High-Efficiency Multi-Quantum Well Electroabsorption Modulators

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Electroabsorption modulators (EAMs) are attractive for applications requiring signal modulation at high speed and with high efficiency (high extinction ratio at low voltage). They are promising devices for external signal modulation in high-bandwidth optical communication systems. EAMs can be integrated with other devices like laser diodes, semiconductor optical amplifiers, and mode transformers. Electroabsorption modulators are based on the electroabsorption effect, i.e., on the change of the absorption coefficient due to an electric field. In bulk semiconductors, the absorption edge moves to lower energies with increasing electric field due to a combination of band-to-band absorption and tunneling processes (Franz-Keldysh effect). In our multi-quantum well (MQW) modulator, the transition energy between confined energy levels for electrons and holes is reduced as an electric field is applied in growth direction (quantum confined Stark effect, QCSE, Fig. 1). As the field is increased, the overlap of electron and hole wavefunctions is reduced thereby decreasing the absorption strength at the transition energy. Thick quantum wells are advantageous for high field sensitivity (high modulation efficiency) whereas thin quantum wells give stronger absorption. Compared to bulk materials, quantum well QCSE type modulators have higher modulation efficiencies (lower drive voltage), however, Franz-Keldysh type modulators are less wavelength sensitive (larger optical bandwidth).

A fabricated InGaAsP/InP MQW EAM is shown in Fig. 2. Our devices exhibit low polarization sensitivity, more than 25 GHz modulation bandwidth, and a modulation efficiency larger than 20 dB/V. Further performance optimization requires a detailed analysis of internal physical processes and their interaction. For this purpose, we employ a two-dimensional self-consistent EAM model to analyze and optimize our devices. The model self-consistently combines kp bandstructure and absorption calculations with a drift-diffusion model and optical waveguiding. The required low polarization sensitivity of EAMs leads to strong valence band mixing so that usual effective mass models fail to produce correct results. Optical loss mechanisms are analyzed, including intervalence-band absorption (Fig. 3). Transmission characteristics are calculated which are in good agreement with measurements. Modulation efficiency, linearity, and saturation effects will be discussed in detail.

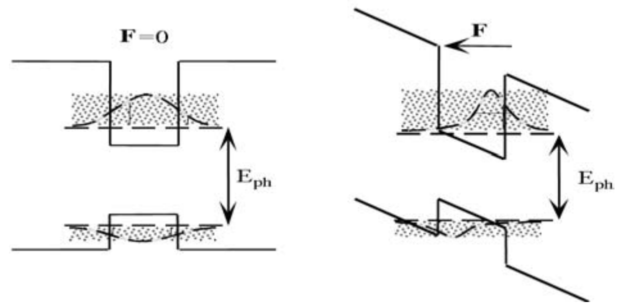

Figure 1

Quantum confined Stark effect (F - electric field, E_{ph} - transition energy).

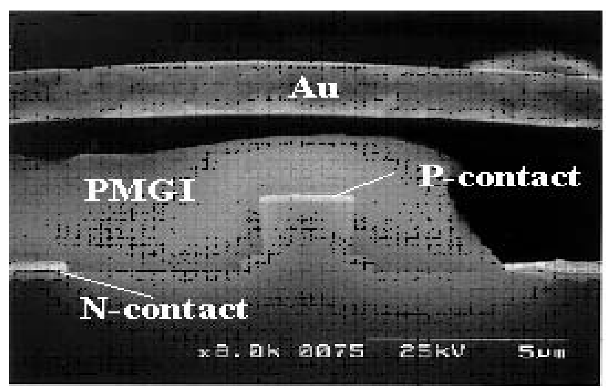

Figure 2

Facet view of a finished electroabsorption modulator.

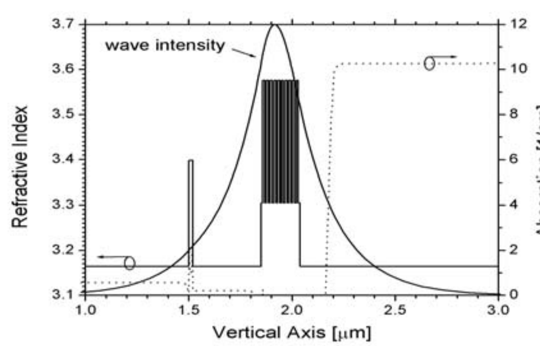

Figure 3

Vertical profile of refractive index, optical mode, and intervalance-band absorption.

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