Experimental Study of Strain−Compensated InGaAs−In(GaAl)As MQW Structures for Electroabsorption Modulator Applications

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- Introduction

Electroabsorption (EA) modulators based on III−V semiconductor multiquantum wells (MQW) are promising candidates for a variety of long haul and/or high bit rate telecommunication applications because they feature large absorption variations at low driving voltages. However, these components often suffer from narrow spectral ranges, low saturation powers and strong polarization dependence. For the latter problem, it has been shown that nearly polarization independent electroabsorption can be obtained by using strained−layer materials in order to equalize transitions contributing to the polarization sensitivity, at the expense of extremely sharp control of material composition. In particular, various authors had reported that InGaAs−InAlAs tensile–strained quantum wells with nearly degenerate heavy and light holes can provide almost identical electroabsorption curves in the TE and TM polarizations [1, 2, 3]. Here, we concentrate on the problem of designing electroabsorption modulators exhibiting a very high extinction ratio and a very high bit rate (> 40 Gb/s) for OTDM system applications.

In this work, we report on the realization of EA modulators based on strained GaInAs−AlGaInAs MQWs. These devices operate in the 1.5−1.6 µm wavelength range and show extinction ratios as high as 30 dB for sample length and width of 50 µm and 3 µm respectively.

- Device structure

In order to evaluate the trade−off between the extinction ratio and the saturation effects, we designed three different structures with varying barrier height. Our samples were grown by LP−MOVPE in a 3x2" AIX200/4 reactor at 670°C using TMGa, TMAl, TMIn, AsH3, PH3, SiH4 and DEZn as precursors.

contact	GaInAs	p+
	InP	p
	GaInAsP	u
MQW_w x10	GaInAs	u
MQW_b x11	Al(Ga)InAs	u
	GaInAsP	u
	InP	n
Substrate	InP	n+

Fig. 1 : Schematic structure of the Al(Ga)InAs-GaInAs strain compensated MQW electroabsorption modulator.

The structures of the proposed devices are shown in Fig. 1. The active region consists of 10 periods of 9−nm−thick, undoped In0.49Ga0.51As quantum wells (0.3% tensile strained) and 9−nm−thick

In0.60(AlxGa1−x)0.40As barriers (0.5% compressively strained). The x aluminum content was 0, 0.07 and 0.19 in samples A, B and C respectively. An undoped InGaAsP layer is inserted between the MQW layers and the InP cladding layers, both above and below the active region. In addition, the structure is topped by a p+ GaInAs contact layer.

The unprocessed sample was characterized by room temperature photocurrent (PC) with light propagating along the growth axis. The general shape and bias dependence of the PC spectra displayed in Fig. 2 (sample A) illustrate the high quality of the heterostructure. A sharp excitonic absorption edge is observed, and, when the bias increases, it shifts to lower energies according to the quantum confined Stark effect. It is possible to distinguish the (H−E)ex and (L−E)ex excitonic transitions at all bias and to observe that the Stark shift of the (L−E)ex transition is effectively smaller than that of the (H−E)ex transition. Sample B and C spectra are very similar. Varying the aluminum content in the AlGaInAs barrier leads to different electron (hole) barrier height between the E1 (HH1) level in the well and the E3D (HH3D) level in the barrier. The simulated E1−E3D (HH1−HH3D) offsets for sample A, B and C are respectively 366 (112), 273 (71) and 135 (8) meV.

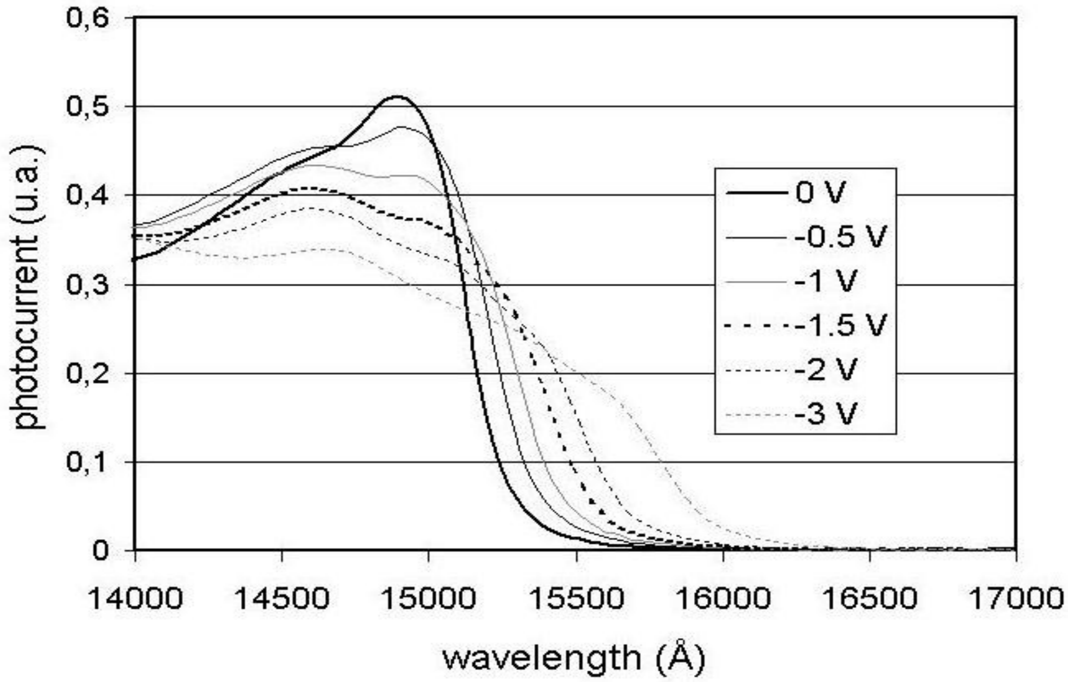

Fig.2 : photocurrent spectra at room temperature (300 K) for different reverse applied voltages

• Device characteristics

The shallow−ridge waveguide structures were chosen for stable single mode operation at large guide width. Processing procedure included dry etching, Pt/Au metallisation and SiO2/TiO2 antireflection coatings. The active modulator lengths were defined by 10 µm narrow proton implantation providing electrical isolation. Typically 50 and 75 µm long and 3 µm large waveguides were tested at room temperature. High saturation powers (+1 dB transmission points), in excess of 12 dBm at 1550 nm have been evaluated for sample C. For sample A, this amounts to only 4 dBm at the same wavelength. These results may be interpreted in terms of the potential barrier (HH1−HH3D) experienced by the holes, which is higher for sample A than for sample C. Guided−wave absorption was measured on these modulators by end−fire coupling, using photocurrent data to determine the on−state loss. Transmission per 75 µm device length (sample C) is shown in Fig. 3 for both TE and TM absorption polarization states and for two operating wavelengths (1.55 and 1.56 µm). The evaluated extinction ratio are 10 dB/1V/75µm at

1.56 µm. These static performances are higher than those previously reported for quaternary InGaAsP materials [4, 5]. A low polarization sensitivity is measured for sample C (1 to 2 dB) while a higher value (~5 dB) is observed in the case of sample A. This may be attributed to the difference in the HH – LH level separation arising from different confinements.

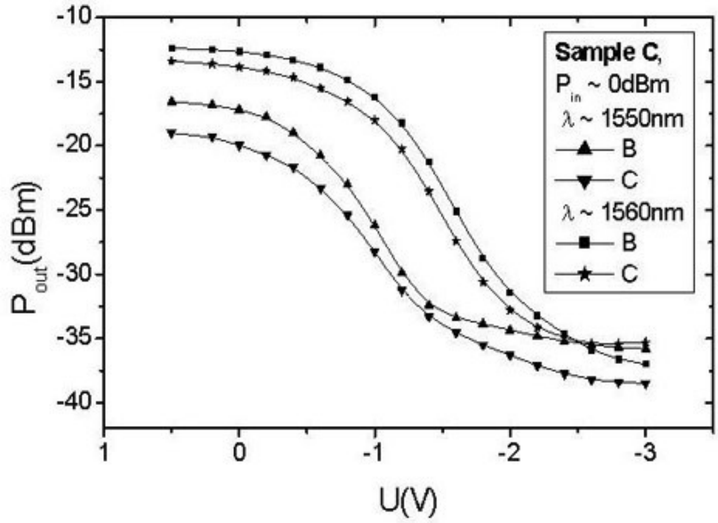

Fig. 3 : TE and TM absorptions reverse bias for a 75 µm long modulator for two operating wavelength, 1.55 and 1.56 µm

Fig. 4 shows the normalized power of the light transmitted through the modulator as a function of reverse bias for operating wavelength 1.556 µm. A record extinction ratio slope of 21 dB/1V/50µm is obtained. As seen on the figure, by choosing a bias operation point at 2.5 V and a 1.8 Vpp bias modulation, we could obtain an extinction ratio of 30 dB/50 µm. This represents, to our knowledge, the best extinction ratio ever reported for this kind of device. The modulator length is compatible with very high bit rate operation (> 40 Gb/s). These results open the way to applications such as pulse generation, demultiplexing for which a very high extinction ratio is required.

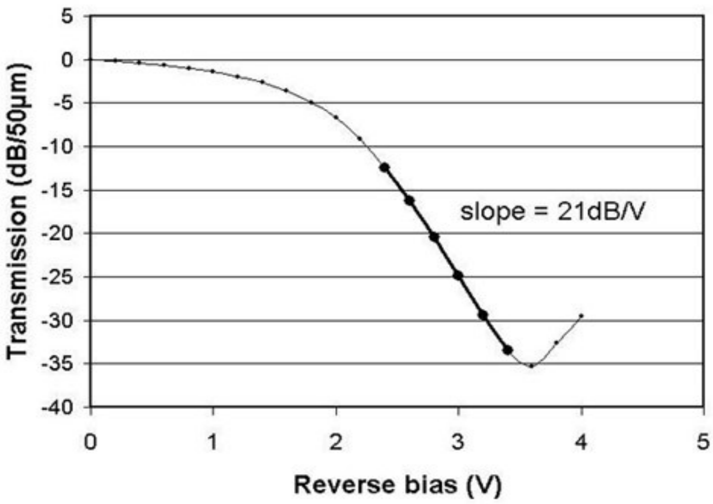

Fig. 4 : Transmitted optical characteristics per unit device length versus reverse bias for a 50 µm long modulator at 1556 nm.

• Conclusion

In summary, we developed EA modulators based on MOVPE−grown strain compensated InAl(Ga)As−InGaAs quantum wells. These devices show record static performances such as an absorption slope of 21 dB/1V/50µm and a voltage modulation below 2V, compatible with 40 Gb/s applications. Our results indicate that the barrier height is a key parameter to optimize to yield extinction ration, saturation power and polarization insensitivity compatible withapplication requirements.

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[1] K. Wakita et al., IEEE Photon. Technol. Lett., vol. 7, No. 12, 1995, pp1418−1420.

[2] S. Chelles et al., Appl. Phys. Lett. 67 (2), 10 july 1995, pp 247−249.

[3] K. Yoshino et al., CLEO, Pacific rim, p51, 1995, pp277−278.

[4] F. Devaux et al., IEEE Photon. Technol. Lett., vol. 5, No. 11, 1993, pp1288−1290.

[5] J. R. Bury et al., Electronic lett., vol. 38, No. 14, pp740−741, 4th july 2002.