Jahn-Teller Effect of Cu-Ferrite Films by Solid Reaction

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Abstract: Copper iron oxide (CuFe_2O_4 : Cu-ferrite) thin film was prepared on a glass substrate by vacuum evaporation and solid reaction, and annealed at 400°C in the air. The obtained film was identified by X-ray diffraction analysis as Cu-ferrite film having a tetragonal lattice. The axial ratio (c/a) of the film was 1.507 and was larger than that of ASTM data because the lattice distortion of the films seems to be large by difference of a preparation method. The temperature dependence of the magnetization and conductivities of the film showed remarkable changes at about 360°C , which were considered to be caused by phase transition due to the Jahn-Teller effect.

1. INTRODUCTION

Copper iron oxide (CuFe_2O_4 : Cu-ferrite) have a distinctive feature of the phase transition from a tetragonal to a cubic lattice at 360°C due to the Jahn-Teller effect [1,2]. It is the purpose of this study to point out the influence of the phase transition due to the Jahn-Teller effect on the magnetic properties and electrical conductivities.

2. EXPERIMENT

Cu-ferrite film was prepared through the solid reaction described the following. Iron film of 200 nm thickness was evaporated onto heat-resisting glass substrate at room temperature using a vacuum evaporation method with an L-type electron beam heating gun under a pressure of 2×10^{-6} Torr. The deposition rate was 0.2 nm/s. Iron film was oxidized to form $\alpha\text{-Fe}_2\text{O}_3$ film in the air at 400°C for 3 hours. Then, iron film of 40 nm thickness was evaporated onto $\alpha\text{-Fe}_2\text{O}_3$ film at room temperature, which was reduced to form Fe_3O_4 film in a vacuum at 400°C for 6 hours. Next, copper film of 120.1 nm thickness was evaporated onto Fe_3O_4 film at room temperature, which was annealed in a vacuum at 400°C for 8 hours. Finally, Fe_3O_4 film included metallic copper was oxidized to form Cu-ferrite film in the air at 400°C for an hour. The thickness of Cu-ferrite film was about 850 nm. The thickness was measured after an evaporation by talystep. The crystal structure was identified by X-ray diffraction (XRD) analysis. The surface condition of the film was observed by scanning electron microscopy (SEM). The magnetic properties and electrical conductivities were measured by vibrating sample magnetometer (VSM) and two-point probe method, respectively.

3. RESULTS AND DISCUSSION

3.1 Crystal structure and surface condition [3]

By the result of the XRD analysis, Cu-ferrite film have a tetragonal lattice and the diffraction spectrum from (200), (211), (220) and (400) faces are appeared. We compare the lattice constants between the value that calculated from diffraction spectrum and the data listed on ASTM files of Cu-ferrite. The values of the axial ratio (c/a) of the film and of ASTM data are 1.507 and 1.477, respectively. Consequently, the lattice distortion of the film seems to be large by difference of a preparation method.

For the purpose of investigating the surface texture of the film, it is observed by SEM. The grain structure is formed in the film, and the grain size is about 100 nm.

3.2 Magnetic properties

The M-H curve of the film is measured by VSM, where the magnetic field is applied in-plane to the film, is shown in Fig. 1. The saturation magnetization and coercive force of the film are 2.4 kG and 290 Oe. Because the diffraction spectra from (200) and (400) faces are appeared and the induction of the uniaxial magnetic anisotropy is expected, the magnetic field is applied perpen-

pendicular to the film. But the M-H curve is not almost observed. It is thought that the anisotropy to the perpendicular direction of the film is small because they are not c-axial dominant orientational film.

Figure 1: M-H curve of a Cu-ferrite film.

3.3 Temperature dependence of the magnetization and conductivities

For the purpose of investigating the influence of the phase transition due to the Jahn-Teller effect on the magnetic properties and electrical conductivities, the temperature dependence of the magnetization and conductivities of the film are measured and shown in Fig. 2 (a) and (b). The remarkable changes are observed at about 360°C, which are considered to be caused by phase transition due to the Jahn-Teller effect. The Curie temperature T_c is about 460°C. It is thought about the magnetization that the magnetic moment is influenced by gap of the band structure caused by phase transition. On the other hand, it is thought that the conductivities are changed by phase transition even though a similar material system because it is ruled by band structure decided by crystal structure.

The conduction type of a carrier is judged by thermoelectric power method. As a result, the film is the n-type semiconductor in the area of a tetragonal lattice. The conductivities are related to $\ln(s_1/s_2) = -(E_g/2k)(1/T_1 - 1/T_2)$. Here, E_g is the energy gap, k is the Boltzmann's constant and (T_1, s_1) , (T_2, s_2) are two voluntary points of the characteristic curve of the conductivities. If this relation is applied to a result of Fig. 2 (b), E_g is about 3.3 eV in the area of a tetragonal lattice.

Figure 2: Temperature dependence of the magnetization and conductivity for the Cu-ferrite film.

4. CONCLUSIONS

Here we may draw the following conclusions: (1) The temperature dependence of the magnetization and conductivities show remarkable changes at 360°C, which are considered to be caused by phase transition due to the Jahn-Teller effect. (2) The axial ratio (c/a) of the film is 1.507 and is larger than that of the data on ASTM files because the lattice distortion due to the Jahn-Teller effect is large. (3) The conductivities of the film show the characteristic of the n-type semiconductor in the area of a tetragonal lattice.

References

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