrical and Computer Engineering, University of California, Santa Barbara, CA 93117, USA
[2]Ziva Corporation, San Diego, CA 92121, USA
ajit@ece.ucsb.edu

Abstract: We report on the use of asymmetric current injection to electrically switch between the orthogonal linear polarization modes of VCSELs using a four terminal architecture. A record high electrical polarization modulation speed of 4Gb/s has been obtained.

OCIS codes: (140.0140) Lasers and laser optics; (250.0250) Optoelectronics

1. Introduction

The output polarization of a typical VCSEL ispolarized along one of the two linearly polarized modes, aligned to the crystallographic directions. It has already been demonstrated [1-3] that it is possible to control the polarization by means of asymmetric current injection (ACI) in the active region of the VCSEL. Since this technique relies on current induced anisotropies in the VCSEL, the polarization can be controlled at ultrahigh speeds. However, the speed of polarization modulation obtained with ACI has been limited to 50kHz [4] due to the dominant thermal polarization switching. Here, we report on electrically controlled polarization modulation speeds of over 4Gb/s - an impressive, several orders of magnitude improvement. Moreover, the VCSELs reported here have ultralow threshold currents (~150-300μA) and excellent differential quantum efficiencies. Since the data can essentially be modulated on both the polarization modes, with similar power efficiency as the direct modulation, this technique is extremely attractive for polarization sensitive, reconfigurable data networks.

2. Device Design

The VCSELs consist of MBE grown, strained InGaAs/GaAs quantum wells embedded in a GaAs/AlGaAs separate confinement heterostructure, optimized for lasing at 980nm, with a bottom emitting architecture. A dual intracavity structure was used to maximize the effect of asymmetric current injection. The schematics of the device architecture is shown in Fig. 1. The first etch creates a circular mesa through the undoped top DBR to expose the p-contact region. The cross-shaped second mesa etch exposes the n-contact region, etching through the active region. A parabolically tapered oxide aperture in the outer mesa is used to provide optical and current confinement. The dimensions of the cross and the oxidation lengths are designed such that the entire area of the cross is oxidized, leaving a small elliptical oxide aperture at the center of the mesa, to eliminate the current leakage. This geometry is chosen to minimize the crosstalk between the two sets of P-contacts. The eccentricity of the ellipse is varied over the entire array in order to obtain different birefringence across different VCSELs. Two sets of P and N contacts are fabricated, such that the current P1N1 flows perpendicular to P2N2, to maximize the current asymmetry.Orientation of these contacts are along <110> and <11 0>crystalline planes, to maximize the anisotropy. Two sets of ground-signal-ground pads are fabricated for the ease of high frequency testing.The N and P metals are separated by 1μm SiO_2 layer, and the N-contact layer is removed from everywhere to minimize the parasitic capacitances.

3. Experimental Setup and Results

The optical power vs bias current (LI) measurements demonstrate excellent DC characteristics, with low threshold currents. The 3dB cut-off frequency for the small signal response varied from 13GHz to 15GHz depending on the active area, and was limited by the parasitic capacitance due to a thin dielectric layer separating the N and P metal pad crossing. The polarization dependent LIV measurements reveal a strong dependence on birefringence (resulting from varying eccentricities) and current directionality. In a particular polarized LI characteristic shown in Fig. 2(a), it can be seen that although the polarization of the VCSEL is switching between X and Y polarizations, the polarization switching current is different for the two directions of current flow. Depending on the bias current, the polarization contrast ratios exceeding 14dB can be obtained just by changing the directionality of the current flow.The experimental setup to exploit this to modulate the polarization of the VCSEL is shown in Fig. 2(b). Both the P contacts are biased at a common DC current. The data is applied across P1N1, while the inverted data is applied to P2N2, keeping the total current constant. The output of the VCSEL is passed through a polarizer, focused on to a multimode fiber and detected with a high speed detector. The Fig. 2(c) shows the time domain response obtained with a high speed oscilloscope, for X and Y polarizations, at the data rate of 4Gbps. Clearly, the two signals are 180^0 out of phase, indicating that the polarization switch is taking place at a much higher timescale. This is the fastest reported direct modulation of the polarization of a VCSEL. It is expected that the polarization switching speed can be further improved with this technique, by using BCB to reduce parasitic capacitance.

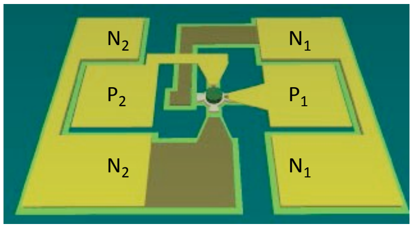

Fig. 1: Schematics of the fabricated device

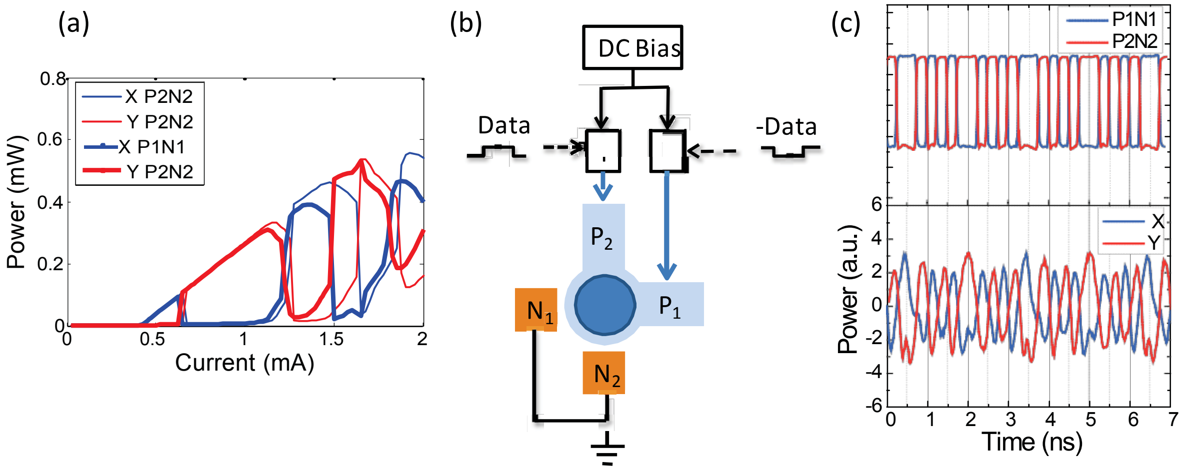

Fig. 2: (a) Measured polarized L-I curve (b) Biasing scheme for time domain measurements (c) Time domain results at 4Gb/s data rate, the top viewgraph shows the data applied to the two pads and the bottom graph shows measured signal at the oscilloscope. The DC part of the signal has been blocked.

4. Acknowledgments

This work was supported by DARPA, via STTR to Ziva Corp. with UCSB as subcontractors.

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