Magnetic Field-Induced Direct-Indirect Bandgap Crossover in $Al_XGa_{1-x}As$

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Introduction

Knowledge of the direct-indirect crossover composition and energy in semiconductor alloys is often critical for optoelectronics design. On a more fundamental level, studying the direct-indirect crossover in terms of behavior in the vicinity of a critical point of a phase transition has proved to be challenging. There has been a question as to whether the crossover occurs at a well-defined critical composition and whether it is continuous or discontinuous. We used high magnetic fields up to 58 T to induce a direct-indirect transition in a single $Al_xGa_{1-x}As$ sample. Changes in the photoluminescence (PL) spectral lineshape and peak energy confirm that the direct-indirect crossover is a first-order phase transition but that it is broadened by alloy composition fluctuations [1].

Experimental

Photoluminescence (PL) measurements on an $Al_{0.376}Ga_{0.624}As$ sample were performed at the Los Alamos NHMFL with the 60 T Long-Pulse Magnet. Evolution of the PL peaks as a function of magnetic field and excitation intensity was probed at 1.6 K using a diode-pumped solid-state laser (515 nm).

Results and Discussion

Figure 1 (top) shows the progression of PL spectra in 1 T increments as the magnetic field is increased from 0 to 58 T. The PL peak energy (bottom) increases linearly, as expected for direct semiconductors, up to fields of ~ 40 T and then begins to decrease in energy at even higher fields. In conjunction with this peak energy "rollover', the PL lineshape also changes from a symmetric Gaussian curve at low magnetic fields to an asymmetric curve with a pronounced high energy tail. This change in the lineshape is indicatively of a sharp increase in the radiative lifetime associated with the direct-indirect transition, which allows carriers enough time to find the lowest energy states in the alloy. While the primary PL peak follows a rather continuous shift through the entire range of magnetic fields, there is evidence of two peaks associated with transitions from both the Γ and X conduction band edges immediately at the rollover. The coexistence of phases (in this case both direct and indirect bandgap transitions) is a distinguishing feature of a first order phase transition. However, the transition between these two peaks is broadened by the ensemble of statistically occurring composition fluctuations in the alloy, which undergo the direct-indirect crossover at slightly different fields.

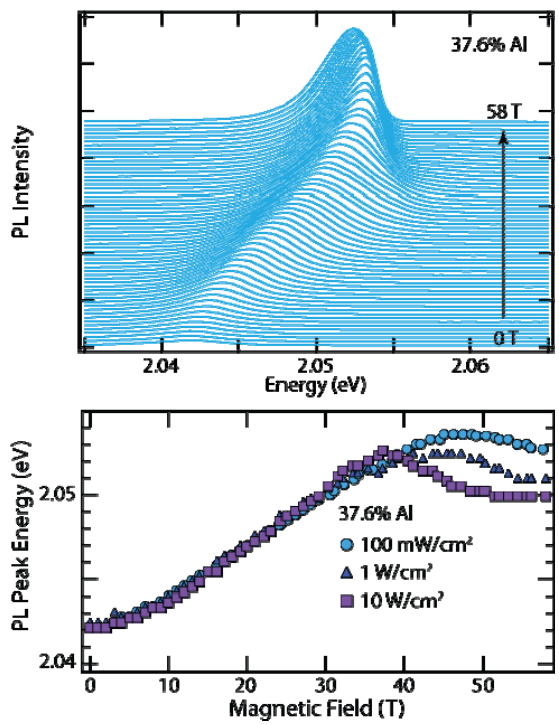

FIG. 1. (Top) Magneto-photoluminescence (PL) spectra of an $Al_{0.376}Ga_{0.624}As$ sample up to 58 T.
(**Bottom)** PL peak energies for the same sample as a function of magnetic field and excitation intensity.

Conclusions

Our study uses high magnetic fields to induce a direct-indirect crossover in a single $Al_{0.376}Ga_{0.624}As$ sample and shows that it is a first-order phase transition.

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References

[1] Alberi, K., *et al.*, Appl. Phys. Express, **7**, 111201 (2014).