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Interplay between strain, quantum confinement, and ferromagnetism in strained ferromagnetic semiconductor (In,Fe)As

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Recently, we have developed an n-type FMS, (In,Fe)As, grown by low-temperature molecular-beam epitaxy (LT-MBE) [1-3]. In this work, we investigated the effects of strain on the ferromagnetism and electronic structure of (In,Fe)As thin films. We show that the ferromagnetism of the compressive-strained (In,Fe)As thin films grown on the $(In_{1-y},Ga_y)As$ (y = 0.05, 0.1) buffer layers can be explained by the hydrostatic deformation effect (HDE) alone, while those of the tensile-strained (In,Fe)As thin films grown on the $(Ga_{1-z},Al_z)Sb$ (z = 0, 0.5, 1) buffer layers can be explained by HDE *and* the quantum confinement effect (QCE). The Curie temperature (T_C) of the (In,Fe)As layers strongly depends on the strain, which can be explained by the *s-d* exchange mechanism taking into account HDE and QCE.

The electronic structure and ferromagnetism of the (In,Fe)As layers were investigated by magnetic circular dichroism (MCD) spectroscopy. The solid circles in Fig. 1(a) show the E_1 peak shift of strained (In,Fe)As layers from the bulk value (2.61 eV). The dashed line is the theoretical E_1 peak shift due to HDE assuming that the hydrostatic deformation potential of the L band of (In,Fe)As is -13 eV. We found that the E_1 peak shift of the compressive-strained (In,Fe)As layers follows the theoretical line, but that of the tensile-strained (In,Fe)As layers lies higher than the theoretical line. This deviation can be explained by QCE [4]. Here, the quantum wells (QWs) consist of the InAs / (In,Fe)As double layers. The potential barriers of the QWs are the vacuum barrier at the surface of the top InAs layer, and the conduction band offset between the (In,Fe)As layer and the $(Ga_{1-z},Al_z)Sb$ buffer layer. The E_1 peak shift of tensile-strained (In,Fe)As is the sum of the red-shift due to HDE and the blue-shift due to QCE at the L band of the (In,Fe)As layers. Next, we investigated the effects of strain and quantum confinement on the ferromagnetism in (In,Fe)As. Solid diamonds in Fig. 1(b) show the experimental T_C of all the samples. We

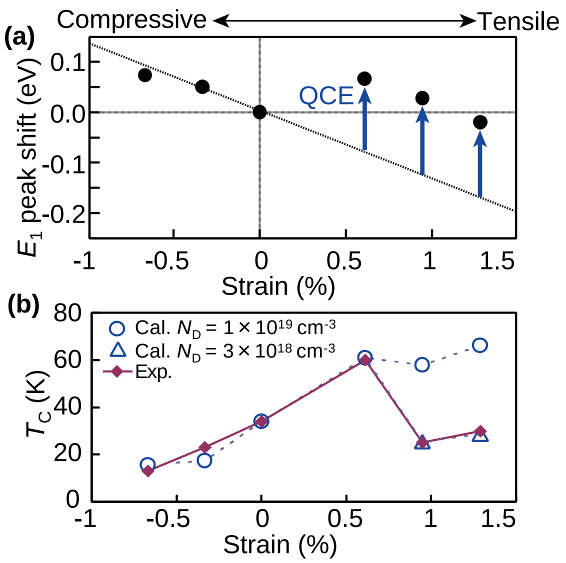

Fig. 1 (a) E_1 peak shift from the bulk value (2.61eV). Dashed line is the theoretical E_1 peak shift due to HDE assuming that the hydrostatic deformation potential of the L band of (In,Fe)As is -13 eV. Arrows indicate the blue-shift due to QCE. **(b)** T_C of all the samples, plotted as a function of strain (diamonds). Open circles and triangles are calculated T_C assuming an ionized donor density $N_D = 1\times10^{19}$ cm^{-3} and 3×10^{18} cm^{-3}, respectively.

found that T_C strongly depends on the strain, and reaches maximum for the (In,Fe)As layer grown on a GaSb buffer layer. In order to explain such a strong strain-dependence of T_C, we consider the *s-d* exchange mechanism in three (3D) and two dimensions (2D). In the 2D cases, we have performed self-consistent calculations using the Schrödinger and Poisson equations [4] to obtain the electron wavefunctions and the quantized levels at the Γ band of the (In,Fe)As layers. The calculated T_C, shown by open circles and triangles in Fig. 1(b), reproduces the experimental values very well. This work is supported by Grant-in-Aids for Scientific Research including the Specially Promoted Research, and the Project for Developing Innovation Systems of MEXT.

References

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