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Relative contributions of surface and grain boundary scattering to the spin-polarized electrons transport in the AlN/NiFe/AlN heterostructures

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ABSTRACT

When the film thickness approaches the electron mean free path (MFP), the relative contributions of surface/grain boundary scattering to the resistivity remain indefinitive. In this work, series of NiFe films sandwiched by AlN barriers were employed to study the transport properties. Surface scattering is found to provide the strongest contribution to the resistivity increase for very thin films ($d_{NiFe} \leq 10$ nm). With the increase of the film thickness, the effect of the grain boundary scattering gradually increases while the surface scattering decreases. When the thickness of the film is over 30 nm, the former becomes predominant.

1. Introduction

In recent years, the burgeoning anisotropic magnetoresistance (AMR) materials based on novel structures [1,2] or new physical mechanism (such as tunnel AMR, ballistic AMR, and antiferromagnetic AMR) [3–5] have attracted extensive attention. In particular, $Ni_{81}Fe_{19}$ (permalloy) film is the most adopted AMR material [1,2,6–10] in basic spintronic research due to its good soft magnetic properties and larger AMR value. For the permalloy films, when the film thickness is reduced to the nanometer scale, especially approaching the mean free path (MFP) of an electron in NiFe (<10 nm) [11], resistivity markedly increases, causing a significant decrease of MR value. The phenomenon that the film resistivity increases with decreasing film thickness is called the classical resistivity size effect, which was initially found by Thomson in 1901 [12], and later was first described by the Fuchs–Sondheimer (FS) theory [13,14]. Then, Mayadas and Shatzkes (MS) [15] treats grain boundary scattering as the primary mechanism for resistivity increasing with decreasing the film thickness. In recent years, there is extensive investigation attempting to reveal the relative contributions of surface and grain boundary scattering to the electrons transport. For example, Zhang et al. [16] and Sun et al. [17] studied nanoscale copper films and found that grain boundary scattering plays a crucial role in determining the resistivity. Wu et al. [18] found that the influence of surface scattering is less than previously speculated, while grain boundary scattering is dominant. In contrast, according to a study by Henriquez et al. [19], the electron surface scattering is the dominant electron scattering mechanism for nanoscale Au layers. Up to now, there has been much debate regarding the relative contributions of surface scattering and grain boundary scattering to the classical resistivity size effect. The current research on the resistivity size effect is mainly focused on the non-magnetic metals which do not involve electron spin, but there are few reports on the study of the spin-dependent resistivity size effect. Therefore, a better understanding of this issue will extend previous studies. Moreover, during the design process of spintronic materials and devices, this study also provides new insight into manipulating the spin-polarized electrons transport for optimizing device performances through controlling thickness of magnetic layers.

2. Experimental

In this study, Ta(5 nm)/AlN(4 nm)/NiFe(d nm)/AlN(3 nm)/Ta(5 nm) multilayered films, with NiFe thickness d ranging from

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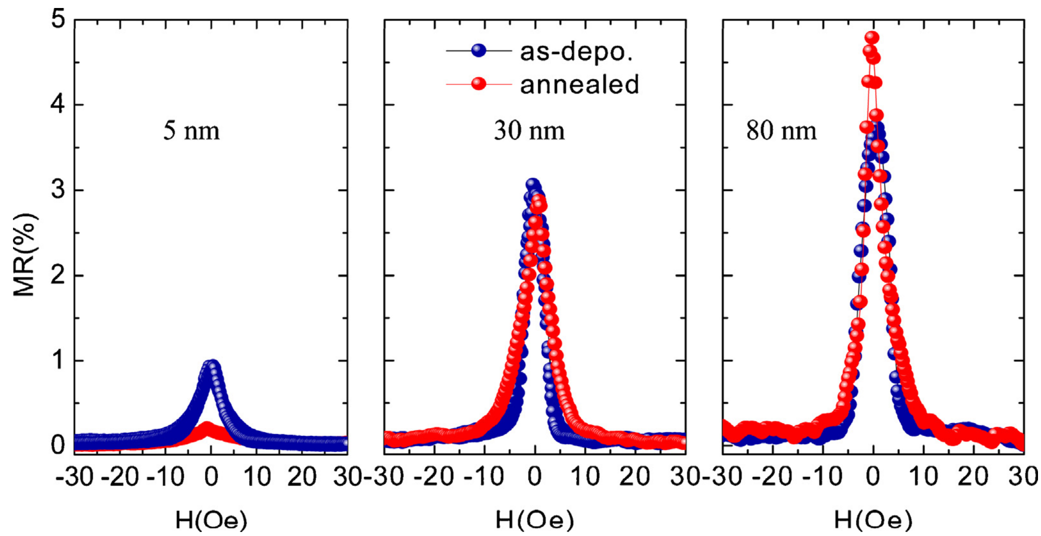

Fig. 1. MR–H curves for the Ta(5 nm)/AlN(4 nm)/NiFe(*d* nm)/AlN(3 nm)/Ta(5 nm) films [d_{NiFe} = 5, 30, 80] before and after annealing at 400 °C.

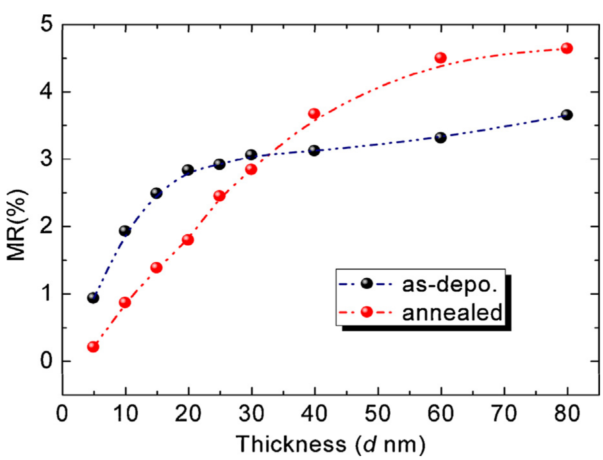

Fig. 2. MR value vs. the NiFe thickness for the Ta(5 nm)/AlN(4 nm)/NiFe(*d* nm)/AlN(3 nm)/Ta(5 nm) films before and after annealing at 400 °C.

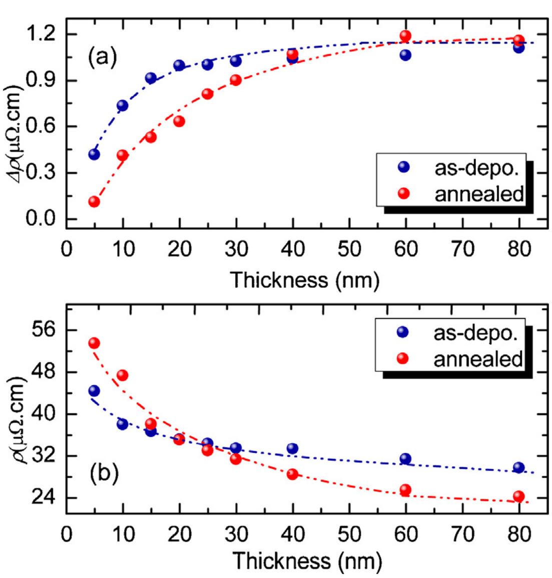

Fig. 3. (a) $\Delta\rho$ and (b) ρ vs. the NiFe film thickness for the Ta(5 nm)/AlN(4 nm)/NiFe(*d* nm)/AlN(3 nm)/Ta(5 nm) before and after annealing. The dash dot lines are guide for the eye.

5 nm to 80 nm, were deposited on 10 mm × 10 mm Corning glass substrates at room temperature by magnetron sputtering. The film thickness in the artificial structure, referring to the physical thickness, was estimated based on the deposition rate which can be calculated using the total deposited film thickness plotted against deposition time. The base chamber pressure was better than 1.0×10^{-5} Pa and the working Ar pressure was kept at 0.2 Pa during sputtering. The Ta and NiFe layers were deposited from respective Ta and $Ni_{81}Fe_{19}$ targets by dc sputtering, and the AlN layers were deposited from an AlN ceramic target by rf sputtering. A deposition field of about 25 kA/m was applied parallel to the substrate to induce a magnetic easy axis in the NiFe layer. The same films were

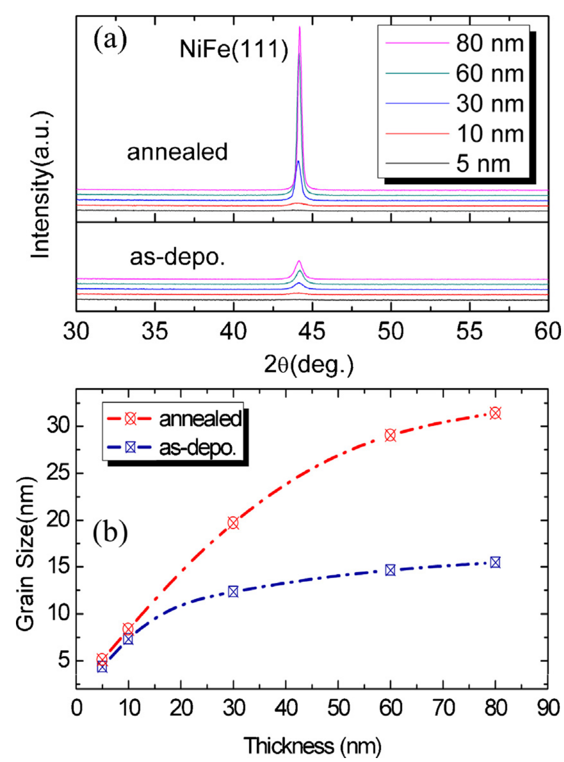

Fig. 4. (a) XRD patterns and (b) average grain size for the films Ta(5 nm)/AlN(4 nm)/NiFe(*d* nm)/AlN(3 nm)/Ta(5 nm) with different NiFe thickness before and after annealing. The grain size is determined from XRD studies applying the Scherrer formula to the half-width of the (1 1 1) reflex.