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INFLUENCE OF PHOTO-MODULATION ON REFLECTANCE OF HETERO NIPI SUPERLATTICES

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The effect of room temperature photo-modulation on the reflectance of GaAs/AlGaAs hetero NIPI superlattices is reported. We propose a modulation mechanism which produces first derivative functional lineshapes in weak modulation limit. This model gives a good explanation of all the experimental phenomena.

Hetero NIPI superlattices, a combination of doping superlattices (or NIPI structures) and compositional superlattices(such as the GaAs/AlGaAs system), have many novel preperties.[1] In GaAs/AlGaAs hetero NIPI structures the doping layers, i.e. the AlGaAs layers, have large bandgap. The small bandgap layers i.e. the GaAs layers, remain undoped. Similar to selectively doped heterostructures,[2] there exist tilted triangular potential wells at the heterointerfaces, which confine the carriers to form quantized states. In this structure the electrons and holes are spatially seperated, just like in conventional NIPI structures.[3] Because both electrons and holes occupy only weakly broadened quantized states, transitions between the distinct subbands are much easier to be resolved in photoluminescence(PL).[4] Although photo-modulated reflectance (or photoreflectance, PR) has been widely used in the studies of microstructures in semiconductors,[5-12] PR of hetero NIPI superlattices, to our knowledge, has not been reported until now. In this paper, we report on the influence of photo-modulation intensity and its wavelangth on the reflectance of hetero NIPI superlattices. We propose a modulation mechanism which explains all the experimentally observed phenomena.

The samples with the energy band diagram shown in Fig.1 were grown by molecular beam epitaxy(MBE). The n(Si)- and p(Be)-doped

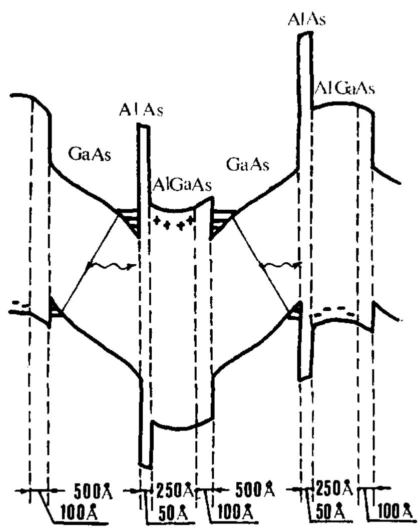

Fig.1 Energy band diagram of hetero NIPI superlattices

AlGaAs layer thicknesses are 250Å, the doping levels are about $1\text{-}2\times10^{18}cm^{-3}$. The thicknesses of undoped GaAs layers are 500Å. 100Å undoped AlGaAs and 50Å undoped AlAs spacer layers, respectively, keep the donors and acceptors away from the GaAs layers, in order to suppress impurity scattering and reduce the impurity induced level broadening of the subbands in the tilted triangular wells. The mole fraction of Al is 0.3. The two dimensional carrier concentrations determined by Hall measurements are $N_{2D}^{300K}=3.4\text{-}4\times10^{11}cm^{-2}$.

Fig.2 shows the room temperature PR spectra of sample No.4777 at different modulation intensities. The modulation(pump beam) wavelength is 6328Å. With the increase of the pump beam intensity, the features in PR are gradually disappear. Our experiments also show that when the wavelength of the pump beam is larger than a critical value (which corresponds to the AlGaAs bandgap), the PR lineshapes appear to be phase reversed then. In the following we develop a simple model to explain the experimental results.

Similar to conventional NIPI structure and compositional superlattice[3], the hetero NIPI superlattices represent a quasi-two dimensional system. The dielectric function can be written as follows:

$$\epsilon=\epsilon_1+i\epsilon_2=1-\sum_i I_i \ln(E-E_{gi}+i\Gamma_i) \qquad (1)$$

where E_{gi}, Γ_i are the threshold energy and broadening parameter of a two dimensional critical point; I_i is the integrated oscillator strength; ϵ_1 and ϵ_2 are, respectively, the real and imaginary parts of the dielectric function ϵ. Summation is over all the critical points. For modulation spectroscopy, we have the relation[13]

$$\Delta R/R=\alpha\epsilon_1+\beta\epsilon_2 \qquad (2)$$

where $\Delta R/R$ is the relative change of reflectance of the material and α, β are Seraphin's coefficients. Let P be the pump beam intensity, the dielectric function modulated by photo-injection of carriers has then the first derivative functional form

$$\Delta\epsilon=\sum_i\left[\frac{\partial\epsilon}{\partial E_{gi}}\frac{\partial E_{gi}}{\partial P}+\frac{\partial\epsilon}{\partial\Gamma_i}\frac{\partial\Gamma_i}{\partial P}+\frac{\partial\epsilon}{\partial I_i}\frac{\partial I_i}{\partial P}\right] \qquad (3)$$

just like in conventional NIPI structures[12] and compositional superlattices[9,10].

In the weak modulation limit, neglecting the influence of the modulation on broadening parameter Γ and integrated oscillator strength I, we have

$$\Delta\epsilon\propto\sum_i\frac{\partial\epsilon}{\partial E_{gi}} \propto\sum_i I_i(E-E_{gi}+i\Gamma_i)^{-1} \qquad (4)$$

Based on (2) and (4), we can calculate the theoretical PR spectrum in the weak modulation limit(Fig.3), where we use a finite triangular well approximation and take $m_e^*=0.0665m_o$, $m_{hh}^*=0.34m_o$, $m_{lh}^*=0.094m_o$, $Qc=0.60$[14] and $N_{2D}=4\times10^{11}cm^{-2}$. These values yield an effective bandgap of $E_g^{eff}=1.338eV$ at 300K. The assignment of the experimentally observed transitions and the calculated transition energies are listed in Table I, where mnh(1) represents the transition from the mth electron subband to the nth heavy(light) hole subband. It can be seen that the theoretical calculations are in good accordance with the experiments.

With the increase of the pump beam(say, $\lambda=6328$Å) intensity, the photo-injection of carriers neutralizes more of the ionized impurities (donors and acceptors), which flattens the tilted potential wells. In other words, the concentrations of two dimensional electron gas (2DEG) and two dimensional hole gas (2DHG)

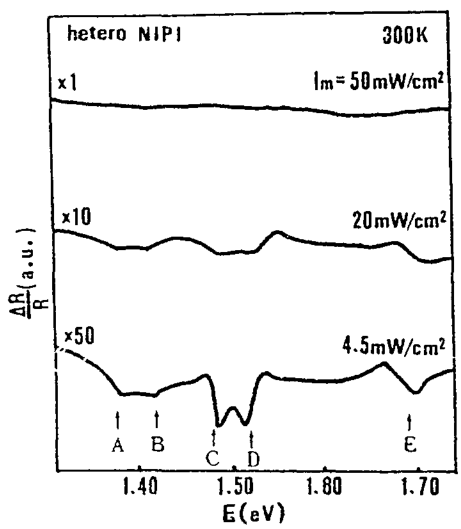

Fig.2 PR spectra of sample No.4777 at different modulation intensities using a wavelength of 6328Å

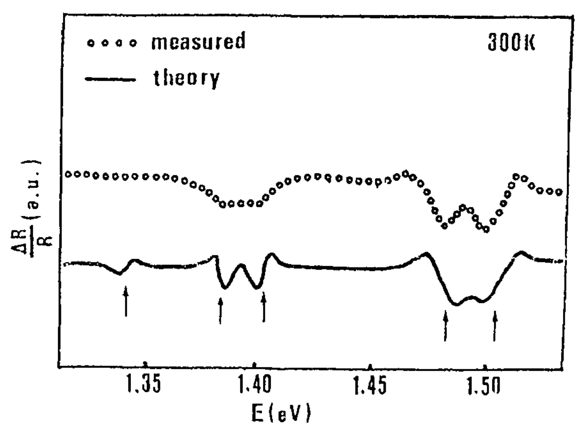

Fig.3 Comparison of the theoretical PR spectrum with the experimental one in the weak modulation limit. The parameters chosen are described in the text.

Table I Observed and calculated PR transition energies and their assignment

Number of features	exp.(eV)	theo.(eV)	assignment
A	1.386	1.386	10h
B	1.409	1.404 1.414	101 11h
C	1.485	1.474 1.485	22h 211
D	1.508	1.506 1.518	32h 221
E	1.693	1.682	551(?)

in the quantum wells are modulated by photo-injection of carriers. The decrease of the 2DEG and the 2DHG concentrations in the wells, however, results in the modulation of the Stark shift of the quantized states and the drop of the PR signal. The PR features associated with the quantized interband transitions can even disappear, as observed in the experiments.

When the wavelength of the pump beam is increased so that its energy is less than the bandgap of AlGaAs, the photo-injection of carriers will only increase the concentrations of the 2DHG and the 2DEG in the tilted triangular wells in GaAs. In this case the wells become steeper. In contrast to the phenomena observed with the energy of the pump beam larger than the bandgap of the AlGaAs layers,this will of course make the PR lineshapes phase reversed.

In summary,we have for the first time studied the dependence of photoreflectance of hetero NIPI superlattices on the modulation intensity and its wavelength.We propose a mechanism which gives a good explanation of all the experimental results.

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