Direct observation of the surface structure and conductance of Fe_3O_4 half-metals using tunneling atomic force microscopy

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Because of their high spin polarization, half-metallic materials are an attractive candidate for use as the ferromagnetic layer in a magnetic tunneling junction (MTJ) attaining large magnetoresistance (MR). Theoretical analyses of band structure models have predicted that Fe_3O_4 has a spin polarization of 100 % at room temperature. Recently, MTJs with Fe_3O_4 half-metallic layers have been used to acquire large MR ratios [1]. However, because it is difficult to fabricate both a stoichiometric composition and an ideal half-metallic property for Fe_3O_4 thin films, the measured MR ratio for MTJs using Fe_3O_4 is usually blow the expected value. Clarification of the relationship between the interfacial structure and the conductivity in a half-metal layer may be helpful for determining the best method for depositing MTJ samples that have a large MR ratio. In this study, surface structure and conductivity were simultaneously observed using tunneling atomic force microscopy (TUNA).

Specimen [Fe_3O_4 (10 – 50 nm)/underlayer] films were deposited by a reactive dual ion beam sputtering method on surface-oxidized silicon wafer substrates and MgO (100) substrates using hetero-epitaxy [2]. Kr was used as the sputtering gas and the beam voltage for sputtering was set at V_{mg} of 850 eV. Specimens were analyzed using TUNA; both specimen and contact AFM cantilever were connected to a power supply and pA current amplifier with filters in parallel. The applied voltage V_{app} between substrate and cantilever was varied from 0 to –5 V through limitation of the current amplifier.

Since Fe_3O_4 behaves as a semiconductor at room temperature, we can detect a small TUNA current of tens of picoamperes. Analysis of the I-V curve revealed that specimens showed a distinctive semiconductor-like trend in conductivity. Although the surface roughness for Fe_3O_4 single-layer samples was less than 1 nm (data from the contact AFM images), specimens showed distributions of conductive current in the range of 10 pA; this distribution is consistent with the slight surface roughness. In contrast, Ru is a suitable underlayer for the epitaxial growth of Fe_3O_4; [Fe_3O_4 (20 nm)/Ru (5 nm)] samples showed a smaller distribution of conductive current due to the flatness of film surfaces. Further influence of deposition conditions, such as underlayer structures and sputtering parameters, for Fe_3O_4 films will be discussed from the point of view of surface structure and distribution of conductivity.

References

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