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Inelastic electron tunnelling spectroscopy of magnetic tunnel junctions with AlN and AlON barriers

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Abstract

We report on electrical transport properties of magnetic tunnel junctions (MTJ) with AlN and AlON barriers. A series of junctions was made with the structure MnFe/NiFe/barrier/NiFe, where the type of the barrier layer was systematically varied. These samples were compared with a reference sample of MTJs with an alumina (Al_2O_3) barrier. Particularly, the bias dependence of tunnelling magneto resistance was found to be less pronounced in nitride barriers than in alumina, which was attributed to barrier-specific phonon-assisted inelastic electron tunnelling.
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1. Introduction

Due to their potential applications as magnetic read head sensors and non-volatile memories, there has been renewed interest in magnetic tunnel junctions (MTJs). Formation of high-quality ultra-thin tunnel barrier in MTJ is probably the most challenging step in achieving high performance MTJs. While alumina (Al_2O_3) is the most popular material for the barriers in MTJ, tremendous efforts have been made in search of alternative barrier materials [1–3] which may promise to supplement the drawbacks of alumina, such as high junction resistance and high pin-hole densities. We report on electrical transport properties of MTJs with AlN and AlON barriers. A series of junctions was made with the structure MnFe/NiFe/barrier/NiFe, where the type and thickness of the barrier layer was systematically varied [1,3]. These samples were compared with a reference sample of MTJs with an alumina (Al_2O_3) barrier. Particularly, the bias dependence of tunnelling magneto resistance (TMR) was found to be less pronounced in nitride barriers than in alumina, which was attributed to barrier-specific phonon-assisted inelastic electron tunnelling.

2. Experimental procedure

MTJs with the structure of Ta 5 nm/NiFe 6 nm/MnFe 10 nm/NiFe 12 nm/barrier/NiFe 8 nm/Ta 5 nm were fabricated by UHV sputter deposition followed by photolithographic microfabrication. Tunnel barriers were formed from 1.25 nm thick Al, through in situ plasma oxidation, oxy-nitridation or nitridation.

TMR values observed were up to 16% in nitride barriers and 19% in alumina. Transport properties of the MTJ were characterized by DC four-probe method. Inelastic electron tunnelling spectra (IETS) employing a standard AC lock-in technique and custom-built electronic circuit measured at cryogenic temperatures to understand the systematic variation of transport characteristics with the barrier structure.

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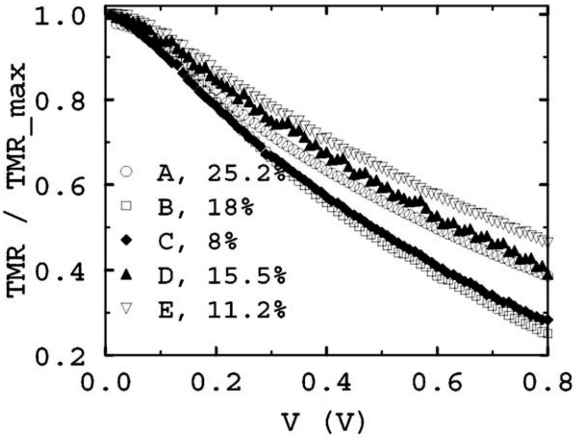

Fig. 1. Bias dependence of TMR in MTJs with various barriers. Each curve has been normalized with TMR_{max} as indicated in the legend.

3. Results and discussion

Fig. 1 displays the bias dependence of TMR in the MTJ with various barriers measured at room temperature (**A** : O_2 for 2.5 min, **B** : O_2-N_2 for 2.5 min, **C** : N_2 for 2.5 min, **D** : N_2 for 5.0 min, **E** : N_2 for 7.5 min). The bias dependence of TMR becomes systematically weakened as the degree of nitridation increases.

To understand the difference in the bias dependence of TMR in various barriers, we took the IETS at various temperatures. Fig. 2 shows the spectra of the two MTJs (A and B) measured at 15 K. A typical MTJ manifests as sharp features at low bias, which have been attributed to magnon-assisted tunnelling. This type of inelastic electron tunnelling has explained the degradation of TMR at finite biases [2].

While the characteristic magnon features are common in both barriers, the energy scales involved in the magnon excitation clearly differ in the two junctions. In MTJs with alumina barrier, we observed inelastic tunnelling features occurring over a broad range of bias (FWHM $\sim$100 mV). In contrast, these features in MTJs with a nitride barrier occur at lower bias and were very sharp (FWHM $\sim$20 mV). This difference may explain the initially smaller zero-bias TMR and the lesser dependence of TMR at high bias in MTJs with nitride

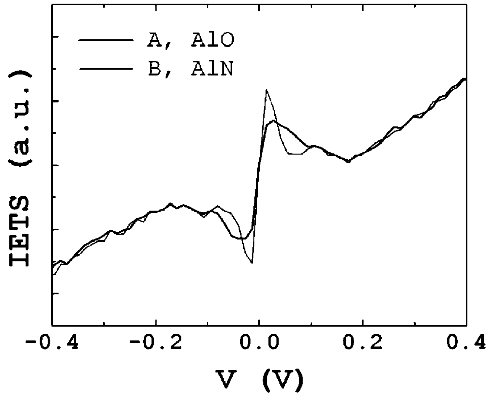

Fig. 2. IETS spectra of the junction **A** and **B** measured at 15 K. The spectra shown are for the parallel magnetization.

barriers. Even though the signal related to the phonon excitation in the barrier is not clearly identified in Fig. 2, the strong contrast in the binding energies of Al–O and Al–N should give rise to different modes of phonon-assisted tunnelling in these junctions. In this regard, the phonon-related features in the tunnel barrier in addition to the magnon features may also play an important role in spin-dependent transport in these junctions [4].

4. Conclusion

We prepared various MTJs with AlO, AlON and AlN tunnel barrier. These samples showed the systematic variation in the transport properties, which correlated with the degree of nitridation of the barrier. Particularly, the bias dependence of TMR was found to be less pronounced in nitride barriers than in alumina, which was attributed to barrier-specific phonon-assisted inelastic electron tunnelling

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