Control of the emergent magnetization process in artificial spin ice

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In artificial spin ice (ASI)[1,2], nano-sized magnetic cells were arranged closely in, for example, square lattices or honeycomb lattices. The cells were magnetically coupled, causing collective magnetization processes such as emergent monopoles and Dirac strings that do not occur when the cells were magnetically isolated. Recently, research on the application of the emergent magnetization process of ASI to devices has attracted attention.[3,4,5] We have experimentally fabricated ASI samples based on magnetic tunnel junction (MTJ) array and observed the magnetization process of individual cells by tunnel magnetoresistance effect. This method is suitable for device implementation because the magnetization process can be detected electrically. In many previous experiments, the emergent monopoles and Dirac strings were observed spectroscopically in the process of sweeping magnetic fields in one direction. Toward device implementation, it is essential to develop a method to control the emergent magnetization process.

In this study, MTJ thin films with a magnetic free layer of 15-nm-thick FeB was patterned into a stadium-shaped cell with a width of 150 nm and a length of 800 nm, and a honeycomb ASI consisting of a total of 72 cells was formed by changing the lattice constant a in the range of 0.98 μm to 2 μm. The honeycomb lattice consists of three kinds of cells, one of which the longitudinal direction of the cell is parallel to the x direction, and the other two are tilted ± 60º with respect to the x direction. By comparing minor loops measured after saturating the FeB magnetizations to -x or +x, the magnitude of the magnetic coupling between two adjacent cells was evaluated. The magnitude increased with decreasing a, which was about 2 mT at a = 0.98 μm. After saturating the ASI (a = 0.98 μm) in the -x direction, the magnetic field of the same magnitude was applied alternately multiple times at two angles 0º and 60º, and then the magnetic field strength was gradually increased. In this sequence the magnetization of the neighboring cells was reversed one by one. This corresponds to the extension of the Dirac string one by one, which means that the movement of the monopole or extension of Dirac string can be controlled.

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