ENHANCED AND QUENCHED RAMAN SCATTERING BY INTERFACE PHONONS IN SEMICONDUCTOR SUPERLATTICES: WHAT ARE THE DEFECTS?

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We report on the magnetic field and power density dependences of resonant Raman scattering by interface phonons in GaAs-$Al_xGa_{1-x}As$ superlattices. Strong photoexcitation leads to quenching of the nominally forbidden (and sample-dependent) scattering while a dramatic enhancement of the intensity is observed in the presence of a magnetic field. Alternative mechanisms that partially account for the experimental findings are discussed.

Raman scattering (RS) by interface phonons in polar semiconductor superlattices has attracted much attention in the past few years.[1-5] This is motivated, in part, by the interesting lattice dynamic properties of these electric-field-carrying modes[1,6,7] and also by their role in many aspects of electronic transport.[6,8-10] Within a continuum model, interface vibrations are the solutions of $\nabla^2\phi=0$; ϕ is the associated electrostatic potential.[9,11] For wave-vectors $\vec{k}$ normal to the layers, $\phi\equiv0$.[11] Hence, interface modes are strictly Raman-forbidden in the standard backscattering configuration and only defects, which account for the breakdown in $\vec{k}$-conservation, can explain their presence in the spectra.[5,12] Recently, we reported the observation of a large H (magnetic field)-induced enhancement of RS by interface modes in GaAs-$Al_xGa_{1-x}As$ quantum-well structures (QWS's).[13] Instead of defects, we proposed that intra-Landau-level excitations participate in the $H\neq0$ scattering to make up for the missing wavevector.[13] However, further results have shown that effects due to these excitations are possibly minor.[14] In particular, we could not verify the oscillatory behavior of the intensity that is expected[13] for processes involving intra-Landau-level scattering. The latter findings bring us back to the consideration of defects in both cases: $H=0$ and $H\neq0$, and to the question of their identification. In this work we describe our latest results on the H-and P(power-density)-dependence of interface-phonon RS in GaAs-$Al_xGa_{1-x}As$ structures. The new data suggest that the $H=0$ and $H\neq0$ scattering are related. Specifically, we find that samples showing strong interface features at $H=0$ exhibit intensity quenching at high P's. This behavior is analogous to that of structures which only show interface phonons at high fields.[13] We also present data on thin-layer superlattices exhibiting H-enhancement and P-quenching which is very similar to that shown[13] by quasi-two-dimensional QWS's. This indicates that electron confinement is not an essential ingredient of the problem. The defect that can be turned on by a magnetic field and turned off by increasing P has not as yet been clearly identified. Below, we consider interface roughness and ionized impurities as possible candidates and discuss, in each case, the difficulties involved in the interpretation of the data.

The superlattices were grown by molecular beam epitaxy on (001)GaAs substrates. Raman data on three samples: A,B and C will be reported here. The A-structure consists of 100 periods of 50Å GaAs-20Å AlAs and it is nominally undoped. Sample B has 30 periods of 70Å GaAs-100Å $Al_{0.3}Ga_{0.7}As$; it was intentionally doped with Be acceptors ($p\sim10^{16}$ cm^{-3}) at the well-centers. Results on a structure identical to B, but undoped, show nearly the same H- and P-behavior.[14] Sample C is undoped and has 50 periods of 67Å GaAs-106Å $Al_{0.37}Ga_{0.63}As$. Spectra were recorded in the $z(x,x)\bar{z}$, $z(x,y)\bar{z}$ and $z(x',x')\bar{z}$ backscattering geometries with the samples held at T=2-5K; z is normal to the layers, x,y are along the [100] and [010] directions and $x'\equiv[110]$. Interface-phonon scattering could only be observed using laser energies ω_L in the vicinity of exciton resonances,[5,12,13] and it is strongest for the configurations $z(x,x)\bar{z}$ and $z(x',x')\bar{z}$ (this indicates the importance of intraband Fröhlich coupling to the electronic system, see Refs. 5 and 12). In the case of sample A, we investigated in detail the resonance with

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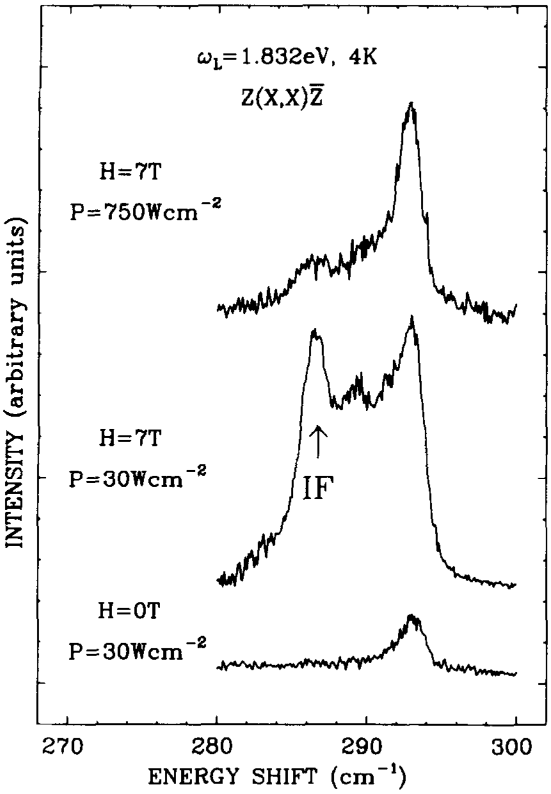

Figure 1. Raman spectra of sample A (50ÅGaAs-20Å AlAs) showing H-induced enhancement and P-induced quenching. IF denotes interface phonons. The features at higher energies are LO modes confined to GaAs slabs. The field is at an angle of 30° with respect to the superlattice axis.

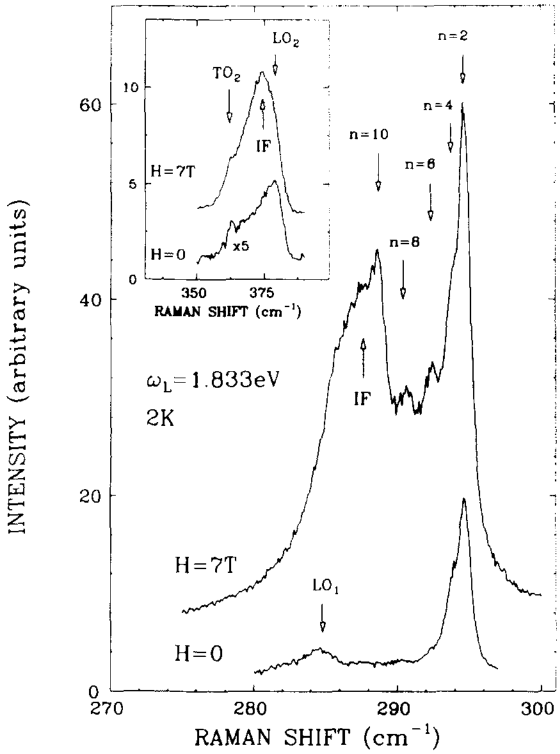

Figure 2. Raman spectra of sample B (70ÅGaAs-100Å $Al_{0.3}Ga_{0.7}As$) at 0 and 7T; the field is normal to the layers. Labels IF and n denote, respectively, interface- and confined LO-modes. The inset shows scattering by AlAs-like phonons. LO_2 and $TO_2(LO_1)$ indicate the positions of AlAs(GaAs)-like modes in bulk $Al_{0.3}Ga_{0.7}As$. The configuration is $z(x',x')\bar{z}$. P=30 Wcm^{-2}.

the exciton derived from LH1[15] which is associated with the lowest conduction and light-hole states of the wells. For samples B and C, we studied the HH2 resonance[15] involving the first-excited conduction and heavy-hole levels.

Figure 1 shows Raman spectra of sample A. Interface phonons are labeled IF. They are weak and poorly resolved in the H=0 spectrum, and show a dramatic increase in intensity at H=7T. The other features at 293, 291 and 289 cm^{-1} correspond to confined longitudinal-optical(LO) phonons of A_1 symmetry with, respectively, n=2,4 and 6(n-1 is the number of nodes in the displacement pattern).[4] The confined modes also exhibit H-induced enhancement. At high P's, quenching of this effect is observed as shown by the top spectrum. Results for sample B are reproduced in Fig. 2. The enhanced scattering by interface- and confined LO-modes is qualitatively similar to that of structure A. This also applies to the P-dependence of the spectra (see Ref. 13 for the data as a function of P in sample B). The enhancement for B is largest when the field is normal to the layers[13] whereas, for A, the maximum signal is obtained at an angle of ≈30° between $\vec{H}$ and the superlattice axis. Results for structure C are shown in Fig. 3. The parameters of this sample are close to those of sample B. Unlike structures A and B, C exhibits strong interface-phonon features at H=0. The P-dependence at zero field for the latter sample (Fig. 3) shows quenching effects that are comparable to those for samples A and B at H=7T. The increase in intensity with H is monotonic for all samples, up to 7T.[14]

As it was stated earlier, Raman backscattering by interface modes in superlattices at H=0 is necessarily an extrinsic effect, i.e., defect-induced.[5,12] For H≠0 intra-Landau-level excitations could (in principle) restore $\vec{k}$-conservation,[13] but our experiments have so far failed to reveal their participation in the scattering. This suggests that the H-induced enhancement is also extrinsic and the question is: What are the defects? Comparing the P-behavior of sample B at high fields and of sample C at H=0, the similarities seem to indicate that there is a single defect responsible for the scattering. Interface roughness in the form of islands[16] provide a partial explanation for our findings. The idea is that scattering that is resonant with excitons localized at islands does not conserve $\vec{k}$. The enhancement due to the field can be the result of an increase in the density of localized states: as the exciton shrinks, it can become trapped by islands of smaller dimensions.[17] A problem with this scenario is that it does not easily account for the

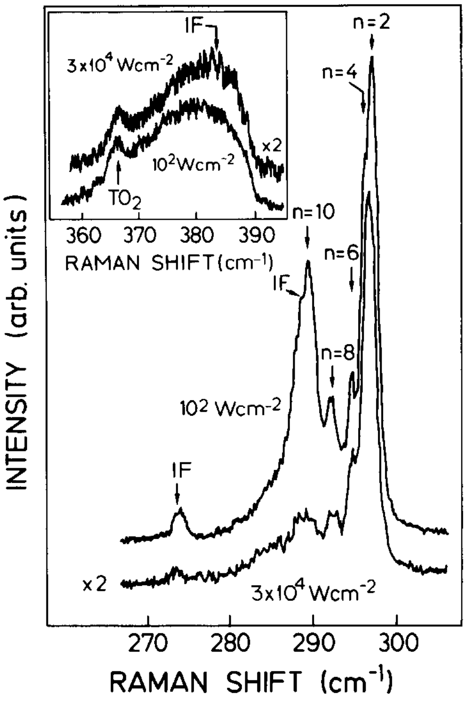

Figure 3. Raman spectra of sample C (67ÅGaAs-106Å $Al_{0.37}Ga_{0.63}As$) at two different power densities. H=0. Labels n and IF are the same as in Fig. 2. The scattering geometry is $z(x',x')\bar{z}$ and ω_L=1.833eV.

P-dependence of the spectra; filling of localized levels at high P's is important for the lowest-lying excitons, but not for the higher-lying states. Nevertheless, it is possible that the intensity-quenching results from a different process, namely, screening of the electron-phonon interaction by photoexcited carriers.[18] If this were the case, one would still need to explain the selectivity of the screening (i.e., the fact that interface modes quench faster than confined excitations) and the results showing nearly the same scattering properties for thin-layer superlattices (sample A) and QWS's (B and C). Neutral impurities are unlikely candidates for solving the problem since, as mentioned above, nominally undoped and acceptor-doped structures exhibit comparable effects. Ionized impurities are a different matter; the P-dependence of the spectra could be explained by considering neutralization of these charged defects through trapping of photogenerated carriers. Unlike interface roughness, however, impurities do not supply us with a simple mechanism for understanding field-induced enhancement. Larger exciton-impurity scattering in the presence of the field is a possibility that needs to be explored further.

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