40 GHz Phase Shifter based on Semiconductor Laser

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This investigation experimentally demonstrates a 40 GHz phase shifter based on a semiconductor laser. The phase shift is achieved by adjusting the bias current and wavelength detuning. The device has an optical delay of 23 ps and a phase shift of about 331°.

Introduction: Recently, interest in applying photonic technology to radio frequency (RF) phase shifters for phased array antennas has been strong and growing. The benefits of the photonic RF phase shifter is its immunity to electromagnetic interference, excellent isolation, lightness and smallness [1, 2]. Recently, phase shifters and optical delays based on optical semiconductor devices have become very attractive because of their inherent compactness, direct electrical controllability, and low power consumption [3, 4]. However, phase shifters and optical delays based on semiconductor lasers at over 20 GHz have not yet been addressed.

This work experimentally demonstrates a quantum well vertical-cavity surface-emitting laser (VCSEL) for a 40 GHz phase shifter. The advantages of VCSELs are low power consumption, narrow beam divergence, and low-cost production. A tunable phase shift can be achieved by adjusting the bias current and wavelength detuning. A 40 GHz modulation signal with a tunable optical delay of 10 ps is obtained by adjusting the bias current. Additionally, the relationship between the optical delay and the wavelength detuning ($\Delta\lambda$) is studied.

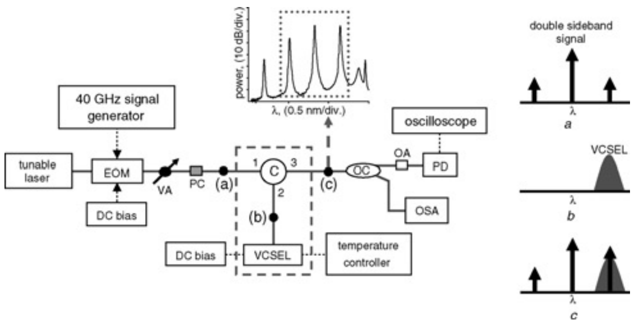

Fig. 1 *Experiment setup*

EOM: electro-optic modulator; VA: variable optical attenuator; C: optical circulator; OC: optical coupler; PC: polarisation controller; OA: erbium-doped fibre amplifier; PD: photodetector; OSA: optical spectrum analyser

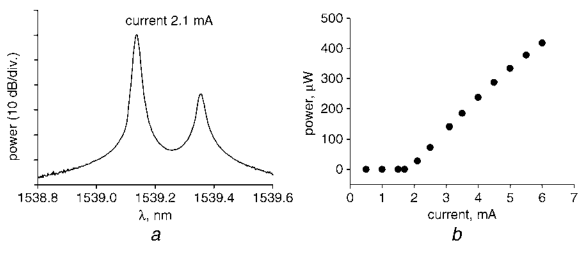

Fig. 2 *Output spectrum and light-current characteristics of VCSEL*

Experiments and results: Fig. 1 presents the experimental setup for measuring phase shift in a quantum well VCSEL. A probe signal is generated by a tunable laser and modulated using an electro-optical modulator (EOM). The signal power is controlled using a variable optical attenuator (VA) at the output of the electro-optical modulator. The polarisation of the probe signal is adjusted using a polarisation controller (PC) to maximise the phase shift in the VCSEL. An optical circulator (C) is employed to couple the probe signal to the VCSEL. This probe signal is a double-sideband signal. The wavelength of the sideband signal is tuned to the resonance of the VCSEL cavity, as displayed in the inset of Fig. 1. The power of the probe signal is approximately −7 dBm. Varying the power and wavelength of the probe signal in the laser cavity vary the available gain and time delay [4]. Fig. 2 shows the output spectrum and light-current characteristics of the quantum well VCSEL. The threshold current is 1.7 mA. The lasing wavelength of VCSEL is around 1539 nm. Fig. 3 plots the measured time delay for a 40 GHz probe signal at various bias currents of the VCSEL. The reference signal is taken as the wavelength of the probe signal outside the resonance of the VCSEL cavity. The probe signal is then directly reflected from the top mirror of the VCSEL. The reference signal is consistent with that described elsewhere [4]. An optical delay of 10 ps and a phase shift of about 144° are observed, and the driving current is at 3.1 mA. Fig. 4 plots the measurements of time delay at various wavelength detunings ($\Delta\lambda = \lambda_{sideband} - \lambda_{VCSEL}$, the wavelength difference between the wavelength of the sideband signal and the lasing wavelength of the VCSEL), when the driving current is 2.1 mA. A time delay of 23 ps is achieved at a wavelength detuning of 0.058 nm, and the phase shift is about 331°.

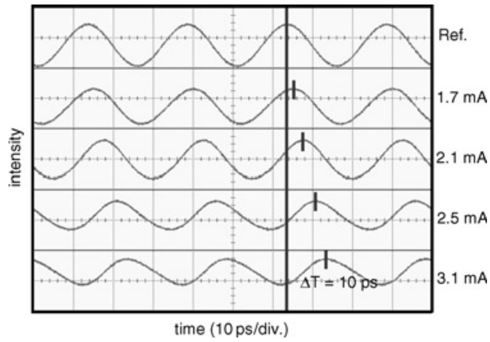

Fig. 3 *Measured time delay for a 40 GHz probe signal at various bias currents of VCSEL*

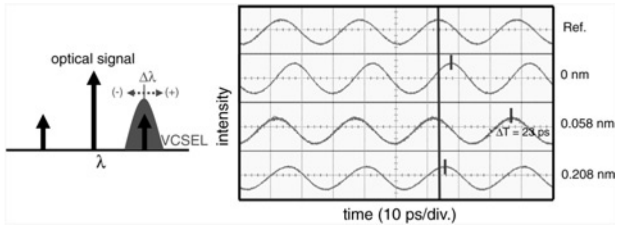

Fig. 4 *Measurements of time delay at various wavelength detunings ($\Delta\lambda$)*

Conclusion: This work experimentally demonstrated for the first time tunable phase shift in a VCSEL at 40 GHz. Optical delays of 10 ps and a phase shift of about 144° are achieved by varying the bias current. The relationship between the optical delay and the wavelength detuning ($\Delta\lambda$) is also studied. The phase can be varied through about 331°. Moreover, the VCSEL could exhibit polarisation-mode dispersion compensation in the subcarrier multiplexed system [5]. In the polarisation-mode dispersion emulator [6], an optical time delay is required to compensate for polarisation-mode dispersion. The VCSEL could reduce the size and cost of the polarisation-mode dispersion emulator in the subcarrier multiplexed system.

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References

1 Chan, E.H.W., and Minasian, R.A.: 'Photonic RF phase shifter and tunable photonic RF notch filter', *J. Lightwave Technol.*, 2006, **24**, pp. 2676–2682

2 Lee, S.S., Udupa, A.H., Erlig, H., Zhang, H., Chang, Y., Zhang, C., Chang, D.H., Bhattacharya, D., Tsap, B., Steier, W.H., Dalton, L.R., and Fetterman, H.R.: 'Demonstration of a photonically controlled RF phase shifter', *IEEE Microw. Guid. Wave Lett.*, 1999, **9**, pp. 357–359

3 Fisher, M.R., and Chuang, S.L.: 'A microwave photonic phase-shifter based on wavelength conversion in a DFB laser', *IEEE Photonics Technol. Lett.*, 2006, **18**, pp. 1714–1716

4 Laurand, N., Calvez, S., Dawson, M.D., and Kelly, A.E.: 'Slow-light in a vertical-cavity semiconductor optical amplifier', *Opt. Express*, 2006, **14**, pp. 6858–6863

5 Adamczyk, O.H., Sahin, A.B., Qian, Y., Lee, S., and Willner, A.E.: 'Statistics of PMD-induced power fading for intensity-modulated double-sideband and single-sideband microwave and millimeter-wave signals', *IEEE Trans. Microw. Theory Tech.*, 2001, **49**, pp. 1962–1967

6 Pua, H.Y., Peddanarappagari, K., Zhu, B., Allen, C., Demarest, K., and Hui, R.: 'An adaptive first-order polarization-mode dispersion compensation system aided by polarization scrambling: theory and demonstration', *J. Lightwave Technol.*, 2000, **18**, pp. 832–841