Investigation of Tunneling Barriers for Si Spin-Valve Devices

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Spin transistors have become a rather popular research direction in semiconductor spintronics. This new type of device has advantages that traditional transistors do not have. It is equivalent to integrating magnetic memory in a single transistor, making it possible to achieve relatively complex functions with very low energy consumption and smaller size. In a spin transistor, it is necessary to inject spin carriers from a ferromagnetic source into a semiconductor channel. Due to the conductivity mismatch between metal and semiconductor, the spin injection efficiency is usually poor, and spin transistors with high spin-dependent output characteristics have not yet been realized. One of effective ways to improve the injection efficiency is to insert a layer of insulating material between the ferromagnetic source(drain) layer and the semiconductor channel, and use the quantum tunneling effect to improve the injection efficiency. As one of the most popular materials currently available, MgO has been studied, and shows a tunneling barrier of about 0.4 eV between Fe and MgO [1]. However, a systematic study on the tunnel barrier height of various insulating materials in ferromagnetic layer / tunnel barrier / Si structure is still lacking.

In this study, we prepared samples of Fe/ tunnel barrier / n^+Si substrate with different insulating materials (MgO, $MgAl_2O_4$, Al_2O_3) as the tunnel barrier, and studied their barrier height. Here, MgO layers were grown by either molecular beam epitaxy (MBE) or magnetron sputtering, $MgAl_2O_4$ layers were grown by magnetron sputtering, and Al_2O_3 layers were grown by atomic layer deposition (ALD). We fabricated diode structures of Fe/tunnel barrier/ n^+Si and measured their *I-V* characteristics at 4.2 K, from which we calculated the barrier height using the Simmons model [2]. Figure 1 shows the effective barrier height of various materials as a function of layer thickness. At 1.0 nm, the effective barrier height increases from 0.28 eV for MgO (MBE) to 0.6 eV for Al_2O_3 (ALD). The effective barrier height of MgO (MBE) is lower than that of MgO (Sputter), probably due to stronger desorption of oxygen under ultrahigh vacuum. The effective barrier of MgO (Sputter) is consistent with that of high-quality Fe/MgO/Fe junction. However, the effective barrier height rapidly decreases with the increasing barrier thickness, especially for $MgAl_2O_4$ (Sputter) and Al_2O_3 (ALD). As a result, at the barrier thickness of 1.5 nm, the barrier height is nearly the same for MgO (Sputter), $MgAl_2O_4$ (Sputter), and Al_2O_3 (ALD). Our results suggest that defect density in $MgAl_2O_4$ (Sputter) and Al_2O_3 (ALD) increases much faster than in MgO when the barrier thickness increases.

References:

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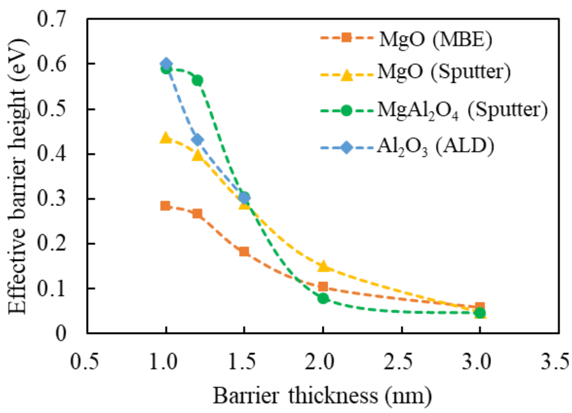

Fig. 1. Effective barrier height of various materials as a function of layer thickness in Fe/tunnel barrier/n^+Si diodes, measured at 4.2 K.