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Size and Relative Co Layer Thickness Dependence of Magnetization-Flop in Magnetic Tunnel Junctions Exchange-Biased by Co/Ru/Co Synthetic Antiferromagnets

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1. Introduction

In a practical density level of MRAM, the cell dimensions are expected to be in the submicron range, where the switching of a magnetic layer is dominated by magnetostatic interactions, causing the switching fields to increase significantly. In a multilayer structure, switching fields of a magnetic layer are related to two characteristic magnetic fields: the bias (or offset) field and the coercivity [1,2]. A large bias field is particularly harmful causing a large switching field asymmetry. In order to reduce the bias field, a synthetic antiferromagnet (SyAF), instead of a single antiferromagnet (AF), is frequently used as a pinning material. In spite of many merits of a SyAF, a potentially serious problem may result from magnetization-flop. Since magnetization-flop is driven by the Zeeman energy, the flop angle will be dependent on the Co thickness [3]. The main focus of the present work is to examine the effects of cell dimensions on the magnetoresistance characteristics of MTJs. The cell dimensions in the submicron range, being relevant to a high density MRAM, are considered.

2. Model and Computation

A single domain multilayer model was mainly used, but, in some cases, a multidomain model was also employed. The structure of MTJs modeled in this work was NiFe(I) (7.5 nm)/ AlO_x (0.7 nm)/ Co(I) (y nm)/ Ru (0.7 nm)/ Co(II) (7-y nm)/ FeMn (10 nm). In order to examine the size effects, the multilayers with varying dimensions were investigated; namely, 0.8×0.4, 1.2×0.6, 2.8×1.4, 4×2, 6×3, 8×4, 11.2×5.6 and 16×8 (all dimensions in μm). The uniaxial induced anisotropy in the free layer was 5 Oe and that in the Co layers was 20 Oe. The ferromagnetic exchange coupling between the free layer and Co(I) was 26 Oe. The magnitude of the antiferromagnetic coupling field between the two Co layers separated by a thin Ru layer was -1000 Oe (the negative sign indicates the antiferromagnetic coupling), which was estimated from the interlayer exchange coupling coefficient (J) of −1 erg/cm^2. The exchange coupling between the FeMn and Co(II) layers was 360 Oe, which was estimated from the unidirectional pinning strength (E_{ua}) of 0.18 erg/cm^2. The intergranular exchange coupling constant (A) was 1.67×10^{-6} erg/cm for Co, and 1.33×10^{-6} erg/cm for NiFe.

3. Results and Discussion

Computer simulation in a single domain multilayer and multidomain multilayer model have been carried out in this work to investigate magnetization-flop in MTJs exchange-biased by pinned SyAFs for MRAM applications. As the cell size decreases, the resistance to magnetization-flop increases due to increased shape anisotropy and hence increased coercivity of the Co layers in the SyAF. This is represented in Fig. 1. In the case of no or weak pinning of the SyAF, MTJs with small cell dimensions are not suitable for MRAM applications, since the MR change accompanying the free layer switching is always from the high MR state to zero, irrespective of the direction of the free layer switching. A large interlayer magnetostatic interaction field from the free layer is responsible for this behavior as shown in Fig. 2. This emphasizes an importance of a strong pinning of a SyAF at small cell dimensions. The resistance to magnetization-flop increases linearly with increasing antiferromagnetic exchange coupling between the two Co layers in the SyAF. This is because, for a given applied field, the deviation from the complete antiparallel alignment is higher at a smaller exchange coupling. The transition from magnetization-flop to the normal SyAF structure, which is the opposite direction of magnetization-flop, occurs at high (low) H_a values when the resistance to magnetization-flop is high (low). Irrespective of the magnetic parameters and cell sizes, the state of magnetization-flop does not exist near H_a=0, indicating that magnetization-flop is driven by the Zeeman energy.

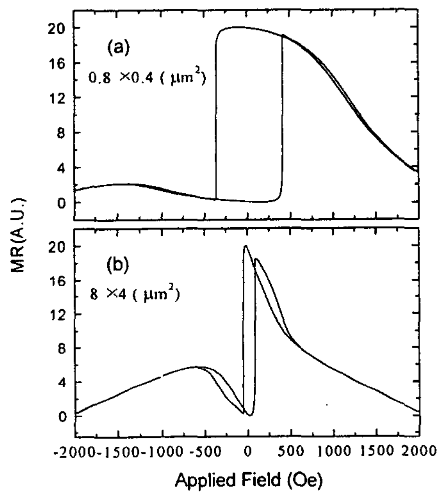

Fig. 1 MR hysteresis loops of MTJs with unpinned SyAFs for the cell size of (a) 0.8 μm × 0.4 μm, and (b) 8 μm × 4 μm. (multidomain multilayer model)

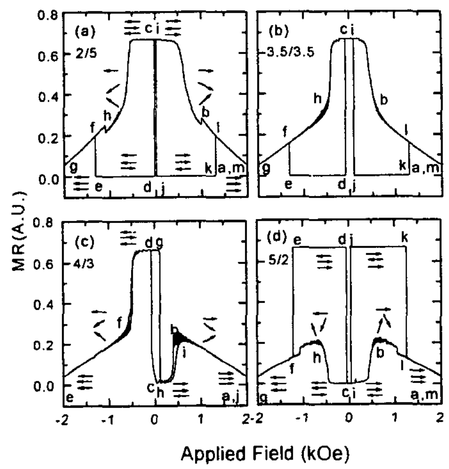

Fig. 2 MR hysteresis loops of MTJs with unpinned SyAFs for the smallest cell size of 0.8 μm × 0.4 μm at various Co(I)/Co(II) combinations of (a) 2/5, (b) 3.5/3.5, (c) 4/3 and (d) 5/2.

Reference

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