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希薄磁性半導体(Zn,Co)O 薄膜における F ドーピングの磁性への効果

The effect of F-doping on magnetism in diluted magnetic semiconductor (Zn,Co)O thin films

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Diluted magnetic semiconductors (DMSs) are considered to be indispensable for the application in spintronics. For the practical device application, the synthesis of DMSs having a ferromagnetic transition temperature (T_C) higher than room-temperature is required. Co-doped ZnO is one of the candidates of room-temperature ferromagnetic semiconductors. According to a theoretical prediction, (Zn,Co)O has *Tc* above room-temperature by n-type doping[1]. However, it has not yet been clarified whether the intrinsic ferromagnetism is actually realized by n-type doping in (Zn,Co)O. So far, there have been many studies on magnetism of (Zn,Co)O co-doped with donor impurities Ga or Al, which substitute the cation site of ZnO, but intrinsic ferromagnetism has not been confirmed. In the present study, we investigate the effect of a donor impurity fluorine (F), which substitutes the anion site, instead of those substituting the cation site. It is expected that a donor impurity substituting the anion site, which can be located in the nearest neighbor site of Co, may have more effect on magnetism due to a short-range interaction. Further, we also investigate the effect of O vacancies which are introduced additionally by the post-growth annealing in a vacuum.

(Zn,Co)O thin films were deposited on (11-20) (*a*-plane) sapphire substrate using PLD technique. The deposition was performed at a substrate temperature of 500°C at an oxygen pressure around 0.5Pa. Some of the grown films were annealed in a vacuum to introduce O vacancies. Structural properties of the grown films were checked using θ-2θ scan of XRD. The magnetization of the films was measured using SQUID. The carrier concentration was deduced from the Hall measurement.

Figure 1 shows the effect of the annealing in (Zn,Co)O without F-doping (referred to as undoped). In this figure, the saturation magnetization (M_S) at 2K and the carrier concentration at 275K are plotted as a function of the anneal temperature. The carrier concentration increases with increasing anneal temperature, but M_S has no correlation with carrier concentration. Figure 2 shows *M-H* curves at 2K of undoped and F-doped (Zn,Co)O films before and after the annealing. When the magnetization of as-grown films is compared, the F-doped film exhibits larger magnetizations than the undoped film. Furthermore, the annealing causes a further increase of magnetization in the F-doped film, in contrast to the undoped film. The increase in magnetization can be interpreted as a result of an enhancement of ferromagnetic interaction between Co spins. Without incorporating F or O vacancies, the magnetization is suppressed by the antiferromagnetic superexchange interaction between Co spins mediated by O in between. A possible mechanism of the ferromagnetic interaction mediated by F or O vacancies will be discussed at the presentation.

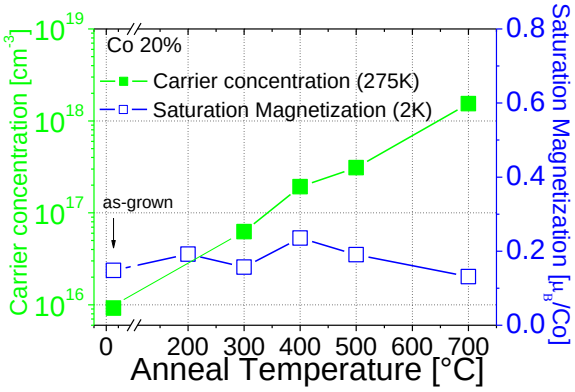

Fig.1 The saturation magnetization and carrier concentration of undoped (Zn,Co)O with 20% Co are plotted against the anneal temperature.

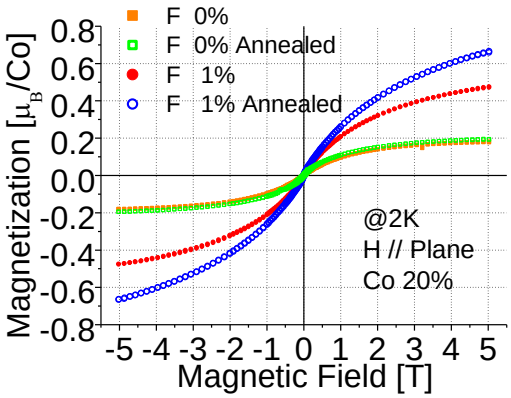

Fig.2 Magnetization curves of undoped and F-doped films of (Zn,Co)O with 20% of Co. The annealing was performed at 500°C.

[1] K.Sato, H.Katayama-Yoshida, Jpn. J. Appl. Phys. **40,** L334 (2001)