㉑ Superconducting qubit and nano-mechanical resonator coupled system

- Entanglement of supercurrent and vibrational quanta -

Motivation

The quantized oscillation mode of nanomechanical structure can serve as a desirable quantum bus in mesoscopic system. Coupling it with superconducting flux qubit forms a novel solid-state cavity QED architecture, which affords great advantage for the quantum state engineering of both.

Originality

We present the first possible scheme to couple the vibration quanta in nanomechanical structure with persistent supercurrent of flux qubit by Lorentz force. The coupling strength is fully tunable and strong enough to reach the “strong coupling regime” of cavity QED.

Impact

This novel architecture of solid-state cavity QED enables quantum coherent operation for this composite system and quantum entanglement for supercurrent with vibrational quanta. It might have great potential to benefit quantum information processing and quantum state engineering.

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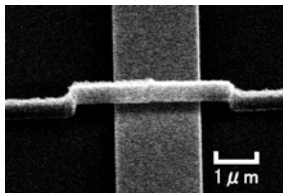
Micro(nano)-mechanical System

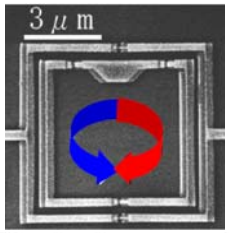


NTT 2007

Harmonic oscillator:
for fundamental flexural mode

$$H_r = \frac{p^2}{2m} + \frac{1}{2}m\omega_0^2 z^2$$

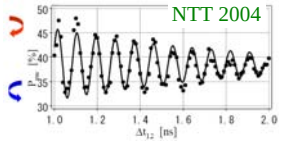
Superconducting Flux Qubit



Artificial Two-level Atom

$$H_f = \omega_f \sigma_z + \Delta\sigma_x$$

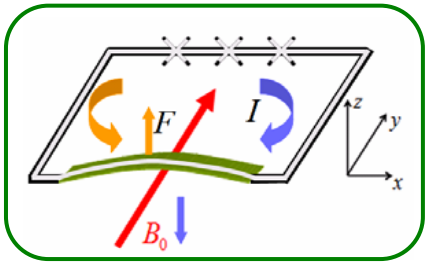
$$\omega_f = I_p \Phi_0 (f - 0.5)$$



NTT 2004

$I_p \sim 10^2$ nA

Circuit QED in Strong Coupling Regime



$$g = B_0 I_p L \delta_z$$

Coupling can be modulated and switched on-and-off by B_0

$$1/g \ll 1/\gamma, \quad 1/\Gamma$$

0.015 μs 1 μs 0.1 μs

Reference: New. J. Phys. 9, 35 (2006)

Lorentz force is induced by coupling magnetic field B_0 when there is circulating supercurrent in the loop

$$\mathbf{F} = (\mathbf{I} \times \mathbf{B})\, L$$

This Lorentz force couples the persistent super current in the superconducting loop with the displacement of nano-mechanical resonator

$$H_I = \mathbf{F} \cdot \mathbf{z} = B_0 I L z = g z \sigma_z$$

$$H = H_f + H_r + H_I$$