NANO-LAYER OF TETRAGONAL Mn-BASED ALLOYS FOR MRAM APPLICATIONS

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A magnetic tunnel junction with a perpendicular magnetic easy-axis (p-MTJ) is a key device for non-volatile magnetoresistive random access memory (MRAM). The CoFeB/MgO-based p-MTJ has been developed and applied to the current-induced spin-transfer-torque (STT) MRAM application. Currently, STT-MRAM for a working memory with a large memory capacity up to 4 Gbit has been demonstrated [1]. Beside, a new spintronic memory has been also proposed and demonstrated, namely voltage controlled spintronic memory (VoCSM) in which magnetization switching is achieved by the current-induced spin-orbit torque (SOT) and voltage-controlled magnetic anisotropy (VCMA) [2]. The CoFeB/MgO is now one of the standard material combinations in those spintronic memories. However, the emergence of new materials for spintronic memories are also demanded because CoFeB has a large saturation magnetization of more than 1000 kA/m and CoFeB/MgO shows moderate perpendicular magnetic anisotropy (PMA) below 1 MJ/m^3. The materials with smaller saturation magnetization and larger PMA are crucial for MRAM with higher memory capacity fabricated with the sub-20 nm semiconductor technology node.

Various ordered magnetic alloys with a large uniaxial magnetic anisotropy have been examined for p-MTJs. Among those alloys, the ordered tetragonal Heusler-like Mn-based alloys, such as Mn_3Ga and its derivatives, have attracted much attention for STT-MRAM because they have high spin-polarization of 88%, related to the Heusler structure and low saturation magnetization of 100-300 kA/m due to ferrimagnetism. A high bulk PMA ~ 1 MJ/m^3 and low Gilbert damping constant < 0.008 also originate from the special property of Mn, *i.e.*, it has nearly half-filled 3*d* electron orbital states in a crystal field with tetragonal symmetry [3]. One technological challenge is to realize p-MTJs with an *ultrathin* Mn-based alloy layer with a large PMA and a typical thickness of 1–3 nm. This is crucial for devices driven by the current-induced torque. However, this has not yet been achieved, because growth of Mn-based alloy nano-layers on conventional buffer layers, such as Cr, has deteriorated their PMA.

Quite recently, this issue has been resolved by our finding of the low temperature crystal growth of MnGa nano-layer [4]. The film deposition was performed by the commercial ultra-high vacuum magnetron sputtering technique, and the point was to use a unique buffer material, CoGa, that is paramagnetic at room temperature for Co concentration of about 50%. Perpendicular magnetization for the epitaxial MnGa films grown on CoGa has been clearly observed even though its thickness was 1 nm. Interestingly, this low-temperature growth technique can be also applied to the polycrystalline growth and the highly (001)-textured MnGa nano-layer can be obtained [5].

Subsequently, we have demonstrated a p-MTJ with a 1-3 nm thick MnGa nano-layer epitaxially grown on a CoGa buffer [6]. The transmission electron microscopy (TEM) showed an atomically flat interface of the MnGa and CoGa buffer layer which promotes an epitaxial strain of MnGa so as to fit CoGa buffer with a lattice mismatch of 4 % [Fig. 1(a)]. This MnGa layer exhibited a PMA of about 0.6 MJ/m^3, magnetization of about 300 kA/m, and those magnetic properties may be suited for advanced MRAM with the large memory capacity. First principles calculations confirmed that the epitaxial strain-induced crystal lattice distortion in this p-MTJ modifies the band dispersion of MnGa and leads a large tunnel magnetoresistance (TMR) effect due to the orbital symmetry filtering effect similar to the Fe/MgO case [7]. Therefore, the large TMR ratio is expected by further optimization of interfaces qualities even though the experimentally observed TMR ratio has not been high yet at the present [Fig. 1(b)].

The above-mentioned low temperature growth process also enables us to investigate the current-induced switching effect for the Mn-based nano-layer, which has never been reported before. To investigate the current-induced SOT switching, we prepared the micron sized Hall bar consisting of Pt-capped 2.5-nm-thick MnGa film grown on CoGa buffer layer. This trilayer film exhibited a low saturation magnetization of 150 kA/m and a large PMA effective field of 2.5 T. The current-induced magnetization

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switching of MnGa nano-layer induced by an in-plane electrical current was clearly observed, as show in Fig. 1(c), and the switching phase diagram was qualitatively consistent with the damping-like torque due to the spin-Hall effect for the Pt layer having the positive spin-Hall angle [8].

In this talk we will overview the above-mentioned results and recent progress of Mn-based nanolayer p-MTJs developments for MRAM applications, including low Gilbert magnetic damping properties for their films [9]. This work was partially supported by the ImPACT program and KAKENHI.

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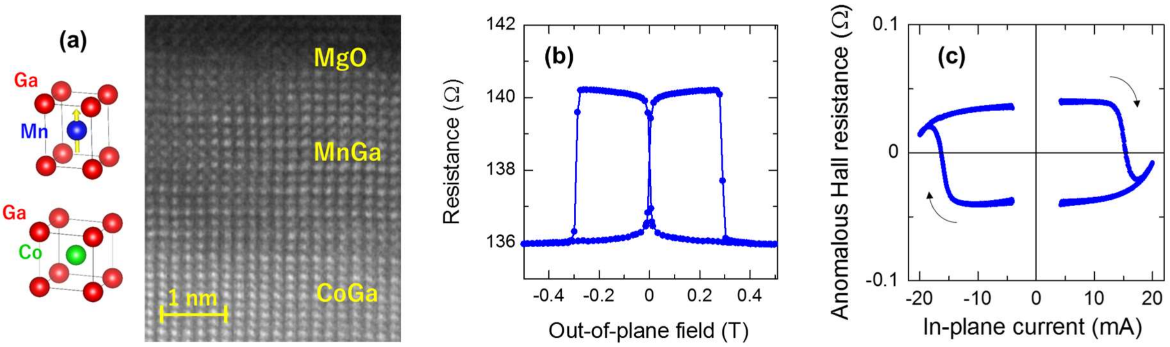

Fig. 1 (a) The cartoon of crystal structures of MnGa and CoGa and the TEM image of the cross section of CoGa buffer / MnGa / MgO /CoFeB p-MTJ. (b) Typical magnetoresistance curve of this p-MTJ. (c) The current-induced magnetization switching for the CoGa/MnGa/Pt trilayer film, which has been measured by the anomalous Hall effect as a function of in-plane applied current under a small in-plane magnetic field.