Influence of electrode width on high-speed performance of traveling-wave electro-absorption modulators

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Abstract

High-speed external modulators are key elements for the realization of high-bitrate, long distance optical fiber links. Electro-absorption modulators based on InP are attractive for their simplicity, and fabrication compatibility with corresponding semiconductor laser light sources. Optimizing such modulators for high performance implies a compromise between modulation bandwidth and modulation efficiency. Ideally, this conflict can be eliminated by using the device in a traveling-wave configuration [1,2]. However, in practice problems such as microwave attenuation, velocity matching, and impedance matching have to be addressed.

In this work, we have designed, fabricated and analyzed several traveling-wave electro-absorption modulators (TWEAM). The signal electrode width has been varied in order to gain a better quantitative understanding of the geometry impact on electrical velocity, microwave attenuation, and characteristic impedance of the modulator transmission line. For the first time this will be subject of systematic investigation on real device structures realized in InP/InGaAsP operating at 1.55µm optical wavelength.

Figure 1 shows an overall view of a fabricated device. A coplanar waveguide (CPW) electrode structure is used as microwave feed line that devolves into the modulator transmission line formed by the top electrode and the contacted n^+-InGaAs layer (see figure 2). The smooth transition is realized by appropriately shaping ground plane and CPW center electrode, avoiding abrupt changes in the characteristic impedance.

The vertical modulator structure is illustrated in figure 2. The top electrode, supported by a dielectric planarisation material, can be extended arbitrarily beyond the width of the optical waveguide mesa. The material chosen for planarisation is dry-etch CYCLOTENE because of its processing feasibility and and low dielectric constant.

Propagation constant and characteristic impedance of the modulator transmission line can be derived from the quasi-static circuit model [3] depicted in figure 2. The capacitance per unit length is primarily given by the mesa width and active layer thickness. These values together with the p-layer conductor per unit length are bound within a rather small range determined by the optical waveguide design. However, a large degree of freedom exists for the electrode width affecting directly and mainly the inductance per unit length of the transmission line, and providing thereby a parameter to adjust characteristic impedance and propagation constant.

Experimental values for characteristic impedance and propagation constant have been obtained from S-parameter measurements in the range from DC up to 60 GHz. The electrode width has been varied from 6 to 24µm. Microwave attenuation increases nearly linearly with frequency for all measured structures. The microwave index shows only a slight decrease above 10 GHz whereas the characteristic impedance remains almost constant in this range. Taking the high frequency asymptotic values of microwave index and characteristic impedance, the curves in fig.3 can be derived, indicating the influence of the electrode width.

In conclusion it can be seen that rather wide electrodes are favorable for low microwave attenuation and operation in the velocity matched region. On the other hand, this will result in lower characteristic impedance which can be disadvantageous because of higher input reflection losses when coupling in from a 50Ω system. However, simulations show that impedance matched wide-electrode devices are feasible for achieving 3dB optical modulation bandwidth >40GHz. Those simulations are supported by data obtained from measurements on a 50Ω terminated, fully functioning device. We will discuss experimental results, i.e., optical modulation bandwidth on correctly terminated TWEAM.

1. K. Kawano et al., Electron. Lett., 33 (18), 1580 (1997).
2. C. Z. Zhang et al., IEEE Photon. Technol. Lett., 11 (2), 191 (1999).
3. G. L. Li et al., IEEE Trans. Microwave Theory and Techn., MTT-47 (7), 1177 (1999).

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Sample: 1-5088IIIF6

Figure 1. Single TWEAM. Mounted for characterization

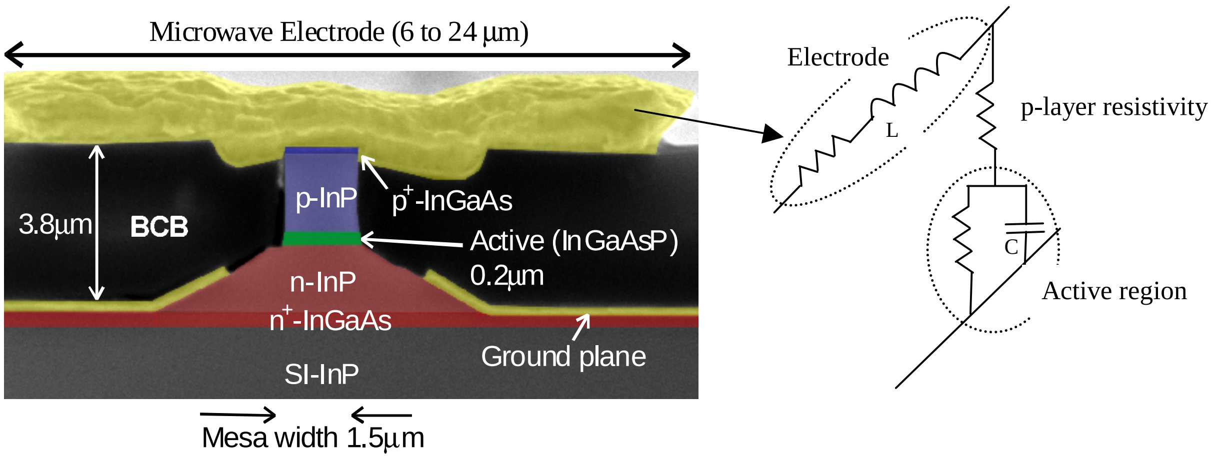

Figure 2. Typical cross section of the TWEAM (created from a SEM picture) and quasi-static circuit model for a unit length of the TWEAM transmission line [3]

$$\gamma = \alpha_e + j\frac{n_e \omega}{c_0} \qquad n_{diff} = n_e - n_{optical} \qquad Z_0 \approx \sqrt{\frac{L}{C}}$$

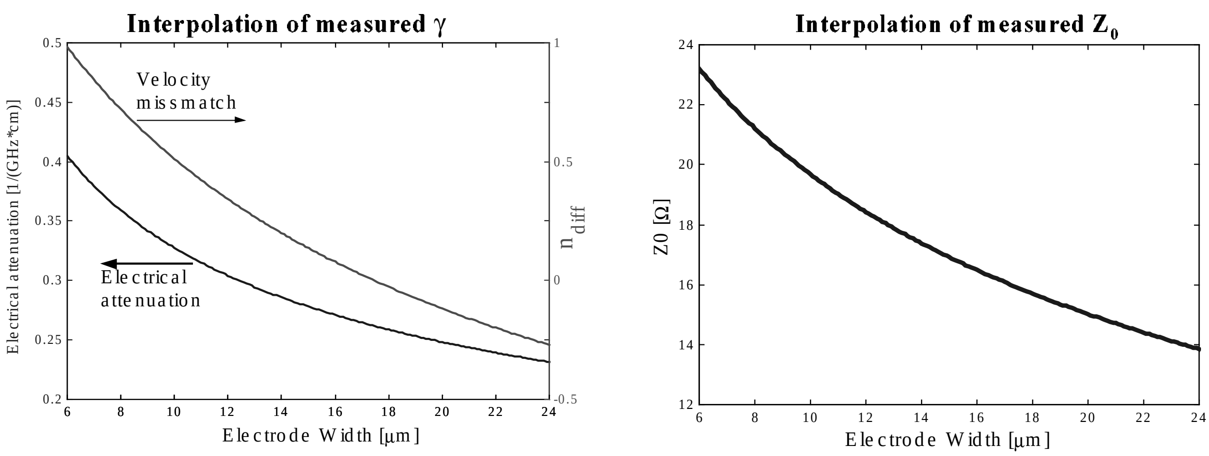

Figure 3. Experimental values for propagation constant γ, and characteristic impedance Z_0.