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# STUDY OF ELECTRIC FIELD EFFECTS ON THE ELECTRONIC STRUCTURE OF QUANTUM WELLS BY RESONANT RAMAN SCATTERING

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Resonant Raman scattering measurements in an external electric field have been performed in $\mathrm{GaAs/Al}_x\mathrm{Ga}_{1-x}\mathrm{As}$ quantum wells. Changes in both the energy and intensities have been observed as a function of the applied electric field and the width of the wells. The variation of intensities depends significantly on the "allowed" ($\delta n = 0$) or "forbidden" ($\delta n \neq 0$) character of the transitions. Photoluminescence excitation spectra are presented for comparison. All the results are explained by a model calculation based on a tight-binding scheme including mixing of valence states. The agreement between theory and experimental results is good for the dependence of the transition energies and probabilities on both the applied field and the well widths.

An important and increasing effort has been devoted in the last years to the characterization by optical means of the electronic structure of semiconductor quantum wells (QW) and superlattices (SL), and particularly, to its dependence on externally applied electric fields [1–7]. this effort is not only justified by the longing for a better knowledge of the involved phenomena, but also for its potential interest in device design.

Resonant Raman scattering (RRS) provides in principle some advantage over other optical techniques: It helps in the study of the spatial localization of the electronic transitions observed [8,9], and it should be more sensitive than optical absorption or photoluminescence excitation (PLE) because of the sharper singularities involved in the RRS cross section [10].

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Nevertheless, only one study, to our knowledge, has been published [11] of the electric field effect on the RRS in GaAs/$Ga_{1-x}Al_xAs$ SL's. The main result of this work is a decrease of the $E_{33h}$-transition intensity (that occurring between the 3rd heavy-hole and the 3rd electron state) with increasing electric field.

We present data of RRS and PLE on the effects of an externally applied electric field on the electronic transition frequencies and intensities of multiquantum well (MQW) samples of GaAs/$Ga_{1-x}Al_xAs$ for different well widths. The results, both for "allowed" transitions (those involving electrons and holes of the same subband index) and "forbidden" ones (those occurring between subbands with different index) are interpreted in terms of a theoretical model based on a tight-binding approach and including mixing of heavy- and light-hole states [12]. Tight-binding parameters are adjusted to give the GaAs gap at 1.518 eV [13] but no explicit excitonic effects are included. The valence band offset is taken as $0.3\Delta E_g$ ($\Delta E_g$ is the gap difference of the two components of the SL). More details about this calculation can be found elsewhere [14].

The samples used are made of 5 GaAs QW separated by 250 Å thick barriers of $Ga_{0.57}Al_{0.43}$ As grown by MBE on an $n^+$-GaAs substrate.

Before evaporating the QW a 0.5 μm thick layer of $n^+$-GaAs followed by 900 Å of $n^+$-$Ga_{1-x}Al_xAs$ and 540 Å intrinsic $Ga_{1-x}Al_xAs$ were deposited. On top of the wells a 1200 Å thick layer of $Ga_{1-x}Al_xAs$ and a Ni electrode (60 Å) were evaporated. The intrinsic carrier concentration was estimated to be $2\times10^{14}$ $cm^{-3}$ for the two samples. RRS and PLE spectra have been obtained at 4 K using a LD-700 dye laser. The flat band potential of the samples is about +1.1 V (+ means and − reverse bias). The applied voltages are converted to electric fields using the equation describing the depletion layer due to the Schottky barrier formed by the sample and the electrode [15]. Two different samples with well widths of 50 and 230 Å have been studied.

Results on RRS are shown in fig. 1a for the 230 Å sample for different applied voltages. The observed peaks correspond to transitions between the $i$th conduction band state and the $j$th valence band one, and are labeled $E_{ij}$ independently of their light or heavy character (this character is in fact mixed by the electric field). These peaks correspond to "outgoing" resonances, i.e. when the energy of the outgoing light coindcides with the transition.

The main facts observed are: (i) a decrease of the intensity of the $E_{21}$ and $E_{24}$ peaks with applied field and a growth of the $E_{14}$ peak and of the one located at 1.593 eV for +0.4 V, which splits into $E_{22}$ and $E_{23}$ for −0.8 V, and (ii) a change of the peak frequency with field at different rates (maximum for $E_{21}$ and minimum for $E_{24}$). PLE spectra corresponding to +0.4 and −0.8 V are shown in fig. 1b. One observe that the "contrast" of the spectra is much higher for RRS than for PLE (note the logarithmic scale of fig. 1a and the linear one in fig. 1b). In fact the $E_{23}$ peak for −0.8 V is not distinguishable from the noise in the PLE spectra.

RRS data corresponding to the $E_{11}$ transition of the 50 Å sample are shown in fig. 2. In this case the resonance is much broader than those for the 230 Å sample,

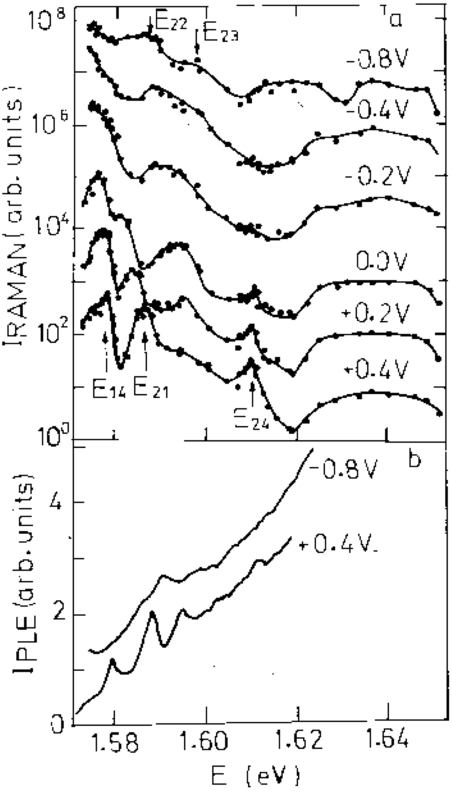

Fig. 1. (a) RRS spectra of the MQW of 230 Å well width as a function of the applied voltage (+means forward and − reverse bias). The ordinate origins are shifted one decade for correlative spectra. (b) PLE spectra of the same sample for the extreme values of the applied voltage. Ordinate origins are shifted by 1 arbitrary unit.

and does not shift appreciably with field. The resonance intensity decrease by a factor of 3 with increasing field in the voltage range studied. We could not find any trace of resonance for the phonons of the barrier. This indicates that no important leakage of the well wave functions into the barriers takes place.

All these experimental facts are well accounted for by our model. The frequency changes with the field for the 230 Å sample observed both by RRS and PLE are shown in fig. 3 (the RRS data are shifted 36 meV (the LO phonon frequency of GaAs) to lower energies to convert them into "incoming" resonances [16]). Here the transitions are also labeled with the explicit heavy- or light-hole character for zero field. The agreement between theory and experiment is very good. For the 50 Å sample our model gives a frequency which is 15 meV higher than the experimental one. This difference corresponds to the exciton binding energy estimated for

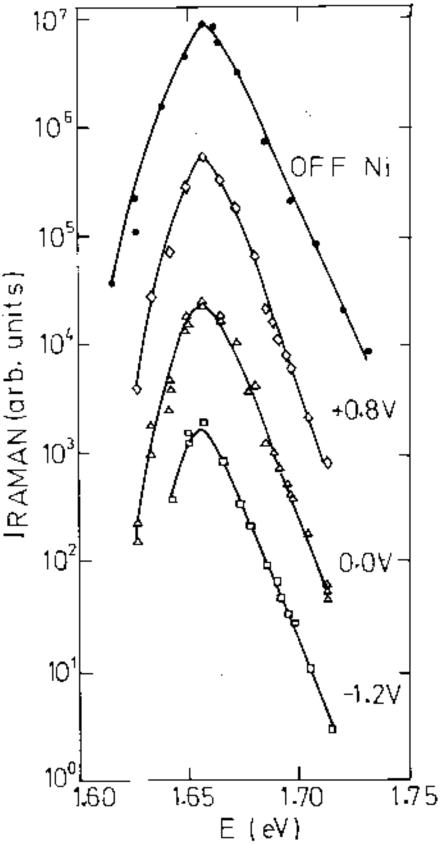

Fig. 2. RRS spectra of the 50 Å MQW as a function of the applied voltage. Ordinate origins are shifted one decade. Solid lines are a guide to the eye.

narrow wells [17]. On the other hand, the model gives a frequency change of 1 meV for the resonance in the field range studied, again in good agreement with the experimental results.

As for the intensities of the Raman resonances they also are qualitatively explained by the model. Thus the $E_{11}$ peak of the 50 Å sample (fig. 2) is essentially allowed and correspondingly its intensity decreases for increasing fields. For the 230 Å sample there is a strong mixing of the valence band states, and the transition probabilities calculated with our model give decreasing intensities with the applied field for the $E_{21}$ and $E_{24}$ peaks (fig. 1a) even if they are both forbidden at zero field (fig. 3) and increasing intensities for $E_{14}$, $E_{22}$ and $E_{23}$ in the studied field range [14].

In conclusion the RRS and PLE study of the present MQW's reveals a complex behaviour of frequencies and intensities for different electric fields and well widths.

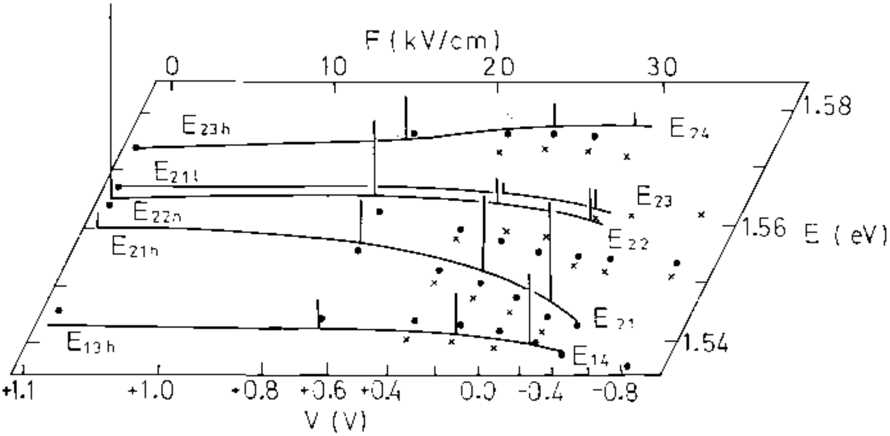

Fig. 3. Comparison of the experimental frequencies (crosses for RRS and dots for PLE) on the 230 Å MQW with the calculations (solid lines) as a function of the applied voltage. (The correlation between voltage and field is explained in the text.) Vertical bars are the calculated transition probabilities, to be compared with the peak intensities of fig. 1.

The main experimental results are nevertheless well explained by the theoretical model presented. On the other hand, RRS has been shown to be more sensitive than PLE, especially for high energy transitions. However, this advantage has to be weighted by the larger spread of the experimental points, and the much more cumbersome and time consuming nature of the RRS measurements compared with PLE.

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