Enhanced Anisotropy in Nanowires for Energy Applications

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ABSTRACT

Arrays of tunneling magnetoresistance (TMR) nanowires were synthesized for the first time by filling Fe/MgO/Fe inside vertically grown and substrate supported carbon nanotubes. Enhanced magnetic properties likely resulted from shape anisotropy of the nanowires and hybridization that occur between the n-electronic states of carbon and 3d-bands of the Fe-surface. Density functional theory is used to calculate current versus thickness of the insulator buffer for a fixed voltage value in both geometries. This anisotropy can be used in highly sensitive sensors useful in electromagnetic systems to conserve energy and as a component in a quantum computer. The hybrid interface between ferromagnetic surfaces and carbon-based molecules play an important role in organic spintronics.

I. INTRODUCTION

TMR is a macroscopic quantum phenomenon that allows electrical current to flow across an insulator with the application of an external magnetic field. It has attracted enormous attention because of important applications in non-volatile magnetoresistive random access memories (MRAM) and next generation field sensors [1]. Fe/MgO/Fe TMR based magnetic tunnel junctions (MTJs) are of great interest as witnessed by several current reports on structural, magnetic, and electronic properties of the multilayer interfaces [2-7]. First principle modeling of TMR Fe/MgO/Fe tri-layers predicted zero bias magnetoresistance (MR) ratio several thousand percent on the basis of model structures involving abrupt Fe-MgO interfaces [3]. MR ratio reduced to 1000% when the Fe/MgO interface oxidation is considered [2]. Theoretical calculation of TMR with a disordered Fe/MgO/Fe junction showed the intermixing of Fe and Mg atoms at the interface decreases the MR ratio rapidly and when about 16% of interfacial Fe atoms are substituted by Mg the calculated MR saturates with increasing MgO thickness in good agreement with experiment [4]. The atomic moments at the interface are non-collinear with the bulk magnetization which may affect the net anisotropy or serve as spin scattering sites [5]. An MR ratio of 220 % was achieved in MTJs with a crystalline MgO(001) barrier [7]. An MR ratio of 180% at room temperature and 247% at 20K were also observed in single-crystal Fe/MgO/Fe MTJs [6]. The origin of this enormous TMR effect is coherent spin-polarized tunneling, where the symmetry of electron wave function plays an important role. Coherent TMR effect is key to making spintronic devices. Changing the geometry from planar thin film to nanowire cylindrical geometry with nanometric diameter introduces shape anisotropy which can play an important role in coherence [8-10]. This report examinens the similarities and differences in the magnetic properties of the two geometries.

II. RESULTS AND DISCUSSIONS

The in-plane value of coercive field (Hc) of nanowires of Fe/MgO/Fe is 54% higher than thin film of Fe/MgO/Fe both synthesized at 100 °C of substrate temperature and the in-plane saturation magnetization (Ms) of nanowires is 173% higher than thin film. The in-plane and out-of-plane values of Ms for nanowires is 25.5% whereas for films it is 76.5%. As the orientation of magnetic field with respect to the sample surface changes the variation in films is three times greater than in nanowires.
In both nanowires and films most of the magnetization occurred by domain wall motion which is confirmed by small change in the values of Hc as the angle between the sample surface and applied field change. Strong dependence on angle of the applied external field was observed much more in films than in nanowires indicating domination of uniaxial anisotropy over magneto crystalline anisotropy in the nanowires. The magnetization of planar nanometric thin films of Fe/MgO/Fe depend on synthesis substrate temperature. The coercive field (Hc) is maximum at substrate synthesis temperature of 100 °C. The values of Hc, magnetic remanent (Mr), and magnetic saturation (Ms) of nanowires is higher than planar films, Hc by 37%, Mr by 55%, and Ms by 63%. These higher values are due to shape anisotropy of the nanowires. According to DFT calculation magneto crystalline anisotropy is predicted to be caused by the change in the relative occupancy of the 3d-orbitals of Fe atoms at the Fe/MgO interface [11]. This higher magnetic property can also be attributed to the significant hybridization that occur between the π-electronic states of carbon and 3d-bands of the Fe-surface since the trilayer Fe/MgO/Fe/MWCNTs nanowires are synthesized inside carbon nanotubes. This work is useful since hybrid interface between ferromagnetic surfaces and carbon-based molecules play an important role in organic spintronics [12].

The hysteresis loops of planar film of Fe/MgO/Fe show higher dependence on the angle between the field direction and normal to the surface. The variation of the hysteresis loop for film implies that the easy axis lies in plane and the hard axis is perpendicular to the surface. The absence of significant change in the nanowires when the external magnetic field angle to the axis change is due to the dense compaction (possibly close to a hexagonal close packing) of the nanowires and the presence of strong dipolar interactions among the nanowires. Previous reports on α-Fe nanowires fabricated in alumina templates the dipole interactions are small due to a large separation between the nanowires, this was indicated by narrower hysteresis loop when the field is applied perpendicular to the nanowire axis [13, 14]. In contrast to these reports, our results on Fe/MgO/Fe nanowires grown dense demonstrate hysteresis loop corresponding to a coherent type reversal magnetization for all orientation of the applied field and abrupt steps are absent.

III. CONCLUSIONS

In this comparative study of the magnetic properties of Fe/MgO/Fe nanowires grown inside substrate supported carbon nanotubes for the first time and planar thin films, nanowires of Fe/MgO/Fe prepared at 100 °C substrate temperature showed superior magnetic property compared to planar thin films. This is attributed to the shape anisotropy of nanowires. The magnetic properties of nanowires synthesized under the same conditions nanometric thin films of Fe/MgO/Fe showed higher saturation magnetization by a factor of 2.7 at a maximum applied field of 1.5 kOe. The small change in the coercive field as the angle between the sample surface and the applied field is changed in both nanowires and films confirmed that most of the magnetization occur by domain wall motion. Strong dependence on angle was observed on the values of coercive field much more in films than in nanowires indicating the dominance of a uniaxial over magneto crystalline anisotropy.

IV. ACKNOWLEDGMENTS

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VI. REFERENCES


