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Title	分子線エピタキシーで成長した不純物注入GaAs層での電子間相互作用と局在スピンについての研究
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Citation	
Issue Date	2008-09
Type	Thesis or Dissertation
Text version	none
URL	http://hdl.handle.net/10119/4771
Rights	
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Study on electron interactions and possible localized spins in impurity-doped GaAs layers grown by MBE

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ABSTRACT

In impurity-doped semiconductors such as P-doped Si, direct evidence of the existence of localized spins was obtained by using electron spin resonance, electron nuclear double resonance and superconducting quantum interference device. However, the observed magnetic moments due to localized spins can be observed only at very low temperatures because of thermal excitation of carriers from shallow impurity levels to either conduction or valence bands. Electron-electron interactions are enhanced in disordered electronic systems such as impurity-doped semiconductors. By theoretical studies, it was predicted that ferromagnetic ordering can occur due to strong electron-electron interactions in these disordered electronic systems. This ferromagnetic ordering, however, has not yet been observed experimentally. In this thesis study, the unique ability of MBE was used to investigate the possible ferromagnetic ordering in impurity doped semiconductors in order to develop a new approach for introducing spin-degree of freedom into semiconductors for applications to the field of spintronics.

Beryllium/silicon pair δ-doped GaAs structures grown by molecular-beam epitaxy exhibit a Hall resistance which has a nonlinear dependence on the applied magnetic field and which is strongly correlated to the negative magnetoresistance observed under the applied magnetic field parallel to the δ-doped layers. Dependence of the occurrence of the nonlinear Hall resistance on the growth condition is investigated. A significantly large increase in both the magnitude and the nonlinearity of the Hall resistance is observed from samples whose GaAs buffer layers are grown under the condition of a low As/Ga flux ratio. Reflection high energy electron diffraction and electron microscope observations show that a faceted surface develops with the growth and postgrowth annealing of a GaAs buffer layer under the condition of a low As flux. From samples which have only Si δ-doped layers and exhibit the *n*-type conduction, such nonlinear Hall resistance is not observed. The nonlinearity of the Hall resistance of Be/ Si pair δ-doped structures depends on the single parameter B/T, where B and T are the applied magnetic field and the temperature, respectively. Based on these results, it is suggested that the nonlinear Hall resistance of Be/Si pair δ-doped structures is the anomalous Hall effect caused by localized spins in δ-doped layers.

High concentrations of donor and acceptor impurities were doped in GaAs layers

in order to form a highly disordered system, and their magneto-transport properties were investigated. With the low substrate temperature and the low growth rate, high concentrations of donor Si and acceptor Be were obtained, being up to $3\times10^{20}\,\mathrm{cm}^{-3}$ and $5\times10^{20}\,\mathrm{cm}^{-3}$, respectively, both of which are higher than the reported maximum values. Magneto-transport properties of Si- and Be-doped GaAs layers grown by molecular-beam epitaxy at low temperatures were studied in order to observe effects of electron-electron interactions enhanced by doping high concentrations of donor and acceptor impurities. The negative magneto-resistance was observed from n-type samples in the whole measured temperature range up to room temperature. Magneto-conductance curves above 150K are in close accord with calculations based on the localization theory, while those below 150K at high magnetic fields are explained with the theory of electron-electron interactions. The temperature-dependence of the inelastic scattering time which was derived from the magneto-conductance curves suggests that it is determined by electron-electron collisions at temperatures below 150K. Results of samples with different impurity concentrations show that doping of higher impurity concentrations along with lower carrier concentrations leads to the significant enhancement of electron-electron interactions. The effect of the spin-orbit interaction on the magneto-conductance was also observed at low magnetic fields. These results can lead to the next step of the study in which the possible ferromagnetic ordering will be investigated in heavily impurity doped semiconductors.