Interdiffusion contributions in optimized surface-acoustic-wave quantum-well modulators

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Surface acoustic waves (SAWs) which propagate at the surface of a material modify the optical properties of the material. The modification can be expressed in terms of the elasto-optic and piezo-electric effects. The latter effect is generated in piezo-electric materials, such as III-V semiconductors. These effects can be used to fabricate acousto-optic devices, such as modulators, beam deflectors and correlators, using the interaction of the SAW with the semiconductor structure for signal processing applications [1]. SAW technology provides the possibility of a two-dimensional array of modulators for opto-electronic integration [2].

Quantum well (QW) intermixing is very useful in modifying the QW active region of optical devices [3]. Intermixing, which is also known as interdiffusion, occurs across the well-barrier interface to modify the subband structure and the transition energies when the sample is annealed. Consequently, interdiffusion provides the advantages of post growth modification of the operating wavelength (λ_{op}) and the optical properties of QW devices [3]. Here, the advantages of both SAW technology and interdiffusion are used to develop high electro-absorption change SAW modulators.

Due to the piezo-electric effect, the SAW induces both a potential and an electric field in the QW structure which reduces non-uniformly with depth [4]. The induced potential modifies the MQW structure and thus its optical properties. A more uniform change of each QW in the MQW structure can be obtained by increasing the SAW wavelength (λ_{SAW}). However, the change of the QW properties with the induced potential reduces when λ_{SAW} increases, i.e. there is a tradeoff between the uniformity and the strength of the variation of the QW properties.

In this paper, a theoretical study of an electro-absorption AlGaAs/GaAs DFQW modulator using SAW QW interactions is optimized so that it makes use of both the steeper potential at the device surface for modulation and a long λ_{SAW} and a low power SAW. Therefore, the fabrication of the interdigital transducer, which is used to launch the SAW, can be simplified and the device can be realized more easily. The non-uniform feature of the SAW induced potential is also taken into account in optimizing the device structure. Interdiffusion is then introduced into the QW stack to modify the modulation performance so that λ_{op} and the optical properties of the optimized structure can be further modified.

A schematic diagram of the waveguide type modulator is shown in Fig. 1. The structure, starting from GaAs substrate, is a thick AlAs cladding layer, a stack of AlGaAs/GaAs QWs which acts as the active region of the modulator and an $Al_{0.5}Ga_{0.48}As$ top cladding layer. The SAW interdigital transducer is deposited at one side of the device structure to launch the SAW. The growth direction of the QWs is <100> and the SAW propagates along the <110> direction. The incident light propagates normal to the propagation direction of the SAW and the QW growth direction is shown in Fig. 1.

In order to investigate the modulation performance of the device, the propagation of SAW is modeled. After calculating the subband structure of the diffused QW (DFQW) structure taking into account the effects of SAW, the optical properties, including absorption coefficient and refractive index and their changes due to the SAW effects, are determined. The modulation efficiency of an incident optical field depends on the guiding properties in the QW active region so that Maxwell's equation are solved. Consequently, the optical guided mode, the change of effective refractive index and change of the effective absorption coefficient taking into account the optical confinement are obtained for the determination of the modulation characteristics.

By optimizing the previous five period $Al_{0.3}Ga_{0.7}As/GaAs$ QW structure [4] with well width (L_z)= 100Å to the $Al_{0.2}Ga_{0.8}As/GaAs$ QW structure with L_z = 120Å. The SAW induced potential is more uniform, therefore, the absorption coefficient spectra of the five QW under the SAW perturbation merge, see Fig.2(a), in comparison to that of the x=0.3 QW structure, see Fig. 2(b). Consequently, to operate as an electro-absorption SAW modulator, all the five QWs of the optimized $Al_{0.2}Ga_{0.8}As/GaAs$ QW structure contribute to a higher $\Delta\alpha_{eff}$ to 1027cm^{-1} at λ_{op} = 0.8675µm from the x=0.3 QW structure of 428cm^{-1} at λ_{op} = 0.864µm.

By diffusing the five period $Al_{0.2}Ga_{0.8}As/GaAs$ QW structure with L_d = 0.5nm, the $\Delta\alpha_{eff}$ can be further enhanced to 1163cm^{-1} and λ_{op} can be finely tuned to 0.865μm where L_d is the diffusion length indicated the extent of interdiffusion [3]. The absorption spectrum are shown in Fig.3. It is worth noting that, using the x=0.2 QW structure, SAW wavelength and SAW power can be increased to 10 μm (from 2μm in the x=0.3 case) and reduced to 5 mW (from 10mW) respectively. Therefore, the fabrication of an interdigital transducer for generating the SAW can be simplified. As a conclusion, for the development of a SAW absorption modulator, the DFQW can provide a better modulation performance.

Reference

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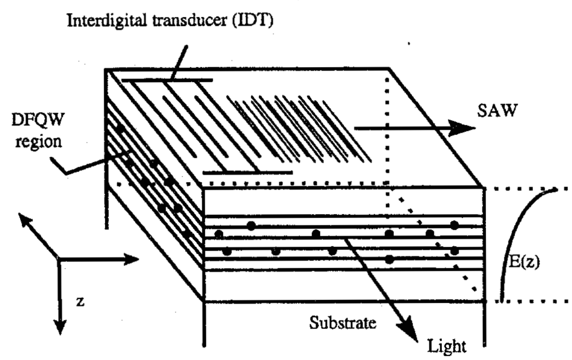

Fig.1

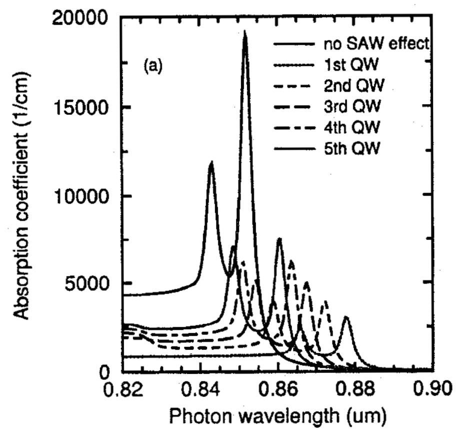

Fig.2b

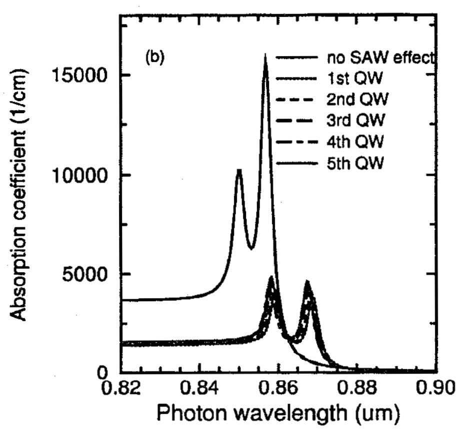

Fig.2a

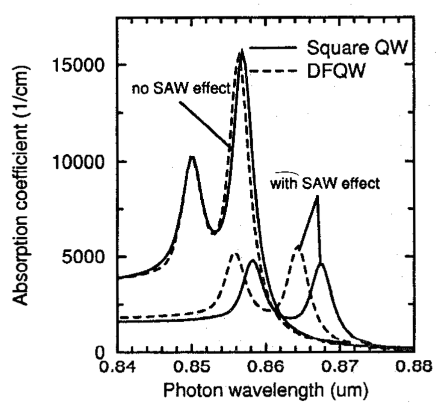

Fig.3

Fig. 1 Schematic diagram of the QW SAW absorption modulator.

Fig. 2 TE mode absorption spectra of each QW in the the five QW structure: (a) five period $Al_{0.3}Ga_{0.7}As/GaAs$ 100Å/100Å QW structure and (b) five period $Al_{0.2}Ga_{0.8}As/GaAs$ 120Å/120Å QW structure.

Fig. 3 TE mode absorption spectra of the optimized QWs structure. Solid and dot lines denote the as-grown without and with SAW effect respectively.