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13. ABSTRACT (Maximum 200 words) The lowest energy interband transitions in AlGaAs/AlAs quantum wells involve electrons localized in the AlAs X-valleys and holes confined in the AlGaAs layers. These transitions are indirect in both real as well as in k-space and are accompanied by strong replicas of the GaAs and AlAs phonons. When a magnetic field is applied perpendicular to the layers a large reduction in the recombination intensity is observed. This reduction is attributed to magnetic field induced localization of the carriers which results in a reduction of the electron-hole wavefunction overlap. We have also studied photoluminescence spectra from type-II, n-type, modulation doped GaAs/AlAs quantum wells due to radiative recombination of electrons localized in the AlAs X-valleys with holes confined in the GaAs layers. In the presence of a magnetic field the emission spectra exhibit features associated with transitions among the AlAs X-valley Landau levels and photo-injected holes. The slopes of these transitions yield an effective mass $m^*=0.44$ for the electrons.				
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Statement of the problem studied

The GaAs/AlAs and related systems such as AlGaAs/AlAs offer an added flexibility not present in the widely studied GaAs/AlGaAs system. This flexibility is provided by the AlAs X-valleys which lie approximately 190 meV above the bottom of the GaAs conduction band. By tailoring the dimensions of the GaAs layers one can control the position of the confinement subbands with respect to the energy of the AlAs X-valleys. The latter have a large k-vector which makes them a useful tool for the study of phonons and their interactions with band electrons. In this project we have carried out a systematic study of AlGaAs and GaAs/AlAs quantum wells. In the AlGaAs/AlAs system the band alignment as well as the nature of the interband transitions and the role of the phonons was investigated. In addition, magnetic localization of carriers was observed in this type-II system and proved to be a powerful tool for the study of interfaces. The properties of a two-dimensional electron gas with non-zero k-vector were investigated in especially designed n-type modulation doped GaAs/AlAs quantum wells. The photoluminescence (PL) spectra from these structures associated with the electron gas populating the AlAs X-valleys were studied as function of magnetic field. All the samples used in this project were grown by molecular beam epitaxy (MBE) at the Army Research Laboratory.

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**Summary of the Results**

Below we summarize the results of the above project. The report is organized in three subsections.

**I. Interband transitions in AlGaAs/AlAs Quantum wells**

We have studied interband transitions in undoped as well as n-type modulation doped AlGaAs/AlAs heterostructures. The PL spectra from the undoped structures contain features associated with type-I transitions in the AlGaAs layers as well as type-II transitions that involve electrons in the AlAs X-valley minima and holes confined in the AlGaAs layers. In the undoped samples the type-II transitions are dominated by phonon replicas (GaAs LO, AlAs TA, AlAs LO, AlAs LO+TA, GaAs 2LO, AlAs 2LO), while the zero-phonon  $X_{xy}h_1$  and  $X_zh_1$  transitions are much weaker. The  $X_{xy}$  minima lie below the those of the  $X_z$  band for the samples we studied. In modulation doped structures (doped with Silicon donors in the AlGaAs layers) the intensities of the zero-phonon  $X_{xy}h_1$  and  $X_zh_1$  transitions and those of the phonon replicas are comparable. The electron density in the AlAs X-valleys was measured using the van der Pauw method. Areal densities between  $10^{11}$  and  $10^{12}$   $\text{cm}^{-2}$  were achieved, depending on the donor density in the AlGaAs layers. The change in the relative intensities of the zero-phonon transitions and their phonon replicas is attributed to the partial population of the  $X_z$  valleys by electrons. The  $X_zh_1$  transitions are pseudo-direct in k-space and thus are not accompanied by strong phonon replicas. The latter are characteristic of the  $X_{xy}h_1$  transitions which are indirect in both real as well as in k-space.

II. Magnetic field induced carrier localization in AlGaAs/AlAs quantum wells

We have observed evidence of carrier localization induced by an externally applied magnetic field  $B$  in AlGaAs/AlAs quantum wells. In these structures when a magnetic field is applied perpendicular to the layers, the cyclotron orbit radius  $(\hbar/Be)^{1/2}$  decreases and the electrons and holes which participate in the  $X_{h_1}$  type-II interband transitions are captured on shallow traps on the AlGaAs/AlAs interfaces and become immobile. Because carriers are localized the electron-hole wavefunction overlap decreases and results in a marked reduction of the recombination probability and thus the photoluminescence signal. When the sample temperature is raised electrons and holes become untrapped and are free to move along the AlGaAs/AlAs interfaces. As a result, the PL signal is less dependent on magnetic field. This work shows that the application of high magnetic fields is a powerful tool for the study of type-II interband transitions in which the participating electrons and holes straddle the interfaces of a heterostructure.

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III. Interband transitions associated with X-valley Landau levels in GaAs/AlAs quantum wells.

We have studied band-edge emission spectra in GaAs/AlAs quantum wells in which the  $X_z$  valleys of the AlAs layers are populated by a dense two-dimensional electron gas. The electrons originate from Silicon donors in two n-type AlGaAs layers grown on either side of the AlAs barriers. The GaAs well width is 50 Å, so that the AlAs X-valleys lie below the  $e_1$  confinement subband. Recombination across the gap is type-II with electrons confined in the AlAs and holes in the GaAs layers of the structure. The zero-phonon  $X_{h_1}$  line has weak replicas associated with the GaAs and AlAs phonons. The small relative intensity of these replicas indicates that the electrons populate the  $X_z$  (rather than the  $X_x$  or  $X_y$ ) valley. This is corroborated by the analysis of the PL spectra in the presence of a magnetic field B applied perpendicular to the structure's layers. In the presence of B the zero field emission band evolves into discrete features associated with the  $l=0$  and  $l=1$   $X_z$  valley Landau levels. The slope  $dE/dB$  of these transitions yields an in-plane effective mass  $m^*=0.44$ , consistent with  $X_z$  electrons.

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List of Publications

1. "Interband transitions in AlGaAs/AlAs quantum well structures", S.T. Lee, J. Haetty, A. Petrou, P. Hawrylak, M. Dutta, J. Pamulapati, P.G. Newman, and M. Taysing-Lara, Phys. Rev. B 53, 12912, (1996)
2. "Magnetic field induced localization of carriers in AlGaAs/AlAs multiple quantum well structures", J. Haetty, M. Salib, A. Petrou, T. Schmiedel, M. Dutta, J. Pamulapati, P.G. Newman, and K.K. Bajaj, Phys. Rev. B 56, 12364, (1997)
3. "Magnetically induced back transfer of electrons confined in wells to donor states in n-type modulation doped GaAs/AlAs quantum wells", M. Dutta, J. Pamulapati, P.G. Newman, J. Haetty, G. Kioseoglou, A. Petrou, T. Schmiedel, and P. Hawrylak, Physics of Low Dimensional Structures, 11/12, 103, (1997).
4. "Observation of interband transitions associated with X-valley Landau Levels in GaAs/AlAs quantum well structures", J. Haetty, G. Kioseoglou, A. Petrou, M. Dutta, J. Pamulapati, and M. Taysing-Lara, Phys. Rev. B 59, 7546, (1999).

List of Participating Scientific Personnel

1. S.T. Lee, PhD, 1996
2. J. Haetty, PhD, 1998
3. M. Salib, PhD, 1998
4. G. Kioseoglou, PhD candidate

Honors and Awards: The PI (A. Petrou) was made a Fellow of the American Physical Society in 1998.