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Hot electron birefringence and absorption in tunnel-coupled quantum wells due to real space transfer

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Abstract. Birefringence and absorption modulation under longitudinal electric field in the tunnel-coupled GaAs/AlGaAs quantum wells have been found and investigated in the spectral region corresponding to intersubband electron transitions. The observed phenomena are explained by electron heating in electric field and electron transfer in real space. The equilibrium absorption spectra at different lattice temperatures are analyzed too.

Introduction

The radiation corresponding to intersubband transitions in quantum wells (QW) of semiconductor heterostructures usually lies in the mid and far infrared region ($\lambda >$ 5 μm). A lot of devices such as mid and far infrared photodetectors and modulators, cascade laser and fountain laser with optic pump [1, 2, 3, 4] are based on intersubband transitions of electrons. The physical processes leading to light modulation in simple rectangular QW under longitudinal electric field were investigated in [5, 6]. In this paper we study absorption and birefringence modulation under electron heating with longitudinal electric field in specially designed tunnel-coupled GaAs/AlGaAs quantum wells.

1 Samples

The investigated structure contained 150 pairs of GaAs/$Al_xGa_{1-x}As$ QW, separated by the wide barriers (20 nm). The surface concentration of electrons was $N_S = 5 \times 10^{11}$ cm^{-2}.

The states with the energies $\varepsilon_1 = 88$ meV and $\varepsilon_4 = 316$ meV are generated by the first (narrow) well and the states $\varepsilon_2 = 120$ meV and $\varepsilon_3 = 235$ meV by the second (wide) well. The energy interval $\varepsilon_3 - \varepsilon_2$ was about CO_2-laser quantum energy (117 meV) and the interval $\varepsilon_2 - \varepsilon_1$ was less then the optical phonon energy ($\hbar\omega_0 = 37$ meV). These conditions had to ensure electrooptical modulation of CO_2-laser radiation.

2 Equilibrium absorption spectra

The transitions between neighbor levels generated by the same QW give the most contribution to intersubband absorption. The optical matrix elements for such transitions are the greatest: $|M_{23}|^2 = 1$; $|M_{14}|^2 = 0.89$. For transitions between levels generated by

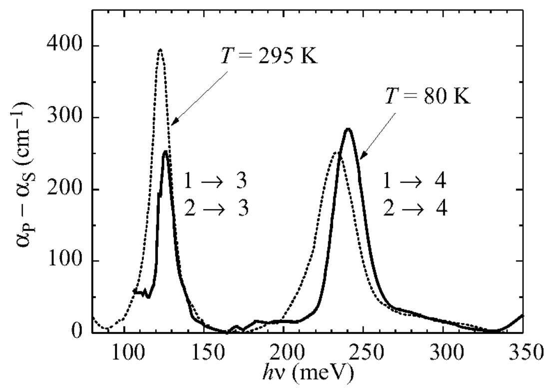

Fig 1. Equilibrium absorption spectra for two temperatures.

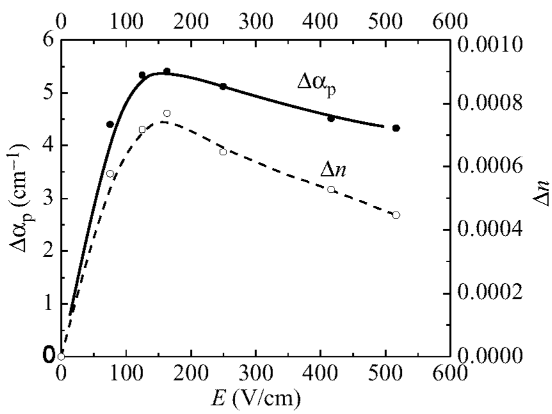

Fig 2. Absorption coefficient variation for p-polarized light and birefringence modulation versus longitudinal electric field.

different QW the optical matrix elements are less: $|M_{13}|^2 = 0.16$; $|M_{24}|^2 = 0.0062$ (in a.u.).

There are two absorption bands in equilibrium absorption spectra shown in Fig. 1. The longwavelength band corresponds to transitions $\varepsilon_1 \to \varepsilon_3$ and $\varepsilon_2 \to \varepsilon_3$, and the shortwavelength one is related to transitions $\varepsilon_1 \to \varepsilon_4$ and $\varepsilon_2 \to \varepsilon_4$.

3 Electrooptical investigations

This experiments were carried out with the help of CO_2-laser radiation at a lattice temperature $T_0 = 80$ K. The pulse electric field was applied parallel to plane of QW. Multipass waveguide geometry of the samples was used for input of radiation. The absorption coefficient variation dependence upon longitudinal electric field intensity is presented in Fig. 2. Modulation of absorption coefficient α was found only for light of p-polarization and there was no modulation for light of s-polarization. It corresponds to selection rules for intersubband transitions.

Due to these selection rules QW have a strong optical anisotropy: refractive index

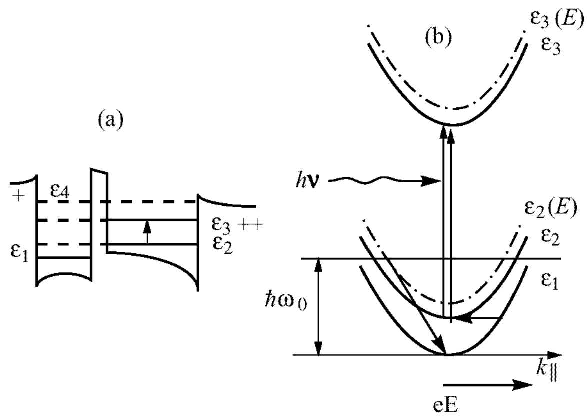

Fig 3. Potential relief with considering of the space charge (a); heating and redistribution of the electrons between subbands ε_1 and ε_2 under electric field E (b).

n is different for waves of p- and s-polarization. This difference is changed in electric field. Values of $\Delta\alpha_p$ and $\Delta n = \Delta\,|n_p - n_s|$ are connected by Kramers–Kronig relations. Dependence Δn upon electric field determined experimentally is shown in Fig. 2 too. It is similar to dependence $\Delta\alpha_p(E)$. Let us discuss these results. The potential of QW is distorted due to space charge of electrons located in the wells and space charge of impurity ions situated in the barriers. The approximate potential relief of our QW with considering such distortion is shown in Fig. 3. The potential deformation results in shifting down levels ε_2 and ε_3 and decreasing difference $\varepsilon_2 - \varepsilon_1$. Without external electric field the electrons are in the first subband and are located in the narrow well. Under effect of external longitudinal electric field the average electron energy increases due to electron heating. The electrons transit to the second subband on account of scattering and it leads to increasing absorption connected with the transitions $\varepsilon_2 \to \varepsilon_3$. The region of increasing absorption in Fig. 2 is explained with a filling the second subband. Again the other factors appear in strong electric fields. The electrons occupying subband ε_2 are mostly located in the wide well while the electrons of subband ε_1 belong to the narrow well. So with intersubband transitions the redistribution of electrons happens in the real space and levels ε_2 and ε_1 shift. Therefore the part of electrons in the subband ε_2 causing absorption decreases. Due to strong scattering by optic phonons, the number of electrons with the energy $\varepsilon > \hbar\omega_0$ is small. All this leads to decreasing electroabsorption with a field. Besides more strong heating of the electrons in the subband ε_2 leads to intensive scattering with optical phonon emission and their returning to the first subband. So in strong electric fields electroabsorption is saturated and then decreases.

The theoretical calculations are consistent with experimental data.

Conclusion

Optical phenomena connected with intersubband electron transitions in tunnel coupled quantum wells have been investigated. The observed birefringence and absorption modulation under longitudinal electric field have been explained by electron heating and electron transfer in real space.

Acknowledgments

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References

[1] B. F. Levine. *J. Appl. Phys.* **74** R1 (1993).
[2] J. Faist, F. Capasso, D. L. Sivco, C. Sirtori, A. L. Hutchinson, A. Y. Cho. *Science* **264** 553 (1994).
[3] O. Gauthier-Lafaye, S. Sauvage, P. Boucaud, F. H. Julien, R. Prazeres, F. Glotin, J.-M. Ortega, V. Thierry-Mieg, R. Planel, J.-P. Leburton, V. Berger. *Appl. Phys. Lett.* **70** 3197 (1997).
[4] E. Dupont, D. Delacourt, V. Berger, N. Vodjdani, M. Papuchon. *Appl. Phys. Lett.* **62** 1907 (1992).
[5] L. E. Vorobjev, E. A. Zibik, Yu. V. Kochegarov, S. N. Danilov, D. A. Firsov, A. A. Toropov, T. V. Shubina, E. Towe, D. Sun. *Semiconductors* **29** 588 (1995).
[6] L. E. Vorobjev, I. I. Saidashev, D. A. Firsov, V. A. Shalygin. *JETP Lett.* **65** 549 (1997).