Low V_π High-Speed GaAs Travelling-Wave Electrooptic Phase Modulators Using an n-i-p-n Structure

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High speed semiconductor optical modulators are very important components for optical communication systems [1]. Characteristics such as low drive voltage, wide bandwidth, low insertion loss, low wavelength and temperature sensitivity, and low cost are essential for these optical modulators. Recently 40 GHz InP modulators with a drive voltage of only 2.3 V have been reported which use an n-i-n waveguide structure instead of the conventional p-i-n structure to reduce both the microwave and optical losses [2]. However InP-based modulators have the drawback of the wavelength dependence of the drive voltage. GaAs based modulators do not have this problem due to its larger bandgap energy. To date GaAs modulator has been demonstrated with a 35 GHz optical bandwidth and 5 Vcm^{-1} V_π [3]. In this paper, we report a new design for GaAs modulators based on an n-i-p-n structure. The travelling-wave coplanar waveguide (CPW) electrodes are employed to realize high speed operation. By optimization, an electrical 3-dB bandwidth of nearly 40 GHz (optical 3-dB bandwidth of 80GHz) and a V_π around 6.6 V are predicted for a 5 mm long phase modulator.

The device wafer is configured with an n-i-p-n structure as shown in Fig. 1 (a). For electrical loss reduction, n-doped GaAs is introduced to make the Ohmic contact for both the signal and ground electrode. A 0.2 μm-thick p-doped (1×10^{18} cm^{-3}) $Al_{0.6}Ga_{0.4}As$ layer is used as the blocking layer to prevent current flowing between the cap and the lower n-GaAs contact layers. The intrinsic layer is designed as 1.3 μm thick for a trade-off between wide bandwidth and low drive voltage operation. The optical waveguide employed is a deeply etched ridge waveguide with strong lateral optical confinement. The width of the ridge is set to be 2 μm for ease of fabrication. The CPW electrodes are chosen for the TW design due to their ease of fabrication. The widths of the signal conductor supported by bisbenzocycobutene (BCB), the side ground conductor and the gap between the signal and ground are set to be 3μm, 40 μm and 8 μm wide, respectively, which can ensure both impedance matching (50 Ω) and velocity matching.

The compact 2D FDTD method combined with the Padé approximation transform is used to simulate this CPW structure. By the simulation the microwave loss increases with frequency, reaching 5.2 dB/cm at 10 GHz and 12.7 dB/cm at 40 GHz, and the velocity mismatch to the optical wave is within 4% over the frequency range between 5 and 80 GHz for this design. Fig. 1 (b) shows the simulated frequency response of the designed modulator with a length of 5 mm. An electrical 3-dB bandwidth of nearly 40 GHz and an optical 3-dB bandwidth up to 80 GHz are predicted by the simulation. As the bandgap wavelength of GaAs is much shorter than the working wavelength (1550 nm), the linear electro-optic effect is the main factor responsible for the induced index change. Since the intrinsic layer is just 1.3 μm thick and nearly 100% overlapping between the optical mode and the microwave electric field, high modulation efficiency can be expected. For a 5 mm modulation length the calculated V_π is 6.6 V at the design wavelength assuming a linear electrooptic (LEO) coefficient of 1.42×10^{-12} m/V for GaAs. Across the whole C-band from 1528 to 1568 nm, the V_π variation is estimated to be only about 0.25 V.

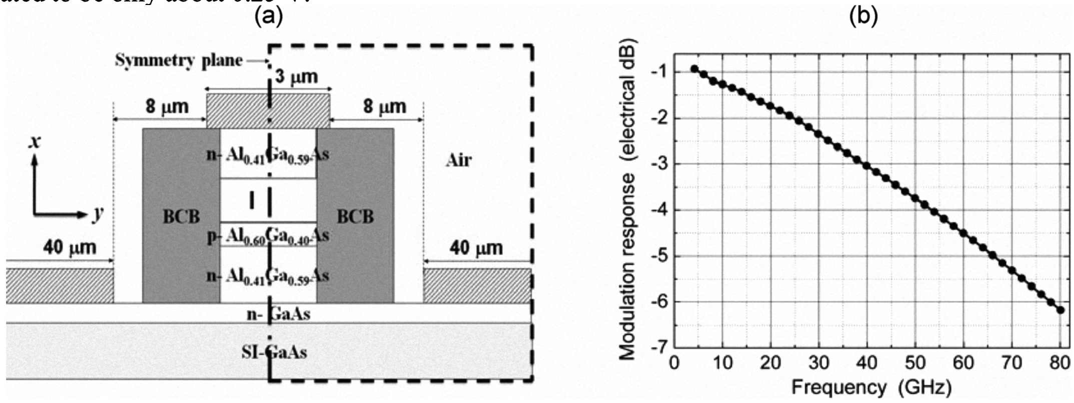

Fig. 1 (a) Cross section of the designed CPW structure; (b) Simulated frequency response of the designed 5 mm long phase modulator.

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