RECENT PROGRESS IN VOLTAGE-CONTROLLED MAGNETIC ANISOTROPY ~TOWARDS THE REALIZATION OF VOLTAGE-TORQUE MRAM~

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I. INTRODUCTION

A magnetoresistive random access memory (MRAM) is expected to realize the ultra-low stand-by power of future computing system using a non-volatile feature of magnetism. However, one of crucial technical challenges is the reduction in operation power, because the magnetization control using electric-current consumes high energy due to Ohmic dissipation. To overcome this fundamental issue, the development of electric-field manipulation of magnetism is strongly demanded. The voltage-controlled magnetic anisotropy (VCMA) effect in an ultrathin ferromagnetic metal layer [1,2] is one of the most promising and practical approaches, because it can be applied in an MgO-based magnetic tunnel junction (MTJ) with high-speed response [3,4]. An important remaining issue of the VCMA effect is to enhance its efficiency to demonstrate the scalability. For example, for giga-bit class memory applications, VCMA coefficient of more than a few hundreds or even 1000 fJ/Vm is required [5,6]. However, the VCMA effect with high speed response is limited to be 100 fJ/Vm at present. In this talk, we'll introduce recent progresses in the materials research for the large VCMA effect and in the voltage-induced dynamic magnetization switching, and also discuss future prospects and challenges for the realization of voltage-torque MRAM.

II. EXPERIMENTAL RESULTS

To investigate the VCMA effect in a high-quality ultrathin ferromagnetic metal layer, we prepared fully-epitaxial MTJs consisting of MgO seed (3 nm)/Cr buffer (30 nm)/Fe-based ultrathin ferromagnetic metal layer (t < 1 nm)/MgO (2.3 nm)/Fe(10 nm)/Ta(5 nm)/Ru(7 nm). The bottom ultrathin Fe-based layer is the perpendicularly magnetized free layer, whose perpendicular magnetic anisotropy (PMA) can be controlled by voltage application. The top 10 nm-thick Fe is the in-plane magnetized reference layer. Tunneling magnetoresistance (TMR) curves were measured under in-plane magnetic fields and various bias voltage applications. The polarity of the bias voltage was defined relative to the top Fe layer. Two ferromagnetic layers takes orthogonal magnetization

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configuration under zero magnetic field. An application of in-plane magnetic field tilts the magnetization of the free layer in the in-plane direction and its behavior can be observed as a gradual decrease of tunneling resistance. Figure 1 (a) shows the bias voltage dependence of normalized TMR curves for the MTJ with the free layer of $t = 0.82$ nm. Voltage applications cause clear shift in saturation field, suggesting the voltage-induced PMA change. Effective PMA energy density, K_{eff} (J/m^3) was evaluated from tunneling conductance curves with saturation magnetization value under each bias condition. Figure 1(b) summarizes applied electric-field dependence of the $K_{eff}\,t$. Large VCMA coefficient of 320 fJ/Vm was observed under the positive electric-field applications. This value satisfies the required specifications for ultra-large last-level cache voltage-torque MRAM.

In the presentation, we'll also introduce the evaluation of write error rate (WER) of precessional magnetization switching induced by VCMA effect [7] and discuss future strategy to achieve the practical low WER value for memory applications.

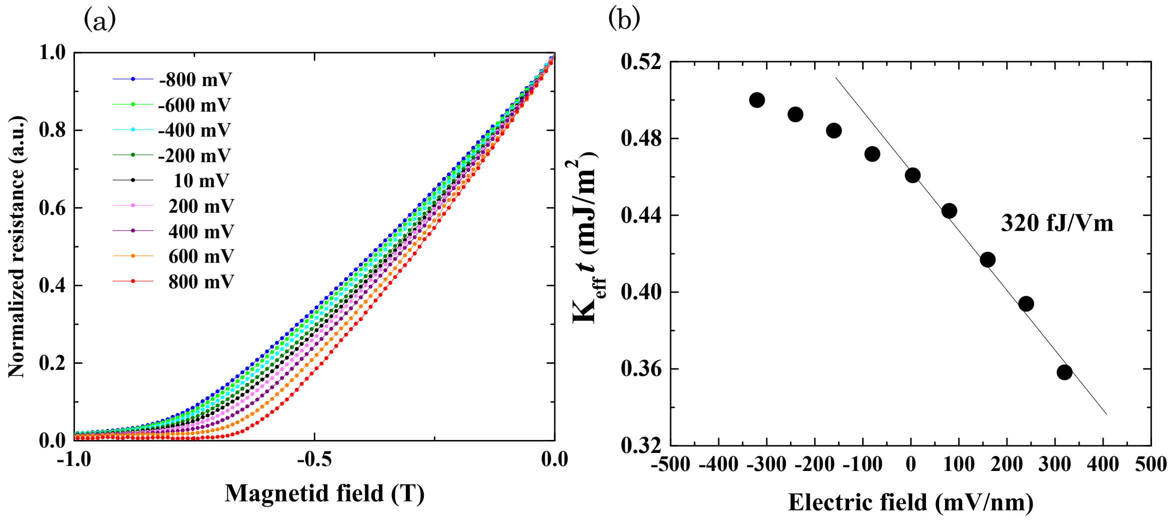

Fig. 1 (a) bias voltage dependence of normalized TMR curves for the voltage-driven MTJ and (b) Applied electric-field dependence of perpendicular magnetic anisotropy energy, $K_{eff}\,t$.

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