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Magnetism of the amorphous and nanocrystalline CoFeSiB thin films

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1. Introduction

Studies on amorphous soft magnetic material are important for better free layer performance in tunnel-magnetoresistance system [1]. Among many candidate amorphous soft magnetic layers, we have prepared CoFeSiB thin films with different Co compositions and measured their microstructure. With increasing the Co composition, the amorphous film is transformed into the nanocrystalline film with nanocrystalline Co phase embedded in the amorphous phase. We report the results of the magnetic and transport properties of the amorphous and nanocrystalline CoFeSiB thin films.

2. Experiment

The CoFeSiB films were prepared using a six-target dc magnetron sputtering system. A $Co_{70.5}Fe_{4.5}Si_{15}B_{10}$ target with small Co chips is added to control the composition of CoFeSiB films. The microstructure was characterized by high-resolution transmission electron microscopy (TEM), electron diffraction (ED) and x-ray diffraction (XRD). The magnetic properties were characterized by a superconducting quantum interference device (SQUID). The magnetoresistance was measured on a dumbbell-like patterned sample by a two-probe dc technique with a physical property measurement system (PPMS).

3. Results and Discussion

The compositions of prepared samples are changed by the number of Co chips from 0 to 16. Here, we focus on only two samples of the $Co_{74}Fe_4Si_{14}B_8$ (Co chip : 6) and $Co_{78}Fe_2Si_{12}B_8$ (Co chip : 10) thin films. TEM images, ED patterns and XRD analysis reveal that the $Co_{74}Fe_4Si_{14}B_8$ is an amorphous thin film and the $Co_{78}Fe_2Si_{12}B_8$ is composed of nanocrystalline Co phase embedded in the amorphous phase matrix, which is shown in Fig. 1 and Fig. 2. Hereafter let the $Co_{74}Fe_4Si_{14}B_8$ and $Co_{78}Fe_2Si_{12}B_8$ thin films are the sample-A (amorphous) and sample-NC (nanocrystalline), respectively.

Magnetization curves of the sample-A and sample-NC are shown in Fig. 3. The sample-A shows soft magnetic behavior due to the lacks of crystalline anisotropy as usually observed in amorphous metallic alloys [2]. However, we find unexpected magnetic properties in the sample-NC. The square hysteresis loop at the low field region comes from the amorphous matrix. The linear response part at higher fields reaches the saturation magnetization around 4 kOe. A possible scenario is an antiferromagnetic exchange coupling between the amorphous phase and nanocrystalline Co phase, in a manner similar to the case of Co/Co_2TiSn thin films [3]. Such antiferroamgnetic coupling can be explained as both the linear response and the large saturation field. In order to check the possible existence of antiferromagnetic coupling, we have measured the magnetization as a function of temperature with varying applied magnetic fields up to 4 kOe.

The antiferromagnetic transition temperature (T_N) shifts to lower temperatures from T_N = 400 K at 2 kOe to 45 K at 4 kOe, which is not shown here. This behavior is typical characteristics of antiferromagnetic coupling. The standard longitudinal magnetoresistance data measured at 5 K are shown in Fig. 4. For the sample-A, it shows a typical anisotropic magnetoresistance (AMR) loop shape. For the sample-NC, there is a small dip around zero field, followed by a monotonic decrease of magnetoresistance with field. Then it saturates around 4 kOe, which corresponds to the saturation field of magnetization.

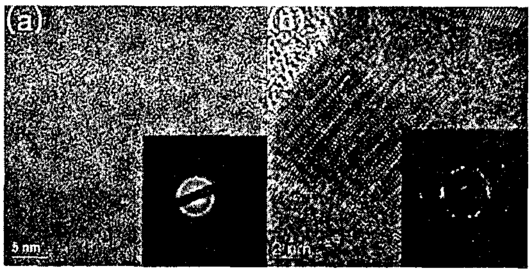

Fig. 1. TEM image of the sample-A (a) and the sample-NC (b). The insets represent the electron diffraction patterns for (a) and (b).

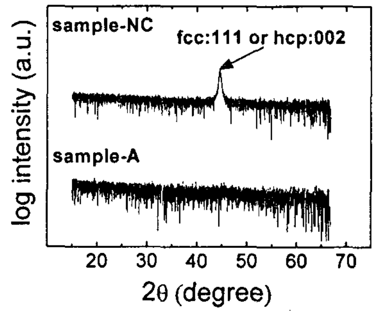

Fig. 2. The XRD patterns of the sample-A (bottom) and sample-NC (top).

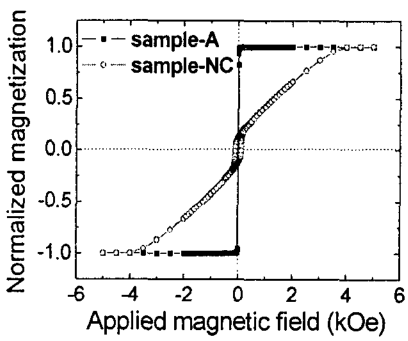

Fig. 3. In-plane magnetization curves of the sample-A and sample-NC measured at 5 K.

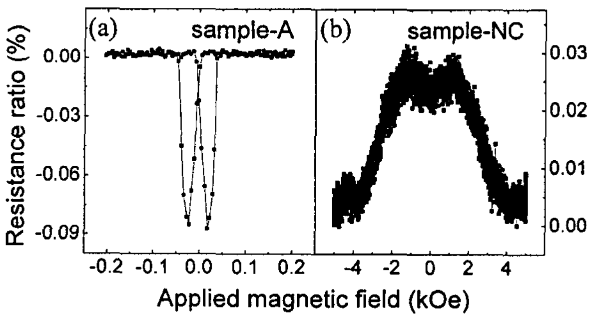

Fig. 4. Longitudinal magnetoresistance curves of the sample-A (a) and sample-NC (b).

4. Conclusion

In summary, the sample-A and sample-NC have been investigated by measuring the structure, magnetic and transport properties. The sample-A is amorphous and the sample-NC is composed of nanocrystalline Co phases surrounded by the amorphous matrix. The magnetization and magnetoresistance curves of the sample-A show good soft magnetic property, while a large saturation field is unexpectedly found for the sample-NC. Such an unexpected magnetism could be related with antiferromagnetic coupling between the amorphous and nanocrystalline phase.

5. References

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