P:11 Quantized acoustic-phonon shear horizontal modes in a piezoelectric nanoresonator

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To obtain high resonant frequencies of the order of sub-terahertz frequencies, the dimensions of a resonator need to be scaled down to the nanometer regime. As device dimensions shrink, the fundamental physics of phonon propagation and interaction is changed. In this study, to simplify the calculations of the quantum-mechanical coefficients, for the very first time we applied a quantization prescription to the classical acoustic-shear horizontal (SH) modes confined in an infinite piezoelectric nanoresonator. Here, we quantized the displacement amplitudes of the modes using the unquantized equations presented by Auld [1], in a way that each mode has the appropriate quantum-mechanical energy. As depicted in Fig.1, we consider an infinite piezoelectric X-cut hexagonal plate of a 6mm crystal with thickness, t, along with two perfectly conducting electrodes away from the surfaces of the plate by a gap of h. The coordinate system used in this problem is shown in Fig. 1. Here, the assumption is that the plate has stress-free boundaries and its thickness is small enough for the quasi-static approximation to be valid. We only consider the x-polarized particle displacement which is electrically coupled to the generated potential. The unquantized acoustic SH displacement wave propagating in the y direction can be written as follows [1]:

$$U_x = \begin{cases} A\cos(ky), & n = 0,2,4,\dots \\ A\sin(ky), & n = 1,3,5,\dots \end{cases} \tag{1}$$

where $k=\frac{n\pi}{t}$ is the wave vector, and $A$is the unknown amplitude of the acoustic wave. Now we can obtain the normalized expression of classic acoustic SH modes confined in the nanoresonator depicted in Fig. 1, for two cases of (i) even symmetry modes and, (ii) odd symmetry modes, by following the general quantization procedure discussed by Stroscio et al. [2],

$$\frac{1}{t}\int_0^t dy\{U_X.U_X^*\} = \frac{\hbar}{2m\omega_n} \tag{2}$$

where $\omega$is the wave angular frequency and m is the atomic mass. Substituting the displacement fields given in Eq. 1 into Eq.2, yields

$$\frac{A^2}{n\pi}\int_0^{n\pi} \cos^2(u)\,\mathrm{d}u = \frac{\hbar}{2m\omega_n} \tag{3}$$

for the even symmetry modes and

$$\frac{A^2}{n\pi}\int_0^{n\pi} \sin^2(u)\,\mathrm{d}u = \frac{\hbar}{2m\omega_n} \tag{4}$$

for the odd symmetry modes, so that

$$A^2 = \frac{\hbar}{m\omega_n} \qquad \text{for all } n. \tag{5}$$

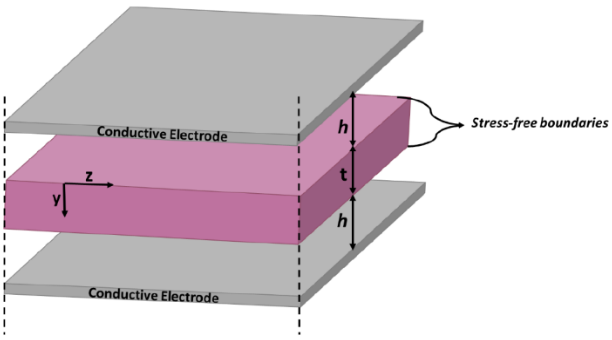

Fig. 1: Quantization of acoustic SH modes in an unbounded piezoelectric x-cut hexagonal crystal (class 6mm) nanoresonator.

[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