Tunneling magnetoresistance effect in Fe–Pb–O and Fe–PbO granular films: a comparison

Jen-Hwa Hsu*, Yi-Hong Huang

Department of Physics, National Taiwan University, Taipei, Taiwan

Abstract

The spin-dependent tunneling phenomenon has been investigated by using two granular systems with Fe granules embedded in different lead oxide materials. The results of magnetoresistance measurement indicate that only negligible TMR value has been found for all Fe–PbO granular films, whereas a large TMR effect that is about 10% at room temperature has been discovered for Fe–Pb–O. The magnetic PbO : 3Fe₂O₃ ferrite on the surface of Fe granules is believed to play an enhanced factor for spin-polarized tunneling, which causes a large TMR effect in Fe–Pb–O. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Spin-dependent tunneling; Granular systems; Magnetotransport

1. Introduction

The tunneling magnetoresistance effect (TMR) has attracted much attention these days. It contains many challenging and interesting topics and provides great application potential. This phenomenon which exists in many types of materials was first observed in a trilayer junction [1]. More recently, some granular systems with an insulating or semiconductor matrix have been investigated and found to exhibit TMR effect [2,3]. However, the effect in granular systems is not quite so large as in the trilayer sandwiches. The spin-dependent tunneling is believed to be responsible for TMR effect [4]. However, the detailed mechanism is not quite clear yet. In order to understand the key factors which determine the electronic tunneling behavior, the magnetotransport properties of two similar granular systems, Fe–PbO as well as Fe–Pb–O, have been explored.

2. Experiment

The Fe–PbO granular films were prepared by magnetron rf co-sputtering with a composite target. The kapton

foils were used as the substrates. In order to compare the heating effect during sputtering, the substrates were cooled by LN₂ and flowing water, respectively. The Fe–Pb–O granular films, however, were obtained from a new and unique method. The first step of fabrication was to make metastable Fe–Pb alloy films. Then the films were annealed in the oven with the flowing Ar gas for 1 h. The annealing temperature has been set at 400°C which is higher than the melting point of lead (m.p. = 327°C). The detailed description of preparation has been described elsewhere [5].

The phases of the films were identified from the X-ray diffraction patterns. The microstructure of the films was determined from transmission electron microscopy (TEM). The magnetoresistance measurements were carried out at room temperature by the conventional four-probe method with a maximum applied field of 0.9 T. The TMR value is defined to be the ratio of $\{\rho(H = 0.9 \text{ T}) - \rho(0)\}/\rho(0)$.

3. Results and discussion

In Fig. 1 the X-ray diffraction patterns of Fe–PbO and Fe–Pb–O granular films are shown. The Fe–PbO films with LN₂ quenched during sputtering contains only the

* Corresponding author. Tel.: + 886-2-23661867; fax: + 886-2-23639984.

E-mail address: jhsu@phys.ntu.edu.tw (J.-H. Hsu)

attributed to the appearance of magnetic $\text{PbO} \cdot 3\text{Fe}_2\text{O}_3$ ferrite on the surface of iron granules. In order to further justify this argument, several $\text{Fe}_x\text{Pb}_{1-x}$ metastable alloys with $0.1 \leq x \leq 0.5$ have been prepared and then annealed under the same conditions as described earlier. It turns out that the relative amount of $\text{PbO} \cdot 3\text{Fe}_2\text{O}_3$ becomes smaller as x is decreasing, and it is accompanied by a much reduced TMR value. According to Moodera et al., tunneling through the barrier, the polarization of electrons can be greatly amplified if the barrier material is magnetic [8]. Thus, strongly polarized electrons can lead to a large TMR effect. Our experimental results from Fe–Pb–O granular films are consistent with their reasoning.

In conclusion, the conductance of spin-dependent electron tunneling from Fe particles to Fe particles through the PbO insulating matrix can be substantially increased by the existence of a thin magnetic $\text{PbO} \cdot 3\text{Fe}_2\text{O}_3$ intervening layer.

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