Magnetization process of a single MTJ cell in artificial spin ice

AIST[1], Osaka Univ.[2], CSRN-Osaka[3], Tohoku Univ. SRIS[4], °H. Kubota[1], S. Tsunegi[1], K. Yakushiji[1], T. Taniguchi[1], S. Tamaru[1], T. Yamamoto[1], A. Sugihara[1], H. Nomura[2,3,4], Y. Suzuki[1,2,3]

E-mail: hit-kubota@aist.go.jp

Artificial spin ice (ASI) is an ensemble of patterned ferromagnet cells coupled through magneto-static interaction [1]. The magnetization directions of the cells can be measured microscopically under a uniform magnetic field. It has been found that ASIs show various emergent behaviors, domain wall propagation [2] or phase transitions [3]. Recently, the ASI is expected to be a substrate of physical reservoir computing (RC) because the exotic properties can inherently realize non-linear transformation, fading memory and echo state property for temporal input, which are essential functionalities of RC [4-6]. Last few years we have investigated the ASI consisting of a magnetic tunnel junction (MTJ) array, which makes it possible to electrically read/write cells in the ASI. All electric access to the reservoir is important to develop compact physical RC devices. In many experiments of the ASIs, samples were prepared by patterning a permalloy film into stadium-shape (SS) cells. Since in most studies the magnetization of the cells has been regarded as a macrospin, detailed magnetization process of individual cells has not been well investigated. To operate the ASI for RC, it is necessary to understand the detailed magnetization process of the cells. In this study, we patterned films and evaluated magnetization process of a single cell in the ASI through the magnetoresistance (MR) effect. The MTJ films of sub/buffer/IrMn/CoFe/Ru/CoFeB-based alloy/MgO/FeB (5 nm)/cap were patterned into stadium shape (SS) cells and elliptical shape (ES) cells (800 nm x 150 nm). Three types of arrangement were prepared: (i) single cell, (ii) three cells, and (iii) 72-cell honeycomb lattice. The type (ii) corresponds to a part of (iii), three neighbor cells arranged in every 120º. The cell distance (a) was varied between 860 nm and 2 μm for (ii) and (iii). In every type, one MTJ cell was selected for MR measurement. The others were fabricated but electrically isolated. The MR curves were measured by sweeping magnetic fields parallel to the direction of field cooling to induce unidirectional anisotropy in the pinned layer. Maximum MR ratio in all types of the arrangement was about 200%, which was independent of a. The ES single cells showed MR curves with sharp switching and high remanent at zero field. The SS cells also showed high remanent but small resistance change prior to the large switching. Coercivity (H_c) of SS was 89 ±4 Oe, which was about half of that of ES (158 ± 9 Oe). These results indicate that the magnetization process of SS cell is different from that of the simple macrospin model. The magnitude of H_c slightly increased with decreasing a, suggesting the effect of the magnetic coupling to emergent behavior of the ASI.

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