

Structural and magnetic properties of Co doped GaN

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Introduction

Diluted magnetic semiconductors (DMSs) have attracted considerable interest as materials for spintronic devices. Among the various DMSs, GaN-based DMSs have received great attention since the Curie temperature (T_c) higher than room temperature was predicted for p-type GaN doped with Mn[1]. Since then several experimental studies were reported regarding the magnetic properties of GaN:Mn. Theoretical prediction for magnetic properties of GaN incorporating various concentrations of V, Cr, Mn, Fe, Co, and Ni assuming that magnetic atoms were randomly substituted with Ga atoms has also been reported, and the systematic variation of the magnetic properties were suggested. Recently, the T_c higher than room temperature obtained experimentally in Cr doped GaN has been reported. Co may be interesting since the T_c of Co doped TiO₂ and ZnO have been reported to be above room temperature, however, experimental reports of Co doped GaN are very few. In this study, we report the structural and magnetic properties of Co doped GaN.

Experimental and Result

Co doped GaN were grown on sapphire(0001) substrates by gas source molecular beam epitaxy (GSMBE) using uncracked ammonia as a nitrogen source. Metallic Ga of 6N-purity, and Co of 4N-purity were evaporated from conventional Knudsen cells, and ammonia gas of 6N-purity was introduced to the growth surface. Prior to the growth of the Co doped GaN, sapphire substrate was thermally cleaned at 950°C for 5 min and then at the same temperature substrate was nitrided under 4×10^{-4} Torr of NH₃ for 20 min. The Co doped GaN films were grown at 700°C.

The concentration of Co were varied between 0.3at% and 4.7at%. The thickness of the epitaxial layer was about 0.5 μ m. Co-K edge extended x-ray absorption fine structure (EXAFS) measurements were carried out in fluorescence mode using beam line 12C at the High Energy Accelerator Research Organization (KEK) to study the local structures around Co atoms. The analysis of the EXAFS data were performed Fourier filtering and curve fitting techniques using FEFF8 program. The bond length, coordination number, and Debye-Waller factor were used as fitting parameters to yield optimum values.

We obtained the EXAFS function with k weighting value of three of Co doped GaN with Co concentration of 1at%. Fourier transform was applied to the region from 3.0 to 12.6 in k-space to get radial distribution in distance space. A large peak at about 2.3Å which is attributed to the first-nearest-neighbor atoms was observed. If the Co

atom was incorporated into a substitutional Ga lattice site, peaks corresponding to the first- and second-nearest-neighbour atoms should be observed at about 1.9Å and 3.2Å, respectively, since the atomic radius of Co is almost the same as that of Ga. Therefore, it seems that Co atoms are incorporated into other site than the substitutional Ga lattice site in GaN. We carried out back fourier transform to the range between 1.8Å and 2.5Å in the radial distribution function, and curve fitting to yield the optimum value using several fitting models such as CoGa, hcp- and fcc-Co. A good curve fitting was obtained only for the model of CoGa, and it was not possible to yield a good fitting in case of the model of hcp-, fcc-Co. The analytical results and theoretical value of CoGa were listed in table I.

Table I Analytical results of Co-K edge measurements.

	1.0%	1.8%	4.7%	CoGa
Nearest-Neighbor atom	Ga			
Bond length	2.5	2.5	2.5	2.5
Coordination number	8.4	9.3	9.7	8
Debye-Waller factor	0.077	0.1	0.086	

The coordination numbers for Co in CoGa and hcp-Co are 8 and 12, respectively. Therefore, the increase in the coordination number with increasing Co concentration may suggest the formation of hcp-Co. From these results, it can be concluded that the secondary phase mainly formed is CoGa

The magnetic properties of these Co doped GaN showed ferromagnetic behavior. The origin of this magnetic property is unclear at present. It may be possible to consider the contribution from CoGa since the existence of secondary phase of CoGa was confirmed by EXAFS analysis. However, the magnetic property of CoGa is reported to be paramagnetic [2]. Another origin of the ferromagnetism could be caused by Co clusters those are too small to be detected by EXAFS analysis. Therefore, we considered that the most plausible reason for the magnetic property is Co clusters.

References

- [1] T. Dietl et al, Science **287**, 1019 (2000).
- [2] J. G. Booth et al, Phys. Lett. **A32**, 149, (1970).

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