4-2 Study of a Dilute Magnetic Semiconductor by Observing Soft X-ray Magnetic Circular Dichroism

— Way to Improve *Spintronics* Material Performance Revealed by Synchrotron Radiation —

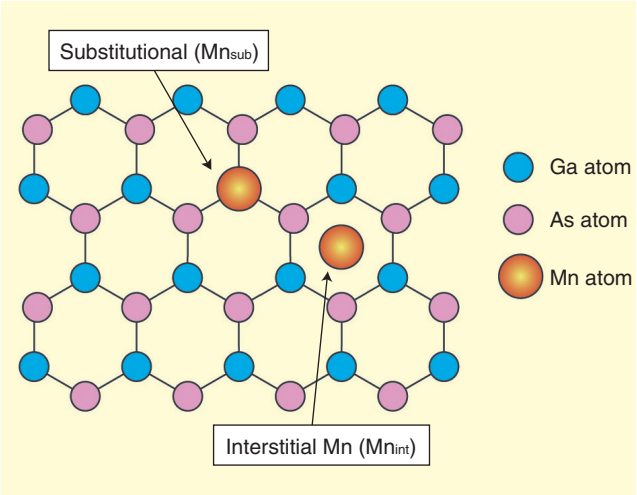

Fig.4-4 Schematic view of $Ga_{1-x}Mn_xAs$ (111) surface
Mn_{sub} and Mn_{int} represent the Mn ions replacing Ga ions and inserted in interstices, respectively.

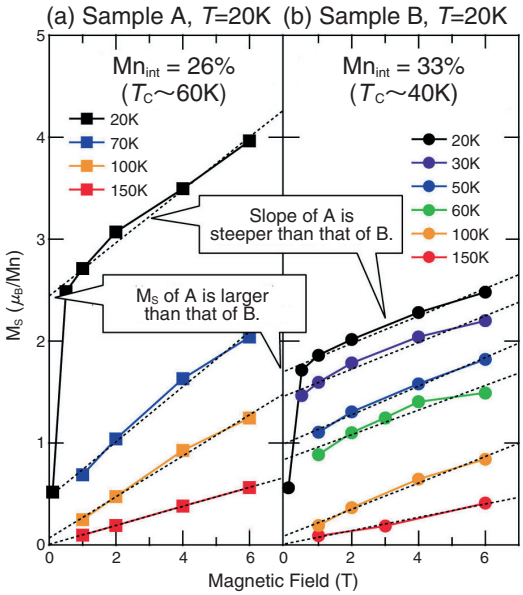

Fig.4-5 Magnetic dependence of the spin moment (M_S) of $Ga_{1-x}Mn_xAs$ at T = 20K
(a) Sample A with T_C ~ 60K, Mn_{int} / all Mn ions ~ 26% (b) Sample B with T_C ~ 40K, Mn_{int} / all Mn ions ~ 33%. The amount of Mn_{int} was estimated from our XMCD experiments.

Electrons have two characteristics, "charge" and "spin". In semiconductor electronics, we use charge only. On the other hand, *spintronics* technology utilizes spin combined with semiconductor electronics technology. For practical use of *spintronics*, a material is needed which exhibits semiconducting and ferromagnetic properties and a Curie temperature (T_C) exceeding room temperature (RT). Among dilute magnetic semiconductors (DMS's), $Ga_{1-x}Mn_xAs$ is a promising candidate, but T_C above RT has not been achieved yet. This material's ferromagnetic property is caused by Mn ions (Mn_{sub}) substituting for the Ga ions. Because $Ga_{1-x}Mn_xAs$ is grown under thermal non-equilibrium conditions, however, it is difficult to avoid the formation of the interstitial Mn ions (Mn_{int}) as shown in Fig.4-4. It has been speculated that the existence of Mn_{int} might suppress the T_C. The relation between Mn_{int} and T_C has not been revealed yet.

In order to investigate the influence of the Mn_{int} on T_C, we prepared two samples which have different T_C and amounts of Mn_{int} (Sample A: T_C ~ 60K, Mnint / all Mn ions ~ 26% and B sample: T_C ~ 40K, Mn_{int} ~ 33%) and performed soft x-ray magnetic circular dichroism (XMCD) experiments in the Mn $L_{2,3}$ absorption edge region using synchrotron radiation. From the XMCD experiment, we could extract the value of spin moment (M_S) of each Mn atom. The XMCD experiments were done at the JAEA beamline BL23SU of SPring-8.

Fig.4-5 shows the magnetic field (H) dependence of M_S estimated from the XMCD experiment at T = 20K. In the sample A, both the spontaneous magnetization ($M_{S\,H=0\ Tesla}$) and the slope of the H dependence of M_S are larger than those in the sample B. Here, the slope corresponds to the magnetic susceptibility. This indicates that the antiferromagnetic (AF) interaction between the Mn_{sub} and Mn_{int} should exist. Therefore, the M_S of the Mn_{int} is antiparallel to that of Mn_{sub}, In other words, the existence of Mn_{int} prevents increase in T_C. The present results indicate that the AF interaction between the Mn_{sub} and Mn_{int} plays an important role in the magnetic behavior of a typical $Ga_{1-x}Mn_xAs$. In addition, the amount of the Mn_{int} ions should have a strong relation to T_C.

The findings should give a valuable insight into the performance improvement of the magnetic properties of many DMS's in addition to $Ga_{1-x}Mn_xAs$.

Reference

Takeda, Y. et al., Nature of Magnetic Coupling between Mn Ions in As-Grown $Ga_{1-x}Mn_xAs$ Studied by X-ray Magnetic Circular Dichroism, Physical Review Letters, vol.100, issue 24, 2008, p.247202-1-247202-4.