I. 9. Mössbauer Spectroscopy of Co-Evaporated Ag-Fe Alloys

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Introduction

In thermal equilibrium, Ag and Fe are completely immiscible for each other even when both of them are in liquid state and hence no alloy can be prepared by a conventional method as melting. In the present Ag and Fe are vacuum evaporated at the same time and an artificial alloy was prepared. The result of Mössbauer and RBS spectrum measurements on them will be reported in the present. Such a vapor quenching method was successfully applied for Fe-Cu or Fe-Ag and several interesting magnetic behaviors have been reported1).

Experimental

The method of the specimen preparation is almost the same with those in the preceding paper on Fe-Ag layered specimen. Only difference is that Fe and Ag are evaporated simultaneously in the present. Since the exact thickness or the alloy composition of the prepared film cannot be determined by the thickness meter only, RBS spectroscopy was performed to determine these values. Mössbauer spectroscopy was performed to examine the phase and the magnetization direction of Fe in the alloy film.

Results and Discussion

Figure 1 shows the RBS spectrum of the alloy film. Comparing with a simulated spectrum where the composition and film thickness were varied as parameters, the thickness of the film was determined as 380 nm and the alloy has a composition of Fe$_{0.86}$Ag$_{0.14}$. Note that the composition determined by RBS spectroscopy is the averaged one and so the state of Fe atom, namely, dispersed or coagulated, cannot be inferred.

Figure 2 shows the Mössbauer spectrum for the alloy film. The main features and the corresponding physical significance may be summarized as follows:

(1) The spectrum is that of α Fe (bcc ferromagnetic) revealing Fe in the alloy film is in this state. The magnitude of the hyperfine field as determined by the separation between the line 1 and 6 is almost the same with that of pure Fe.
(2) The intensity of the line 2 is extremely small revealing the magnetization direction is not in the film plane and directed about 40 degree to the surface normal (γ-ray direction. See eq.(1) in the preceding paper). This is a rather anomalous effect since the magnetization direction is usually in-plane for the case of thin film giving rise to larger I₂ than I₁.

(3) Such an anomaly in the magnetization direction seems to be quite common for co-evaporated film as shown in Fig. 3, where Mössbauer spectra for Fe-Pb and Fe-Cd prepared in the same way as Fe-Ag are shown. As can be seen from Fig. 3, I₂ / I₁ is about 0.5 for Fe-Pb and Fe-Cd showing the magnetization direction is also off-plane in these alloys.

(4) The ratio I₂ / I₁ was measured as a function of magnetic field strength applied parallel to the specimen plane. The magnetization direction was found to turn into the specimen plane with increasing magnetic field between 0.01T and 0.1T and saturates at 0.4T.

The anomalous off-plane magnetization direction has been found and studied in permalloy (Fe-Ni) and interpreted as due to the columnar growth of Fe phase ². Namely, Fe particles grow along the film normal and non-magnetic oxide occupies the space between the columns. In this case Fe columns have a larger dimension along the surface normal than along the film plane giving rise to the off-plane magnetization because of the lower demagnetization field.

Such a model may be applied in the present alloy cases with non magnetic Ag, Pb or Cd substitutes the role of the oxide.

In the present specimens where Fe content is rather high, following pictures of the co-evaporation process may be speculated. Namely, pure alpha Fe columnar particles grow along the surface normal without any non-magnetic element in it and the spaces between the columns are occupied by these non-magnetic element.

Further study as electron microscopy of the film may be helpful to confirm the picture. Also studies with specimens with less Fe content or prepared at lower temperatures will be necessary to obtain non-equilibrium Fe-AG, Pb or Cd alloys.

References

Fig. 1. The RBS spectrum of a film prepared by co evaporating Fe and Ag.

Fig. 2. Mössbauer spectrum of the specimen in Fig. 1.
Fig. 3. The Mössbauer spectrum of Fe-Pb and Fe-Cd prepared in the same manner as Fe-Ag.