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POLARIZED ELECTRON EMISSION FROM STRAINED GaAs/GaAsP SUPERLATTICE PHOTOCATHODES *

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Spin-polarized electron photoemission has been studied for GaAs/GaAs$_{1-x}$P$_x$ strained superlattice cathodes grown by gas-source molecular beam epitaxy. The superlattice structural parameters are systematically varied to optimize the photoemission characteristics. The heavy-hole and light-hole transitions are reproducibly observed in quantum efficiency spectra, enabling direct measurement of the band energies and the energy splitting. Electron-spin polarization as high as 86% with over 1% quantum efficiency has been observed.

1. Introduction

Single strained GaAs photocathodes were introduced for the SLAC polarized electron source in 1993. After 10 years of experience with many cathode samples, the maximum polarization using the GaAs/GaAsP single strained-layer cathode remains limited to 80%, while the quantum efficiency (QE) for a 100-nm epilayer is only 0.3% or less. Two known factors limit the polarization of these cathodes: 1) a limited band splitting; and 2) a relaxation of the strain in the surface epilayer since the 10-nm critical thickness for the 1% lattice-mismatch is exceeded. Strained superlattice structures, consisting of very thin quantum well layers alternating with lattice-mismatched barrier layers are excellent candidates for achieving higher polarization since they address these two issues. Due to the difference in the effective mass of the heavy- and light-holes, a superlattice exhibits a natural splitting of the valence band, which adds to the strain-induced splitting. In addition,

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each of the superlattice layers is thinner than the critical thickness. This paper presents an investigation of strained GaAs/GaAsP superlattice samples in which the principal structural parameters are systematically varied to define the optimum structural details [1].

2. Experiment

Four parameters specify the superlattice structure: the GaAs well width, the $GaAs_{1-x}P_x$ barrier width, the phosphorus fraction, and the number of periods. Table 1 summarizes the eleven superlattice samples studied here.

Table 1. Strained $GaAs/GaAs_{1-x}P_x$ superlattice samples.

Sample	Well (nm)	Barrier (nm)	x	No. Period
1	4	4	0.25	12
2	4	4	0.30	12
3	4	4	0.36	12
4	4	4	0.40	12
5	4	4	0.36	9
6	4	4	0.36	15
7	4	4	0.36	20
8	4	4	0.36	30
9	3	3	0.36	16
10	4	3	0.36	14
11	5	3	0.36	12

Figure 1 shows the polarization and QE as a function of the excitation photon energy for Sample 3. The peak polarization is 86% with 1.2% QE. The QE spectrum shows two distinct steps as expected from the density of states for the two dimensional structure. The first step corresponds to the heavy-hole (HH) band to the conduction band excitation, while the second step corresponds to the light-hole (LH) band to the conduction band excitation. The energy splitting between the HH- and LH-bands is 82 meV.

When the phosphorus fraction is varied, the lattice-mismatch between the well and the barrier changes, thus the superlattice strain can be varied. While a larger phosphorus fraction generates a larger strain and therefore a larger energy splitting between the HH and LH bands, the strain within a layer may relax. For Samples 1, 2, 3, and 4, the phosphorus fraction was increased from 0.25 to 0.40 keeping the total superlattice thickness

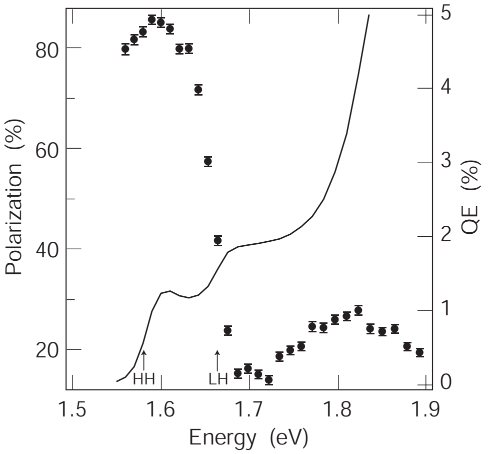

Figure 1. Polarization and QE as a function of excitation light energy

constant. Figure 2 shows the peak polarization and QE anisotropy [2] as a function of the phosphorus fraction for constant total thickness. The measured HH-LH energy splitting is also shown in the figure. Although the HH-LH energy splitting increased from 60 meV to 89 meV, the peak polarization and the QE anisotropy did not change significantly at about 85% and 1.7%, respectively, indicating that this degree of energy splitting is sufficient to maximize the spin polarization.

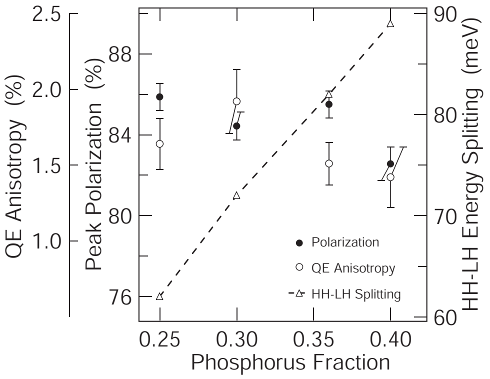

Figure 2. Peak polarization (solid circles), QE anisotropy (open circles), and measured HH-LH energy splitting (triangles) as a function of the phosphorus fraction.

Using samples with the same well (4 nm)/barrier (4 nm) thickness and phosphorus fraction (x=0.36), the total superlattice thickness was varied. Figure 3 shows the peak polarization and QE anisotropy as a function of the number of superlattice periods using Samples 3, 5, 6, 7, and 8. Also shown in Figure 3 is the strain relaxation in the superlattice GaAs well layers measured using x-ray diffraction. Although the well width is smaller than the critical thickness, increased superlattice periods will result in strain relaxation. As the strain relaxation steadily increases with the superlattice thickness, the peak polarization and QE anisotropy appear constant at 85.5%, and 1.5%, respectively, for less than 15 periods. At more than 20 periods, however, the peak polarization decreases and the QE anisotropy increases rapidly.

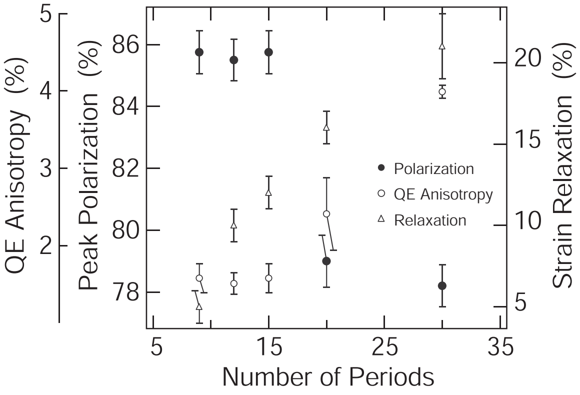

Figure 3. Peak polarization (solid circles), QE anisotropy (open circles), and strain relaxation (triangles) as a function of the superlattice period.

The QE and polarization spectra can be understood in terms of the superlattice band structure. In particular, the band structure is very sensitive to the well width. Using samples with the same barrier thickness (3 nm) and phosphorus fraction (x=0.36), the well thickness was varied while the number of periods was adjusted to keep the same total superlattice thickness. Figure 4 shows the spin polarization as a function of the excitation photon energy for Samples 9, 10, and 11. As the well thickness was increased, the polarization spectra shifted towards lower energy. The peak polarization was, however, independent of the well thickness. While the changes in the band structure differentially affected the polarization spectra for energies above the polarization peak, the maximum polarization remained constant at about 86%, indicating that the valence-band splitting for this range of well thicknesses was sufficient.

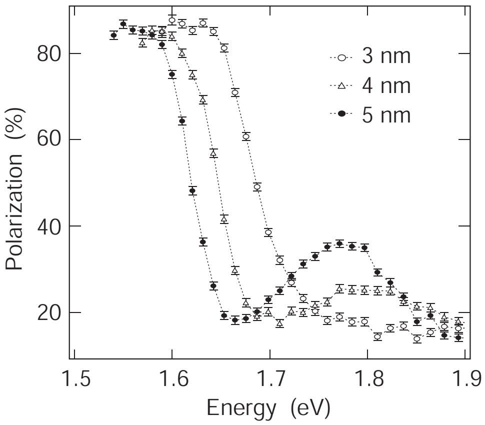

Figure 4. Polarization as a function of the excitation light energy for the three samples with a different well width; 3 nm (open circles), 4 nm (triangles), and 5 nm (solid circles).

3. Conclusions

We have investigated polarized photoemission from strained GaAs/GaAsP superlattice structures by systematically varying the superlattice parameters. The heavy- and light-hole excitations have been observed for the first time in the QE spectra, enabling direct measurements of the heavy- and light-hole energy bands. Spin polarization as high as 86% is reproducibly observed with the QE exceeding 1%. The superlattice structures have superior polarization and QE compared to the single strained-layer structures of GaAs/GaAsP photocathodes.

References

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