INVESTIGATION FOR HIGH-DENSITY STT-MRAM

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Perpendicularly magnetized magnetic tunnel junctions (pMTJs) have been studied for many kinds of applications such as spin-transfer-torque random access memory (STT-MRAM), random number generator (Spin Dice) [1], radio-frequency (rf) detector (spin-torque-diode) [2], holographic display [3] and neuromorphic devices [4]. In these applications, STT- MRAM is the most actively studied device, because it is next generation non-volatile and fast operation memory with “more than moore” technology. In order to commercialize the STT-MRAM, it is necessary to develop for higher capacity of the device. For the higher capacity STT-MRAM, we have to develop not only micro-fabrication process but also pMTJ film property. Before miniaturizing the pMTJ bit size, we improved the stability of reference layer magnetization for stable read-write operation by using Ir spacer layer in antiferro-magnetized coupling structure. Then we tried miniaturizing pMTJ bit, and realized 10 nm order ultra-small sized pMTJ with high magneto-resistance (MR) ratio over 140% which value is the same as blanket one measured by CIPT. But resistance of pMTJ becomes huge in this case around 100 kΩ. Then we also tried evaluation of lower resistance-area (RA) products pMTJs.

The pMTJ films were prepared using Tokyo Electron EXIM™ sputtering system. The film structure was buffer layer/ [Co/Pt] and CoFeB based synthetic anti-ferromagnetic reference layer/ MgO barrier/ [CoFeB/ spcer (W, Mo)/ CoFeB] free layer/ MgO capping layer/ metal capping layer. Metallic layers were deposited by DC magnetron sputtering and the MgO barrier layer was formed by oxidizing an Mg layer. All the pMTJ films were annealed 400 degC for 1 hour after film deposition. Then pMTJ films were patterned into nano-pillars by using an EB lithography, Ar ion etching and conventional liftoff process. For the first experiment, we improved reference layer’s magnetic property. So far, typical pMTJ reference layer has perpendicular magnetized synthetic anti-ferromagnetic structure with Ru (t ~ 0.8 nm, second peak) spacer layer. To obtain stronger anti-ferromagnetic coupling, we applied other spacers Ru (t ~ 0.45 nm, first peak) and Ir (t ~ 0.55 nm, first peak). Figure 1 shows *M-H* curves with different spacer layers, Ru 2nd peak, Ru 1st peak and Ir 1st peak. We obtained strong coupling with Ir spacer. We confirmed that MR ratio does not fall even if Ir spacer was used. Then we patterned pMTJ film (MR ratio 142% and RA value 7.3 Ωμm^2 by CIPT) into minute dot size pillar. In this study, we obtained a device with a minimum electric diameter of 10.4 nm (physically about 15 nm from the TEM image). As shown in figure 2, 10 nm order pMTJ shows still large MR value as blanket film. In order to increase the capacity of the STT-MRAM, it is necessary to miniaturize the pillar size. However, with the miniaturization, the resistance rapidly increases, as shown in figure 2(a) 10 nm pMTJ’s resistance became around 100 kΩ. Then we also investigated pMTJ properties with lower-RA values. Figure 3 shows MR curves with low RA pMTJ pillars (design size of pillar are 50 nm). As shown these results, we succeed high MR values with low RA values. In the talk, we will also discuss the size dependence of pMTJ include STT-switching properties.

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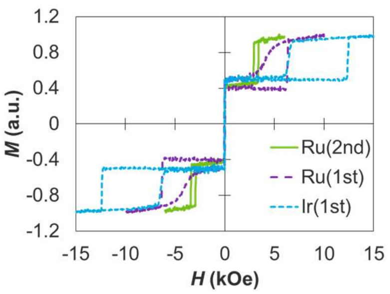

Fig.1 Magnetization loops of pMTJs having synthetic anti-ferromagnetic structure with Ru (2nd peak), Ru (1st peak) and Ir (1st peak) spacer layers.

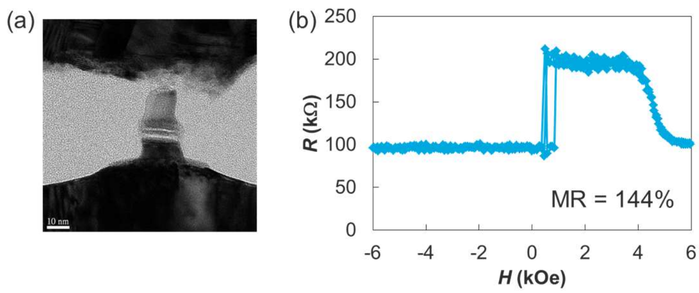

Fig. 2 (a) TEM image and (b) *R*-*H* loops of minimum 10 nm-order diameter pMTJ.

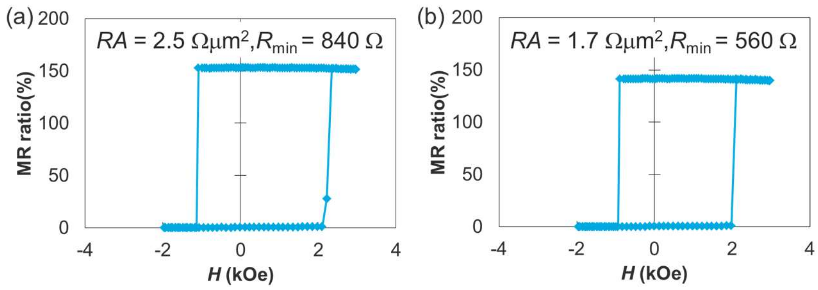

Fig 3 MR loops of low-RA pMTJs.