Ferromagnetic semiconductors with high Curie temperature and unusual magnetic properties – the case of Gd-doped GaN

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Abstract :

Despite more than four decades of research efforts, only a few ferromagnetic semiconductors with Curie temperatures above 300 K have been discovered. Most promising among them is a family of wide-gap semiconductors, which can be labeled as dilute magnetic dielectrics, since they are semi-insulating when doped with transition or rare-earth metals.

We have observed room-temperature ferromagnetism in Gd-doped semi-insulating GaN films grown on SiC(0001) by molecular beam epitaxy. In addition to the high Curie temperature of 800 K, our measurements revealed an unexpectedly high magnetic moment per Gd atom and a magnetic anisotropy with the hard axis along the growth direction and an easy plane parallel to the GaN(0001) surface. The temperature dependence of the magnetic properties points to the existence of two ferromagnetic phases with different order temperature. The coexistence of the two phases can be explained in the framework of a phenomenological model which assumes a large polarization of the GaN matrix by the Gd atoms. We also found that the saturation magnetization shows a dependence on the orientation of the magnetic field, which may result from the anisotropy of the polarization induced in the GaN matrix by internal and external magnetic fields. It is finally important to note that ferromagnetic GaN films with high Curie temperature can also be produced by Gd-focussed ion beam implantation into as-grown GaN. The observed magnetic moment per Gd atom becomes even higher in as-implanted samples, and the measured saturation magnetization of as-implanted GaN can be reduced by thermal annealing at 800 C. This finding points to the important role which defects may play as mediators in the exchange coupling between the Gd impurity atoms in the GaN matrix.

In the rather disorderd wide-gap oxide and nitride semiconductors the standard exchange mechanisms in the absence of free carriers are too short range to overcome the percolation threshold and establish a long-range magnetic order. Intrinsic or extrinsic defects may thus play the part of mediators in the inter-impurity exchange coupling.