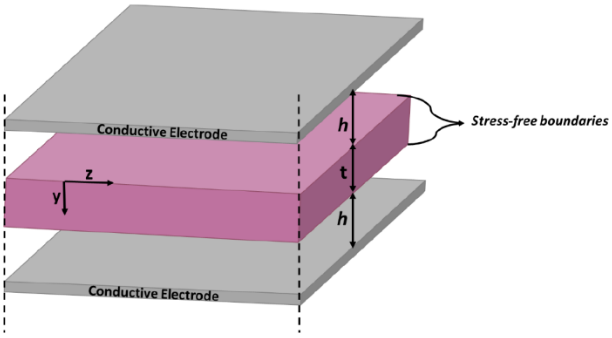

Fig. 1: Quantization of acoustic SH modes in an unbounded piezoelectric x-cut hexagonal crystal (class 6mm) nanoresonator.

[1] B. A. Auld, Acoustic fields and waves in solids, ISBN: 978-5-88501-343-7 (1973).
[2] Stroscio et al., Phys. Rev. B 48, 1936–1938, doi: 10.1103/PhysRevB.48.1936 (1993).

P:12 Exchange-coupled majority logic gate

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Magnetic dipole-field-coupling between adjacent single-domain nanomagnets has long been used to realize logic gates [1]. It has recently been demonstrated that much stronger lateral coupling can be achieved between two neighboring nanomagnets, if they both are antiferromagnetically exchange- coupled to a common bottom magnetic layer [2]. This paper presents a simulation study on majority logic gate, using this novel coupling mechanism as a building block.

PHYSICAL STRUCTURE OF THE EXCHANGE- COUPLED SYSTEM

Two magnetic layers separated by a non- magnetic layer can either point to parallel or antiparallel directions in their ground state (fig.1 (top left and right)), depending on the thickness of the non-magnetic layer [3]. If the ground state is antiparallel, the layers are called antiferromagnetically exchange-coupled. However, if the top magnetic layer is patterned into two closely-spaced single- domain nanomagnets, the magnets force each other to parallel direction, both being antiparallel to the bottom magnetic layer (fig. 1(bottom)) [2]. The competition between lateral dipole coupling energy between the magnets, and the exchange coupling energy between the layers in vertical direction determines the ground state of this system. If the exchange coupling energy overwhelms the dipole coupling energy, the nanomagnets settle into parallel direction. Stronger coupling between the neighboring elements can effectively increase the energy barrier between stable round states, and make the system more immune to thermal fluctuations and process variations, which can cause random errors in complex systems by obliterating the energy barrier.

NUMERICAL SIMULATIONS

In fig. 2, a typical majority gate structure is shown for different input/output combinations. Given the state of input A (0 or 1), the computing magnet (M) performs a logical AND or OR operation between the other two input magnets (B, C), respectively. The computing (M) and output (Out) magnets were clocked along their hard axis by applying a 1 T magnetic field, and then allowed to relax as the field was gradually reduced to zero.

The micromagnetic simulations using OOMMF clearly show logically correct output states for the given input combinations. Unlike a dipole-coupling based majority logic gate, the state of the computing magnet is buffered to the output magnet instead of being inverted. This is due to the dominance of exchange- coupling over the dipole-coupling between them. The bottom layer finds an energetically favorable domain configuration (fig. 2).

We are not aware of any studies on the logic applications of exchange-coupled and patterned films. Besides being an interesting model system, such systems can be engineered to build dense, 3-D magneto-electronic platform for magnetic logic and data storage. We are currently studying this system both experimentally and via further simulation and analytical methods.

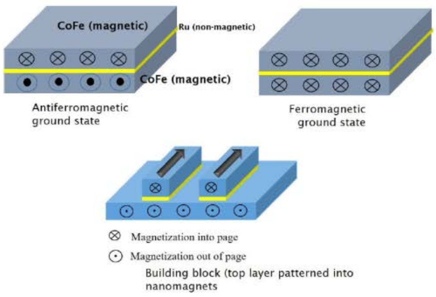

Figure 1: Exchange-coupled nanomagnet system: (top left and right) the antiferromagnetic and ferromagnetic ground state (bottom) building block showing nanomagnets pointing to same direction [2].

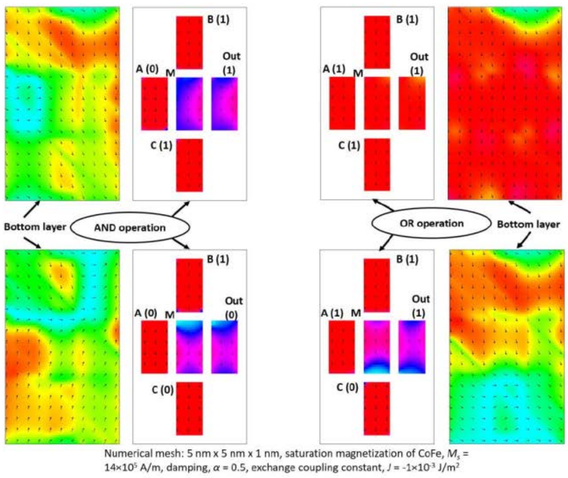

Figure 2: Simulated magnetizations of the exchange-coupled majority logic gates (left column) A=0: AND operation between the inputs B and C (right column) A=1: OR operation between B and C.

[1] Imre, A., G. Csaba, L. Ji, G.H. Bernstein, and W. Porod. *"Majority logic gate for magnetic quantum-dot cellular automata."* Science 80, pp. 1-4 (2006).
[2] Dey, H., G. Csaba, G.H. Bernstein, and W. Porod*. Exchange coupling between laterally adjacent nanomagnets."* Nanotechnology 27, 395202 (2015).
[3] Fullerton, E. et al., *"Antiferromagnetically coupled magnetic media layers for thermally stable high density recording"*, Applied Phys Lett, vol. 77, 3806,2000.