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Giant Magnetostrictive Thin Films and their Applications to Microdevices

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1. Introduction

With their high energy density and fast response time, thin films of giant magnetostrictive R-Fe alloys (R: rare earth elements) have many advantages over currently popular piezo ceramic thin films as a driving material of microdevices. It is therefore no wonder that, since the early nineties, great interest has arisen to apply R-Fe thin films to microdevices. However, due to very large magnetocrystalline anisotropy, giant magnetostriction is usually achieved at a large magnetic field [1]. In order to solve this problem, a systematic investigation has been carried out in this work to develop Tb-Fe (positive magnetostriction) and Sm-Fe (negative magnetostriction) based alloy thin films with large magnetostriction at a low magnetic field. Furthermore, the application of the newly developed thin films to proto-type microcantilevers tested.

2. Experimental

The films with a wide composition range were fabricated by rf magnetron sputtering using a composite target. Microactuators with various sizes were fabricated on a Si {100}-oriented wafer using an anisotropic wet etching technique. Magnetostriction was measured by an optical cantilever method , and the dimension and the deflection of cantilevers were measured with an optical microscope.

3. Results and Discussion

Excellent magnetostrictive characteristics, particularly at low magnetic fields, are achieved in thin films of both Tb-Fe and Sm-Fe based alloys [2, 3]. At a magnetic field of 100 Oe, which can be applied in microdevices applications without any difficulty, a magnetostriction of –350 ppm is achieved in a binary Sm-Fe thin film, while the magnitude of magnetostriction is 140 ppm in a binary Tb-Fe thin film. These absolute values are further increased by a small addition of B to the alloys; at the same magnetic field, the magnitudes of magnetostriction are, respectively, –470 ppm and 173 ppm in ternary Sm-Fe-B and Tb-Fe-B thin films. It is noted here that, although the (absolute) magnitudes of magnetostriction of Tb-Fe thin films are smaller than those of Sm-Fe based thin films, the deflection of a cantilever is of a similar level, since Young's modulus of Tb-Fe based thin films is larger than that of Sm-Fe based ones. The present level of magnetostriction is much higher than that reported in the literature; in particular at a practically important low magnetic field, our values are several times higher than those reported previously [4].

These excellent magnetostrictive properties of the present thin films are well supported by equally excellent magnetic softness. Well-developed in-plane anisotropy, which is considered to be essential to the realization of large magnetostriction at a low magnetic field, is formed, better in-plane anisotropy being observed in Sm-Fe based thin films. The coercivity is low, the lowest value reaching 10 Oe in both Sm-Fe and Tb-Fe thin films.

The present magnitude of magnetostriction, which is an intrinsic materials property, corresponds to a deflection of more than 50 μm at a magnetic field of 100 Oe, when, for example, a 1 μm thick Tb-Fe-B film is coated on a Si cantilever with a length of 15 mm and a thickness of 25 μm. This indicates that the present magnetostrictive films can be suitable for a driving material in microdevices.

The suitability is tested by the fabrication of proto-type microactuators driven by magnetostrictive thin films. In a cantilever with the dimension 3.7 mm (length) x 1.0 mm (width) x 13 μm (thickness), a deflection of 52 μm is obtained at 150 Oe from the first ascending magnetic field by the coating of a 1.2 μm thick $Sm_{42.7}Fe_{56.9}B_{0.4}$ film. Total deflection nearly doubles when a magnetic field of the same magnitude is applied alternately in the length and the width directions. This level of deflection is considered to be very large at a magnetic field applicable with ease in microdevices applications. The magnetic properties of the coated Sm-Fe-B thin film are summarized as follows: coercivity of 122 Oe, magnetization (at 15 kOe) of 5240 G, and the remanence ratio of 0.7. With the consideration that the driving thin film is far from optimized (note the high value of coercivity), there is much room for further improvement of the deflection.

Actuators coated with Tb-Fe thin films are also expected to show large deflection, as can be judged from the values of magnetostriction obtained for a standard sample. However, much smaller deflection is observed for a cantilever with the dimension similar to that coated with the Sm-Fe-B thin film. A deflection of 4 μm is obtained at a magnetic field of 150 Oe in a cantilever with the dimension 4.3 mm (length) x 1.0 mm (width) x 20 μm (thickness) by the coating of a 1.5 μm thick $Tb_{51.4}Fe_{48.6}$ thin film. Although it is expected the deflection can be increased by optimizing the film composition and fabrication conditions, the obtained deflection is much smaller than that observed for the cantilever coated with the Sm-Fe-B thin film.

Since the present deflection level is considered to be high enough for microdevices applications, proto-type microdevices, such as microvalves and micropumps, were fabricated and their performance was tested.

4. References

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