ADVANCED MAGNETIC TUNNEL JUNCTIONS USING SPINEL OXIDE BARRIERS

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I. BACKGROUND

Magnetic tunnel junctions (MTJs) consisting of a ferromagnet (FM)/barrier/FM trilayer structure are used a read head of hard disc drives (HDDs), and has made a great contribution to the increase in HDD capacity. MTJs are also used as memory cells of non-volatile magnetoresistive memories (MRAMs). In recent years, great attention has been paid to researches on high-sensitive magnetic sensors using MTJs for automotive and medical uses. For such new practical applications, further improvement of the performance of MTJs are required.

In MTJs, tunneling resistance changes with the relative magnetization direction of the two FM layers. The proportion of the resistance change is called a tunnel magnetoresistance (TMR) ratio, and this determines the device output performance. Therefore, obtaining large TMR ratios are desirable for practical uses of MTJs. Nowadays MgO is commonly used as a barrier material of MTJs since large TMR ratios exceeding 100% at room temperature (RT) are easily obtained by the spin-dependent coherent tunneling effect [1]. However, it is difficult to tune the barrier properties such as a lattice constant and a barrier height beyond the MgO physical parameters. Therefore, to widen the application range of MTJs further, tuning the MTJ properties by introducing new barrier materials could be a promising way.

In this presentation, I would like to introduce recent research progress in MTJ barrier design using spinel-based oxides. Especially, I will talk about achievement of large TMR ratios and improvement of bias voltage dependence of TMR due to lattice-constant tuning by an $MgAl_2O_4$ barrier. Furthermore, I will introduce achievement of a barrier height tuning by developing a Ga-based spinel barrier, $MgGa_2O_4$.

II. LATTICE-MATCHED MTJ USING $MgAl_2O_4$ BARRIER

$MgAl_2O_4$ (spinel) has a spinel structure with a lattice constant of ~0.809 nm [2]. Although the structure of $MgAl_2O_4$ is much more complicated than that of the rock-salt type MgO, the lattice-spacing of $MgAl_2O_4$ is 4% smaller than that of MgO; therefore, the $MgAl_2O_4$ lattice matches well with lattices of CoFe(B) alloys and Co-based Heusler alloys [3]. Moreover, the lattice-spacing of $MgAl_2O_4$ can be further tuned by controlling the Mg-Al composition, enabling us to obtain perfect lattice-matched interfaces with various bcc-based FM layers. In addition, as observed in MgO-based MTJs, large TMR ratios due to the occurrence of the coherent tunneling through the Δ_1 Bloch states are achievable in $MgAl_2O_4$-based MTJs [4].

An $MgAl_2O_4$ barrier layer can be fabricated by post-oxidation of an Mg-Al alloy layer [3] and direct RF sputtering from a sintered $MgAl_2O_4$ target [5]. Especially, an excellent quality of the $MgAl_2O_4$ barrier and lattice-matched flat interfaces with Fe electrodes were demonstrated by the direct sputtering method as shown in Fig. 1(a) [5]. TMR ratios of the prepared epitaxial Fe/$MgAl_2O_4$/Fe(001) MTJ reached 245% and 436% at RT and 3 K, respectively, which are very large values as an MTJ using Fe electrodes. A TMR ratio can be improved using Co-based Heusler alloy Co_2FeAl electrodes, and a value up to 342% at RT was demonstrated in a $Co_2FeAl/MgAl_2O_4/Co_2FeAl(001)$ MTJ [6].

In general, a TMR ratio reduces with increasing bias voltage, and this causes reduction of electric output of MTJ based devices. The lattice-matching by $MgAl_2O_4$ significantly improves this bias voltage dependence of a TMR ratio due to suppression of inelastic scattering at the barrier interface. A V_{half}, the bias voltage where the TMR ratio is halved, of the Fe/$MgAl_2O_4$/Fe MTJ was around 1.0-1.3 V, which is much larger than that of general MTJs ($V_{half} \sim 0.4$-0.8 V) [3,5].

An ultra-thin FM/$MgAl_2O_4$ interface showed strong perpendicular magnetic anisotropy (PMA), similar to FM/MgO interfaces [7]. Especially, at an ultra-thin $Co_2FeAl/MgAl_2O_4(001)$ interface, it was demonstrated that the perfect lattice-matching resulted in very small Co_2FeAl lattice distortion, leading to

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a large PMA energy [8]. Therefore, the use of $MgAl_2O_4$ is also advantageous to obtain perpendicularly magnetized MTJs, necessity for high-density MRAM applications.

III. MTJ WITH WIDE-GAP SEMICONDUCTOR SPINEL: $MgGa_2O_4$

According to the theoretical reports, spinel oxides (AB_2O_4 type) with (001) orientation are expected to show TMR enhancement due to the coherent tunneling effect [4,9]. In addition, the band gap of spinel oxides can be reduced by substituting heavy elements for *A* and *B* sites, which results in reduction in a barrier height [9]. Recently, an MTJ with a wide-gap semiconductor spinel $MgGa_2O_4$ barrier was prepared by the direct sputtering [10]. As shown in Fig. 1(b), a lattice-matched epitaxial Fe/$MgGa_2O_4$/Fe structure was successfully obtained. The MTJ showed a relatively large TMR ratio of 121% at RT (196% at 4 K). More importantly, the resistance area product of the MTJ was approximately 50 times smaller than that of an Fe/$MgAl_2O_4$/Fe MTJ at a given barrier thickness due to a low barrier height of $MgGa_2O_4$. This result suggests that a barrier height can be tuned while achieving a large TMR ratio through composition control of a spinel oxide barrier.

IV. SUMMARY AND PROSPECTS

The achievement of lattice-matched interfaces by introducing an $MgAl_2O_4$-based barrier resulted in improvement of MTJ performances such as TMR ratios and PMA characteristics. Recently, excellent time-dependent dielectric breakdown properties of $MgAl_2O_4$ barriers were also demonstrated [11], indicating high reliability of $MgAl_2O_4$-based MTJs suitable for practical uses. Additionally, the study of a new spinel barrier, $MgGa_2O_4$, demonstrated that spinel oxides can tune not only lattice constants but also barrier heights as MTJ barriers. These results indicate the possibility of creating new MTJ applications by the “barrier design” using various spinel oxides.

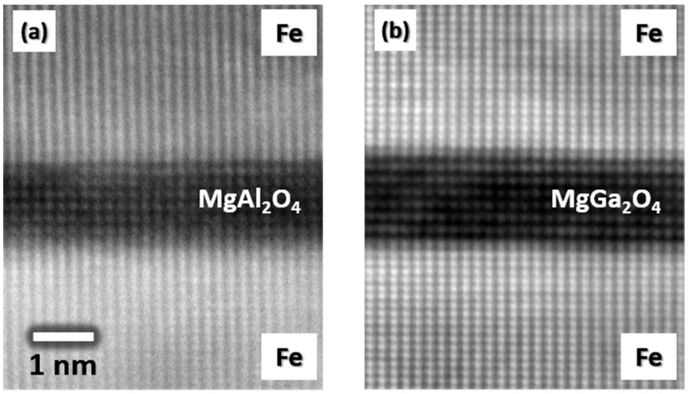

Fig. 1 Cross-sectional scanning transmission electron microscopy images of (a) Fe/$MgAl_2O_4$/Fe(001) and (b) Fe/$MgGa_2O_4$/Fe(001) MTJs fabricated by direct sputtering.

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