Unique Polarization Dependent Electroabsorption Effect in Coupled Quantum Wells

Yuen-Chuen CHAN, and Kunio TADA

Department of Electronic Engineering The University of Tokyo Hongo 7-3-1, Bunkyo-ku, Tokyo, 113, Japan

The electroabsorption effect of coupled quantum wells comprising two GaAs-AlAs quantum wells separated by a thin AlAs barrier and embedded in a planar waveguide structure has been investigated. The field-induced decoupling effect causes the coupled system to evolve to an uncoupled one, leading to large variations of the absorption coefficient at the absorption edge. The TE and TM mode electroabsorption is found to exhibit mutually opposite characteristics at the absorption bandedge of 784nm and respective relative power ratios of $\pm 5dB$ are obtained for a driving voltage of 5V.

1. INTRODUCTION

Quantum wells coupled by a thin barrier so that their eigenwave functions overlap have been found to exhibit unique absorption features that differ from that of isolated quantum wells¹⁻³). The zero field absorption spectrum of such coupled quantum well structures revert to that of the constituent individual wells upon the application of an electric field⁴). This field induced decoupling effect produces large changes in the absorption coefficient and refractive index, making them suitable for optical modulation applications. In this paper, we examined the polarization dependence of the electroabsorption effect of coupled quantum wells at wavelengths of the absorption edge as well as that detuned away from the edge. Mutually opposite characteristics for the TE and TM mode electroabsorption at the absorption edge were obtained.

2. STRUCTURE

The coupled quantum well structure studied, which consists of two 16ML (monolayer, 1ML=2.83Å) GaAs-AlAs quantum wells coupled by a thin AlAs barrier of 2ML, is shown in Fig. 1. The planar waveguide structure for absorption measurement was grown by molecular beam epitaxy on (100) n⁺-GaAs substrates $(N_D = 1 \times 10^{18} \text{ cm}^{-3})$. Thirty sets of coupled quantum wells, each separated by 10ML of AlAs barrier to ensure complete uncoupling, are embedded in the intrinsic waveguide core of the p-i-n doped sample. The sample structure comprises 2000Åof n⁺-GaAs buffer $(N_D = 1 \times 10^{18} \text{ cm}^{-3})$, $1.5\mu \text{m}$ of n-AlGaAs clad $(N_D = 5 \times 10^{17} \text{ cm}^{-3})$, 250Åof i-AlGaAs spacer, the GaAs-AlAs coupled quantum wells layer, 250Åof i-AlGaAs spacer, $1.5\mu \text{m}$ of p-AlGaAs clad $(N_A = 5 \times 10^{17} \text{ cm}^{-3})$



Fig.1 Potential profile of coupled quantum wells and the corresponding electron eigenwave functions.

and 500Åof p⁺-GaAs cap (N_A = 1.5×10^{19} cm⁻³). The aluminium content in all the AlGaAs layers is fixed at 0.35. The sample is lapped to a thickness of 100-150 μ m and then AuGe and AuZn are thermally evaporated for the respective n and p electrodes.

3. EXPERIMENTAL RESULTS

Figure 2 shows the absorption current spectra obtained at room temperature by normal incidence of white light from a tungsten lamp. The electron symmetric-heavy hole symmetric, electron symmetric-light hole symmetric and electron antisymmetric-heavy hole antisymmetric absorption peaks are visible for a forward bias of 0.5V. These three peaks are quenched with an increase in the electric field applied via reverse bias. On the other hand, peaks related to the electron symmetric-heavy hole antisymmetric and elec-





tron antisymmetric-heavy hole symmetric transitions emerge and then approach each other. A single peak at 773.5nm is obtained with -6V. The electric field dependence of the various transitions energies and absorption current peaks, assuming a built-in field of 26 kV/cm, is shown in Fig. 3. The respective red and blue shifts of the absorption peaks of electron symmetric-heavy hole symmetric and electron antisymmetric-heavy hole antisymmetric transitions and the merging of the electron symmetric-heavy hole antisymmetric and electron antisymmetric-heavy hole symmetric peaks indicate the transition of the coupled system to an uncoupled set of quantum wells.

Waveguide absorption measurements were carried out by end-fire coupling of the laser light from a tunable Ti-sapphire laser into the planar waveguide by an objective lens and the output light was detected by a Si photodiode. TE and TM mode absorption correspond to the cases where the electric field of the optical wave is polarized parallel or perpendicular to the plane of the grown layers respectively. It should be noted that due to the polarization dependence of the dipole moments of electron-heavy hole and electronlight hole transitions, TE mode light interacts with both transitions, while TM mode light only interact with electron-light hole transitions⁵. The length of the planar waveguide sample measured is 250μ m.

The variation of output power of the planar waveguide sample relative to that at zero bias with applied voltage is shown in Fig. 4. First of all, at a wave-



Fig.3 Transition energy levels for GaAs-AlAs coupled quantum wells at various transverse electric fields. Solid lines are derived from numerical calculations, while black dots are data from absorption current spectroscopy.

length of 794nm, which is detuned 10nm away from the absorption edge, the relative output power falls with applied voltage for both TE and TM modes as in the case of normal isolated quantum wells. This is due to the electron symmetric-heavy hole symmetric and electron symmetric-light hole symmetric absorption peaks approaching the wavelength of interest. It should be noted that the large shift of the light hole related peak results in a relative output power of -24dB for the TM mode with a bias of -5.5V. The relative output power for TE mode is much reduced as the wavelength of 794nm falls within the tail of the absorption peak of the electron symmetric-heavy hole symmetric transition at zero bias.

On the other hand, the polarization dependence of absorption at the bandedge of 784nm is different. With an increase in the applied voltage, the electron symmetric-heavy hole symmetric peak red-shifts and quenches very rapidly. This leads to an effective blue shift of the absorption edge as can be seen from the absorption current spectra. As a result, the relative output power for the TE mode increases with applied voltage and a value of 5dB is achieved at -5V. However, in the case of the TM mode where only interaction with the light hole is possible, the wavelength of 784nm is still detuned away from the electron symmetric-light hole symmetric peak and when this peak approaches the wavelength of interest with increased applied voltage, the relative output power drops. In contrast to the TE mode, a relative output power of -5dB is obtained at -5V for the TM mode. It is interesting to note that this is in direct contrast to polarization independent switching, which is achievable in parabolic potential quantum wells⁶).

4. CONCLUSIONS

We have studied the polarization dependence of electroabsorption in coupled quantum wells embedded in a planar waveguide structure. Mutually op-



Fig.4 Variation of relative output power with reverse bias for wavelengths of (a) 794nm, which is detuned away from the absorption edge and (b) 784nm, which is at the bandedge.

posite characteristics of the TE and TM mode electroabsorption are obtained at the absorption edge and relative output powers of 5dB and -5dB are achieved respectively, for a driving voltage of -5V at 784nm. At a wavelength detuned away from the absorption edge, both TE and TM modes display the usual drop in relative output power with applied voltage and a large variation in the TM mode of -24dB with -5.5V at 794nm is also obtained. This unique polarization dependence of electroabsorption in coupled quantum wells may contribute to the development of novel optical devices.

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