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Excitons in {311} oriented superlattices: optical anisotropies

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Abstract : The optical response of excitons in (311) oriented GaAs/AlAs superlattices grown by atomic layer molecular beam epitaxy at low substrate temperature is studied by piezoreflectance. Several transitions are detected showing heavy hole and light hole character. The heavy hole transitions are more polarized along the $[\bar{2}33]$ direction whereas the light hole ones are more polarized along the $[01\bar{1}]$ direction. According to the calculation based on an empirical tight binding model, the observed optical anisotropy is related to the different components of the superlatices valence band wave functions.

When quantum well or superlattices heteroestructures are grown on substrates with orientations different from {100} or {111} one may expect the appearance of in-plane optical anisotropies. Such anisotropies are related to the different components of the valence band wave functions[1-2]. At the same time it has been observed that high index surfaces may have reconstructions[3]. The growth of heteroestrutures on those surfaces can give rise to quantum wire (QW) or quantum dot (QD) like structures[4]. To separate the anisotropy resulting from the different components of the valence band and that due to QW-like or QD-like structure is then very important. In this report we address this problem.

It has been recently shown that using conventional molecular beam epitaxy (MBE) strong coupled QW-like structure can be obtained in (311) oriented GaAs/AlAs heteroestructures[4]. Such QW-like structures are due to the faceting formation of the surface (GaAs or AlAs) observed by reflection high-energy electron diffaction (RHEED). Such faceting is not observed if the subtrate temperature is decreased (T_s= 350 °C) and the growth is performed by atomic layer molecular beam epitaxy (ALMBE)[5]. In this paper we present the results of the optical properties of long period (113) AlAs/GaAs SL ($AlAs_{74}$ $GaAs_{17}$ and $AlAs_{58}GaAs_8$ where the subindexes are expresed in monoloyers) grown by ALMBE at a substrate temperature of 350 ° C .

We have performed piezoreflectance measurements at 80 K. For this purpose the samples were thinned to a thickness of 100 μm and glued into a piezoelectric transducer. The experimental setup is standard[6] and the modulated reflectivity was recorded for the two in-plane polarizations : $[01\bar{1}]$ and $[\bar{2}33]$. The principal effect of the modulated strain field is to modulate the energy of the transitions , so the two spectra ($[01\bar{1}]$ and $[\bar{2}33]$) give directly the in-plane optical anisotropy of the transitions.

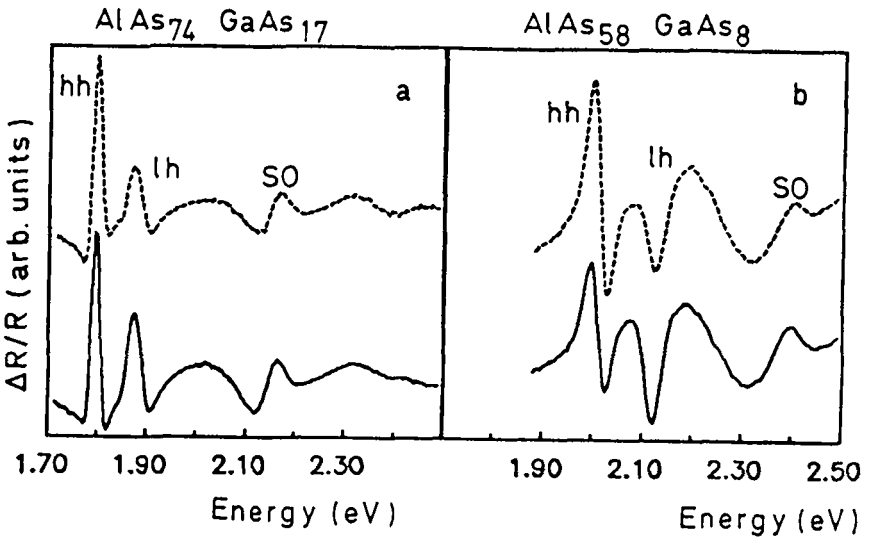

Figure 1 : Piezoreflectance spectra of the $AlAs_{74}GaAs_{17}$ (a) and $AlAs_{58}GaAs_{8}$ (b) superlattices obtained at 80K, with light polarized parallel to $[01\bar{1}]$ (solid line) and parallel to $[\bar{2}33]$ (dashed line).

In figure 1 we present the spectra of the two samples studied here. We observe several transitions which we label in the standard way : heavy hole (hh) like, light hole (lh) like and spin orbit (so) like. As the thickness of the GaAs well decreases the relative intensity of hh like feature of the $[01\bar{1}]$ spectra compared to the $[\bar{2}33]$ spectra decreases, the opposite is true for the lh like feature.The intensity ratios are presented in table 1.

$I_{[01\bar{1}]} / I_{[\bar{2}33]}$	$AlAs_{74}GaAs_{17}$		$AlAs_{58}GaAs_{8}$	
	Exp.	Theory	Exp.	Theory
hh	.9	.86	.7	.77
lh	1.4	1.22	1.5	1.36
so	1.2	1.04	1.	.94

Table 1 : Experimental and theoretical intensity ratio of the different transitions observed.

In order to interpret these results we have performed a calculation based on an empirical tight binding (ETB) hamiltonian with a sp^3s^* basis[7],and interactions up to nearest neighbours only, including spin-orbit spliting[8] ,together with the surface Green function matching (SGFM) method[9]. The ETB hamiltonian is transformed to the new axis corresponding to the (311) interfaces,that is :

$$x = 1/\sqrt{2}\ (0,1,-1)$$
$$y = 1/\sqrt{22}\ (-2,3,3)$$
$$z = 1/\sqrt{11}\ (3,1,1)$$

We have assumed that the valence band offset of lattice matched GaAs/AlAs heteroestructures is not direction dependent[10] and use the same value as that of (100) heteroestrutures. The empirical matrix elements used in this calculation and more information about the calculation are given in ref 11.

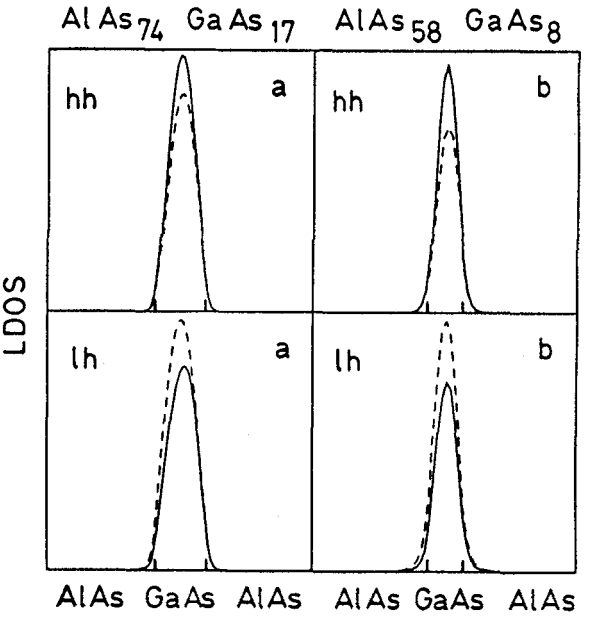

Figure 2 : Spatial distribution of the amplitudes of the p_x component (dashed line) and p_y component (solid line) for the first hh and lh levels of the samples $AlAs_{74}GaAs_{17}$ (a) and $AlAs_{58}GaAs_8$ (b).

As an example we present in figure 2 the spatial distribution of the amplitudes of the p_x and p_y components of the local density of states (LDOS) of the first two levels of the valence band at $k=0$, which correspond to the first hh and first lh respectively for the two samples. For clarity only the envelope of the LDOS of the anion layers have been presented. As can be observed the p_x component is larger in the lh levels than in the hh ones. We associate the observed anisotropy to the difference in orbital components.

To have an idea of the relative intensity of the transitions we have perform a calculation where the intensity of the optical transition is proportional to the overlap of the p_x ($[01\bar{1}]$ spectra) and p_y ($[\bar{2}33]$ spectra) components of the first level of the valence band with hh, lh or so character and the s component of the first level of the conduction band having a strong s component. In that calculation we neglect the matrix elements between nearest neighbours, which is not a bad approximation due to the difference between its value and that of the intra atomic transitions. The results of such calculation are presented in table 1 , and as can be observed the agreement is quite good.We have assumed that the dipolar matrix elements of the As-As transition is three times that of the Ga-Ga or Al-Al[12], similar results are obtained using other relations.

We would like to point out that the observed optical anisotropies cannot be not related to any kind of quantum well wire structure, not present in our samples, but to different orbital components

of the valence band wave functions.

In conclusion, we have studied the optical properties of long period 311 AlAs/GaAs SL. We have observed in-plane optical anisotropies of the different transitions. Such anisotropies are related to the different orbital character (p_x and p_y) of the hh and lh levels.

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