CONTROL OF MAGNETIC PROPERTIES OF FERROMAGNETIC SEMICONDUCTOR (Ga,Mn)As BY FABRICATION METHODS

Abstract

by

YongJin Cho

Ferromagnetic semiconductor alloy (Ga,Mn)As is studied using different fabrication methods, including doping. All (Ga,Mn)As samples were grown by either low temperature molecular beam epitaxy (LT-MBE) or ion implantation followed by pulsed laser melting (II-PLM). The structures of the samples are as follows: (i) (Ga,Mn)As /(Al,Ga)As heterostructures and (Al,Ga)As/ (Ga,Mn) As /(Al,Ga)As quantum wells modulation-doped by Be atoms in (Al,Ga)As layers; (ii) (Ga,Mn)As epilayers grown on GaAs substrates by either LT-MBE or II-PLM; (iii) Si-doped (Ga,Mn)As films grown on GaAs substrates.

First, we study how the ferromagnetic coupling in (Ga,Mn)As films is determined by Mn spins and holes using the modulation-doped (Ga,Mn)As /(Al,Ga,Be)As structures. At small values of hole concentration p the Curie temperature T_C of (Ga,Mn)As is seen to increase with increasing p, as expected from the p-d Zener model. However, as p continues to increase, this trend is reversed: at some point T_C begins to decrease, and eventually the ferromagnetism

of (Ga,Mn)As disappears altogether, in stark contrast with the p-d Zener model. Mechanisms which can lead to this behavior are discussed.

Second, we study the effect of by Mn interstitials and As antisites (defects which are inherent to LT-MBE-grown (Ga,Mn)As) on the magneto-crystalline anisotropy of this alloy; and we study the intrinsic magnetic anisotropy of (Ga,Mn)As using a nearly-freestanding ferromagnetic (Ga,Mn)As layers formed by II-PLM where these defects are virtually absent. In qualitative terms the material formed by II-PLM exhibits all magnetic anisotropy features commonly found in (Ga,Mn)As films fabricated by LT-MBE. Quantitatively, however, magnetic anisotropy of II-PLM (Ga,Mn)As is dominated by cubic anisotropy terms, which we attribute to smaller strain in the II-PLM material due primarily to the absence of Mn interstitials. One will note, however, that the II-PLM (Ga,Mn)As also exhibits a weak but finite uniaxial in-plane magnetic anisotropy similar to that observed in LT-MBE (Ga,Mn)As, the origin of which is not yet understood in either of these materials.

Last, we also investigate the effect of donor doping on $Ga_{1-x}Mn_xAs$ films using Si. Si acts as a compensating donor for the Mn acceptors in $Ga_{1-x}Mn_xAs$ alloys. For a $Ga_{1-x}Mn_xAs$ alloy with low Mn content (e.g., x = 0.033) the presence of Si decreases T_C compared to undoped $Ga_{1-x}Mn_xAs$. At higher Mn concentrations, however (e.g., for $x > 0.10$) we find that Si doping has the desirable effect of improving ferromagnetic properties of $Ga_{1-x}Mn_xAs$, including a significant increase of T_C. Although Si doping decreases p in $Ga_{1-x}Mn_xAs$, interestingly, we find that Si doping increases hole mobility at higher Mn concentration (e.g., x = 0.16). We ascribe this hitherto unknown effect to the effect of Si on the relative occupancy of holes in the impurity band.