Fabrication of magnetic nanostructures for artificial spin ice lattices

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Artificial spin ice (ASI) lattices[1)] attract attention from both fundamental physics and application points of view[2)]. The ASI lattices consist of magneto-statically coupled nanomagnets, in which frustration occurs. The frustration causes emergent dynamics such as magnetic monopole excitation, which has been investigated intensively from physical point of view[1)]. The emergent dynamics is applicable to devices such as a tunable microwave filter[3)] or a reservoir computing hardware[4)]. By controlling the magnetization arrangement of the ASI, ferromagnetic resonance absorption spectrum changes remarkably[3)]. In the reservoir computing, it was demonstrated by simulation that dipole-coupled nanomagnets can perform linear and nonlinear function operation from binary sequence input [4)]. These results indicated that ASI is a promising material for variety of practical devices. For these devices, it is useful to make the ASI using magnetic tunnel junction (MTJ) because of selective magnetization reversal by means of current[5,6)] or voltage[7,8)] induced magnetization switching. In addition, large output signal due to tunnel magnetoresistance effect is inevitable for the computing[9,10)]. However, it is not easy to make dense ASI patterns with MTJs: using conventional MTJ fabrication processes, it is difficult to make a gap between the cells small (<100 nm) because of difficulties of etching with tall and dense resist patterns. In this study, in order to realize such a small gap, we developed a new fabrication process, in which thin Ti (~30 nm) metal mask patterns, replaced the tall resist mask patterns (typically >150 nm), were used in etching. Using the process, we have fabricated arrays of MTJs with a diameter of about 300 nm and a small gap down to 50 nm. The array consisted of 18x18 MTJ cells with a geometry of square lattice. Magnetoresistance effect was measured in the central 18x2 MTJs, exhibited similar resistance values and magnetoresistance curves. We are also investigating the other geometries such as honeycomb or pinwheel lattices with elongated cells. These geometries are suitable to induce the frustration in the ASI. We have fabricated 10x10 – 20x20 arrays having those geometries. This research and development work was supported by the Ministry of Internal Affairs and Communications and by JSPS KAKENHI Grant Number JP20H05655.

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