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Analysis of Strained Superlattice Spectral Shapes

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A strained-well SL structure is suppose to yield the highest possible initial peak polarization, P_0, but since the barriers for CB electrons are high, relatively strong depolarization is expected during transport to the surface. Transport depolarization can be minimized if the barrier layers are allowed to be strained, but this may preclude the highest possible P_0. Strained-well GaAsP/GaAs and AlInGaAs/AlGaAs and strained-barrier AlInGaAs/GaAs structures have each been successfully optimized to yield an extraction polarization of P_{ext}~90%. Is it possible to decide, based on the P_{ext} and *Q*E spectra, if either P_0 or transport depolarization varies in a self-consistent manner from one type of structure to the next when P_{ext} is kept constant? Calculated spectra for various assumed conditions for an InAlGaAs/AlGaAs flat-CB strained superlattice (SLS) structure are illustrated in **Fig. 1**.[Mamaev '06a]

For high peak P_e, the rate of *hh1-lh1* virtual transitions near the absorption edge—given by the *broadening parameter* γ—must be low. Broadening is dominated by impurity scattering. The energy dependence of γ reflects the variation in the density of final states in the *hh1* miniband and is therefore sensitive to any smearing of the hole density of states—given by the *smearing parameter* δ—which contributes *lh-e* transitions to the absorption at the *hh-e* absorption edge. An increase of the separation of the *hh1*- and *lh1*-minibands will decrease δ.

The recent highly-strained-well AlInGaAs/AlGaAs SLS grown at Ioffe, sample # 7-307, is shown in **Fig. 2**. The dopant density in this SLS is 3×10^{17} cm^{-3}, only slightly lower than the 5×10^{17} cm^{-3} in the SLAC GaAsP/GaAs SLS [Maruyama '04], and thus the effects of dopant density on γ and δ may not be significantly different for these two types of SLS.

Data from various experimental and theoretical spectra have been compiled in **Table 1** and are discussed below.

LE-slope of QE. Theory indicates that when γ and δ are increased, the slope of the QE spectrum at excitation wavelengths longer than the absorption edge will decrease. Only at SPbSPU is the QE consistently measured sufficiently beyond the absorption edge to permit an accurate measurement of the slope. An examination of SPbSPU experimental data indicates that the slope is always about 0.3 orders-of-magnitude per 10 meV, consistent with $\gamma=\delta=30$ meV. (For $\gamma=\delta=10$ meV, the slope should double.[Gerchikov '04],[Mamaev '06a])

The highly strained AlInGaAs/AlGaAs strained-well SL structures seem to consistently have a well-defined knee in the QE spectrum near the HE edge of the polarization peak. The presence of the knee may indicate a lesser effect of photoabsorption in the BBR and via surface and defect states.

HE-slope of P_{ext}. Theory also indicates that if γ and δ are increased, the slope of the HE side of the polarization peak should decrease. The experimental data is inconsistent; e.g., the slope for #5-337, **Fig. 3**, which has Pe<90%, has a slope of 20% per 10 meV, whereas #7-307, also a strained-well SLS, but with P_e=91.5%, has a slope of only 9% per 10 meV.

Width of P_{ext} peak. One might expect that the width of the polarization peak varies with *hh-lh* splitting. This does seem to be true although the experimental data is scattered. In addition, the top of the polarization peak should become more square as γ and δ are decreased, although this isn't born out by theory. Nonetheless, the structures with the highest polarization do seem to have the greatest widths and appear qualitatively to be more square.

Conclusion. Although the methodology for measuring the spectral properties to obtain the data shown in **Table 1** was rather crude, the data does point to the absence of a consistent pattern to distinguish high and low values of P_0 when P_{ext} is kept constant.

Table 1. Comparison of Strained Superlattice Spectra Shapes

Sample	*Where Measured?*	*$P_{e,max}$ (%)*	*QE LE-Slope (O per 0.01 eV)*	*P HE- Slope (% per 0.01 eV)*	*P Width @80% (eV)*
Ioffe 5-337 '03 (Strained-W)	SLAC	88-91	0.3	20	0.06
Gerchikov '04 S'ed-B) $\gamma=\delta=10$	Theory	-	1	18	0.09
$\gamma=\delta=30$	Theory	-	0.37	7.5	0.08
Mamaev '04 (S'd-B)	SPbSPU	91	0.3	10	0.1
Maruyama '04 (S'ed-W)	SLAC	86	0.3	14	0.12
Nishitani '05 (S'ed-W)	Nagoya	92(±6)	0.25	14	0.12
Ioakeimidi '05 (S'ed-B) #5501	SLAC	84-90	0.37	9.4	0.074
Ioakeimidi '05 (S'ed-B) #5-777	SPbSPU	91	-	10.6	0.11
Mamaev '06a (S'ed B) $\gamma=\delta=10$	Theory	-	0.62	14	0.10
$\gamma=\delta=30$	Theory	-	0.36	7	0.11
Mamaev '06b (S'ed-W) #7-307	SPbSPU	91.5	0.3	9	0.14

References:

Gerchikov '04: SPIN 2004, p. 908.
Mamaev '04: SPIN 2004, p. 913.
Maruyama '04: APL 2004.
Nishitani '05: JAP 2005.
Ioakeimidi '05: PST 2005.
Mamaev '06a: SPIN 2006.
Mamaev '06b: Private communication.

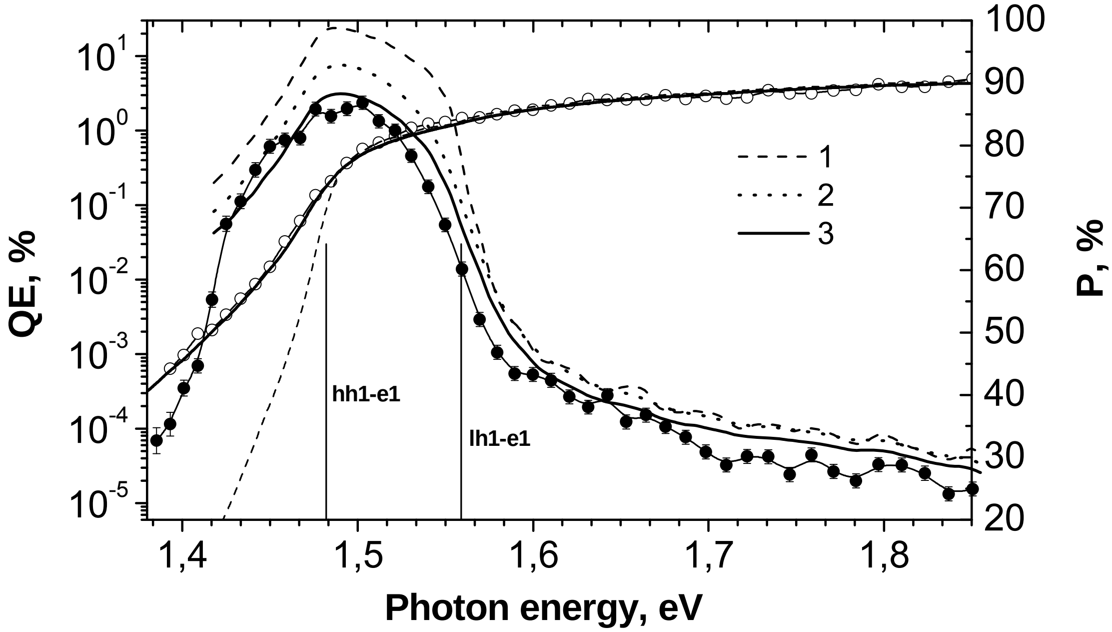
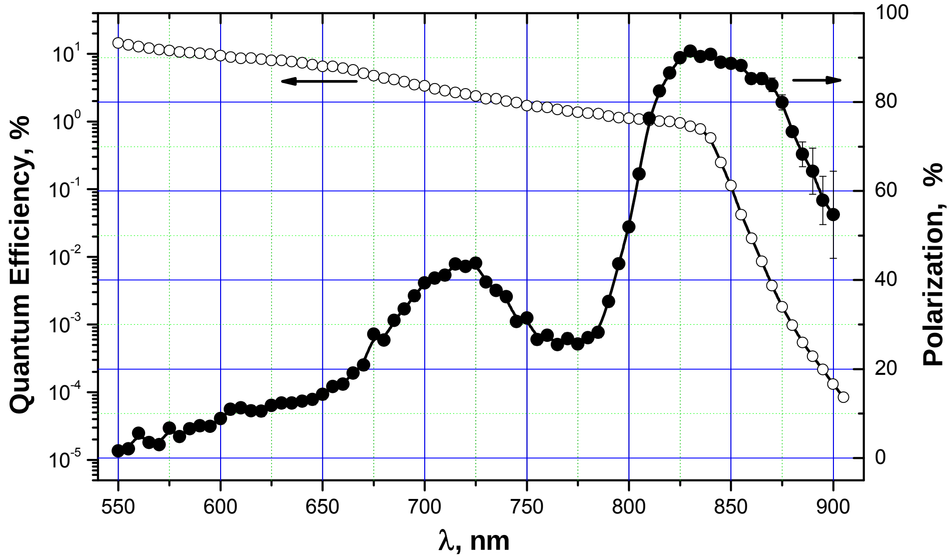


Fig. 1. Spectra of the polarization and *QE* for sample with $In_{0.25}Al_{0.27}Ga_{0.48}As$(4nm)/GaAs(1.1nm) SL. Experimental results: closed circles - polarization, open circles - quantum efficiency. A thin line connects the data points. Results of the calculation: (1) $\gamma = \delta = 10$ meV, (2) $\gamma = \delta = 30$ meV, (3) $\gamma = \delta = 30$ meV with polarization losses B_s =5%. [Mamaev '06a]

SPbSPU data. November 28, 2006
AlInGaAs/AlGaAs Superlattice 7-307. Room temperature



AlInGaAs/AlGaAs Superlattice sample 7-307.
P = 91.5% and QE = 0.85% @ λ = 830 nm

Fig. 2. Sample #7-307 (Christmas Greetings 2006).

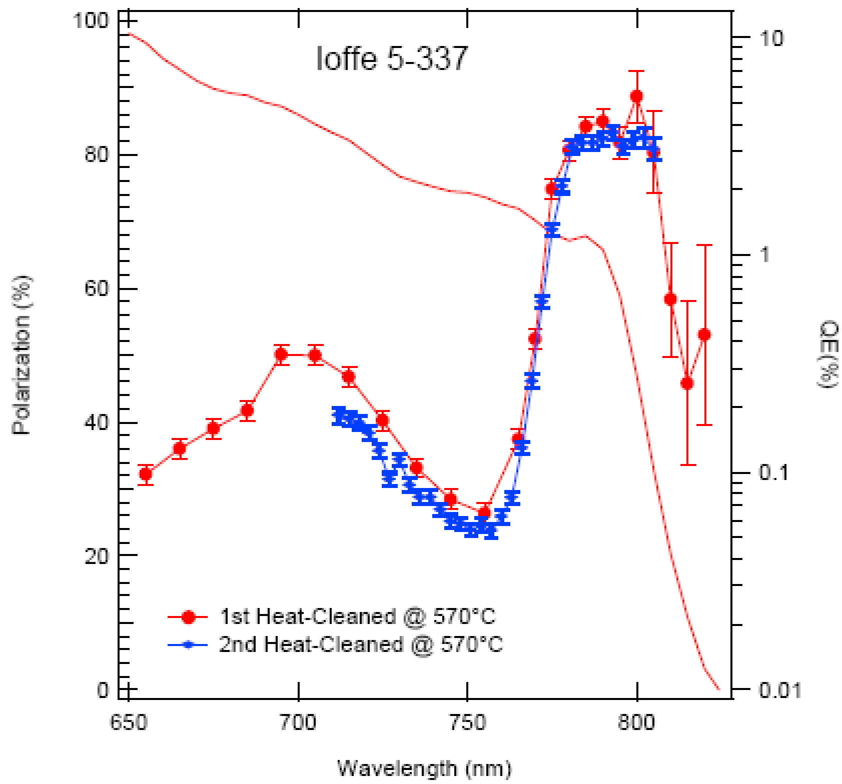


Fig. 3. Sample #5-337 (Received 3-5-2003).