Coupling a membrane resonator with a superconducting microwave cavity

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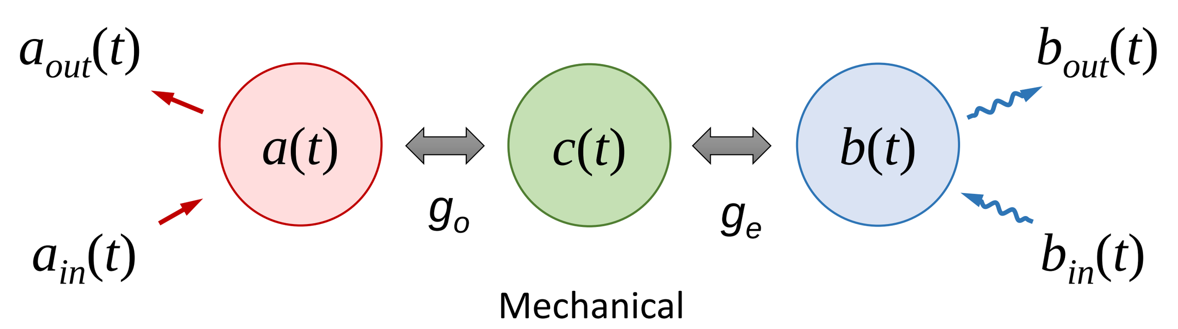
Abstract

Recently, optomechanical systems have been employed in developing a quantum conversion system. A mechanical resonator can be coupled with two different optical resonators simultaneously, and mediate coherent interactions between electromagnetic waves in two different frequencies. An efficient conversion system can preserve entanglement in quantum signals and enable versatile applications. We have fabricated a nanomechanical membrane resonator, and coupled it with a superconducting 3-dimensional microwave resonator. We have demonstrated that the high-order resonance in the microwave cavity can be used to drive the mechanical resonator. The coupled optomechanical system constitutes a basic platform for the quantum network and the standoff sensing research.

Quantum conversion

Electro-opto-mechanical system

- Conversion between optical and microwave photons can be mediated by a mechanical resonator.
- The mechanical oscillator couples to both optical and microwave cavities.



Model Hamiltonian

$$\hat{H} = \hbar\omega_o\hat{a}^\dagger\hat{a} + \hbar\omega_e\hat{b}^\dagger\hat{b} + \hbar\omega_m\hat{c}^\dagger\hat{c} \quad \text{Free modes}$$

$$+ \hbar g_o(\hat{c}^\dagger + \hat{c})\hat{a}^\dagger\hat{a} + \frac{\hbar g_e}{2}(\hat{b}^\dagger + \hat{b})^2(\hat{c}^\dagger + \hat{c}) \quad \text{Coupling}$$

$$+ i\hbar E_o(\hat{a}^\dagger e^{-i\omega_{d,o}t} - \hat{a}e^{i\omega_{d,o}t}) + i\hbar E_e(e^{i\omega_{d,e}t} - e^{-i\omega_{d,e}t})(\hat{b}^\dagger + \hat{b}) \quad \text{Driving field}$$

$\hat{a}, \hat{b}, \hat{c}$: annihilation operators of optical cavity, microwave cavity, mechanical oscillator

$\omega_o, \omega_e, \omega_m$: resonance frequencies of optical cavity, microwave cavity, mechanical oscillator

$\omega_{d,j} = \omega_j - \Delta_{0,j}$: driving field frequency ($j \in \{o, e\}$, $\Delta_{0,j}$: detuning)

g_j : coupling rate ($j \in \{o, e\}$)

E_j : driving field amplitude ($j \in \{o, e\}$)

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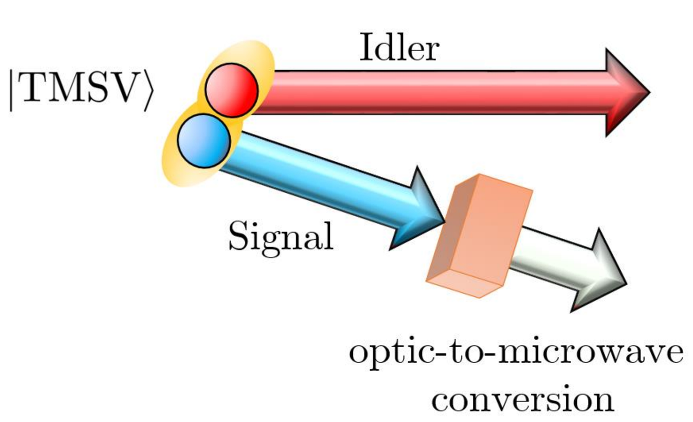
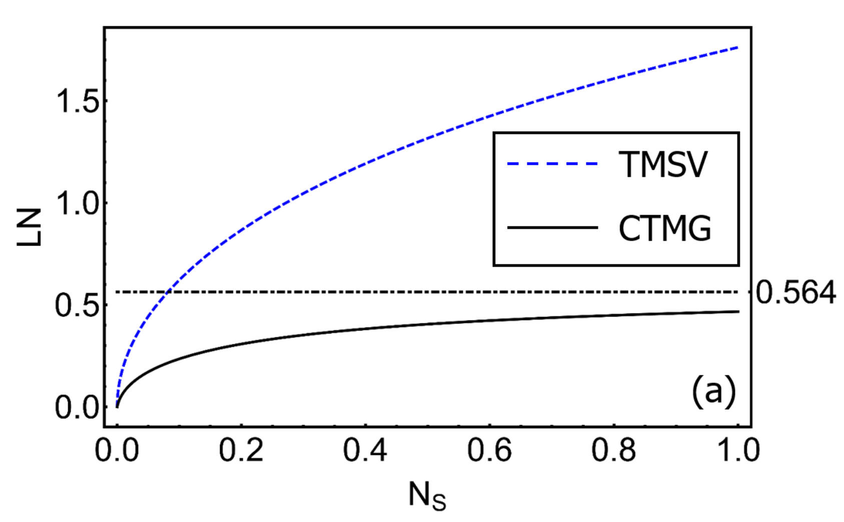
Entanglement preservation after the conversion

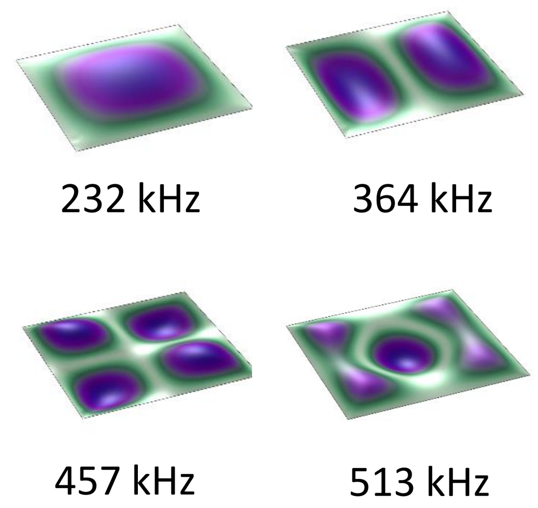




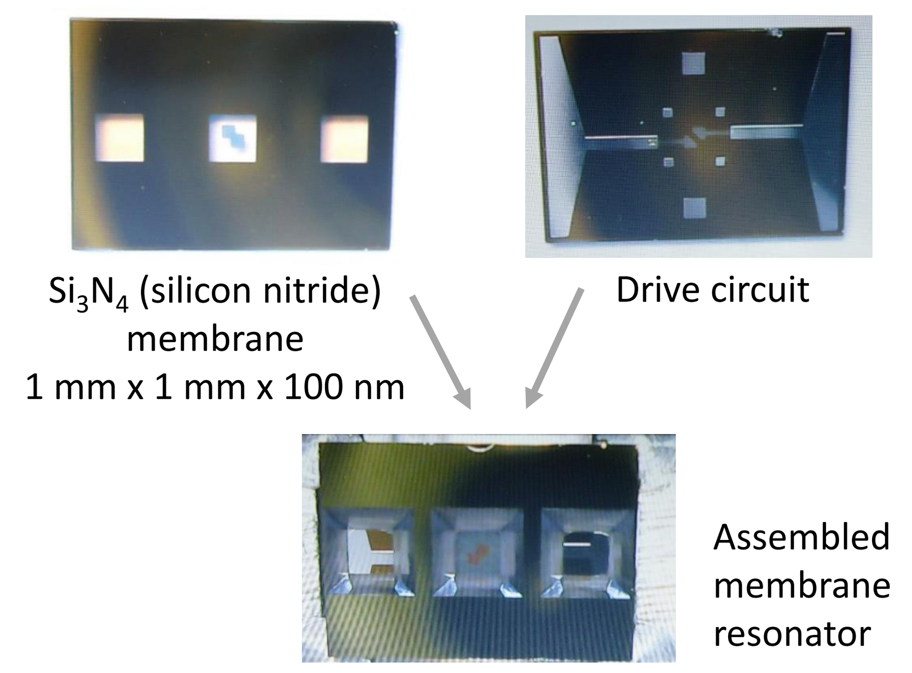
By calculating Logarithmic Negativity (LN), entanglement was quantified for the Converted two-mode Gaussian (CTMG) state, which is produced by converting one mode of the two-mode squeezed vacuum (TMSV) state. The CTMG state has a finite LN suggesting that entanglement is preserved after the optic-to-microwave conversion.

- Yonggi Jo *et al.*, "Surviving entanglement in optic-microwave conversion by an electro-optomechanical system", Opt. Express **29**, 6834 (2021)

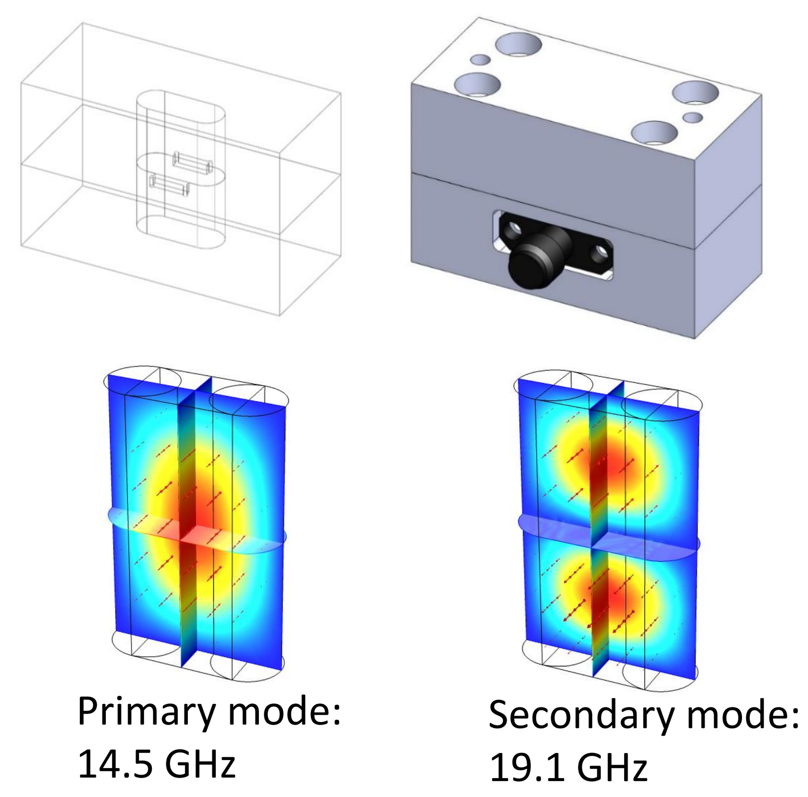
Nanomechanical Membrane



Vibrational modes of the membrane resonator



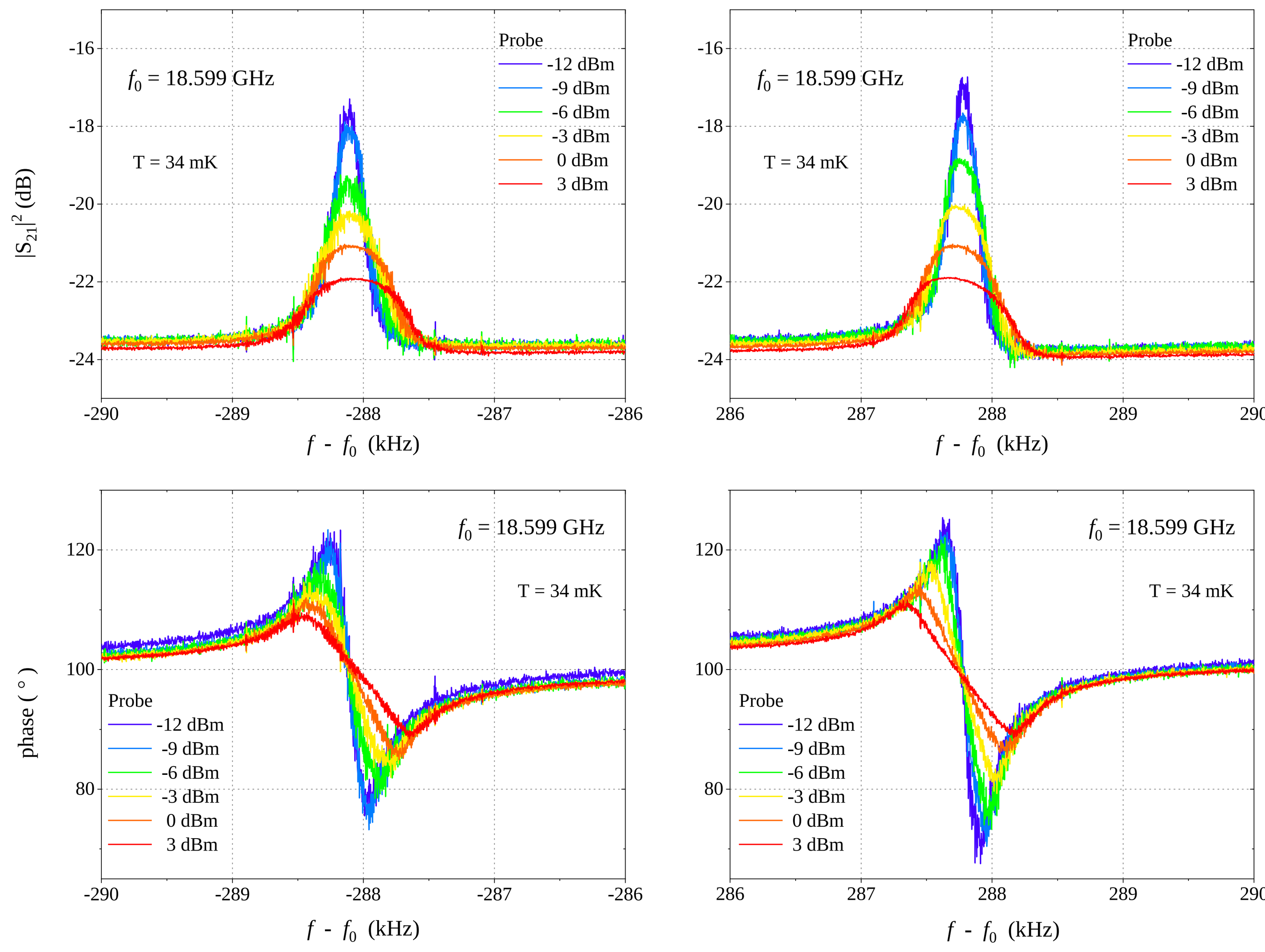
Superconducting microwave cavity



The microwave cavity is made of aluminum with a dimension of 20 x 13 x 5 mm. The membrane resonator is coupled with the aluminum cavity by a galvanic connection.

Coupling the Membrane with the Microwave cavity

When the membrane resonator is installed, the resonant mode of the microwave cavity is shifted to a lower frequency. By applying microwaves with two frequencies, the resonant motion of the mechanical resonator can be controlled and measured.



Conclusion

A nanomechanical membrane resonator is fabricated and coupled to a superconducting microwave cavity. The mechanical resonant mode is measured through the secondary mode of the microwave cavity. The coupled system can be utilized in building an efficient conversion system.

References

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[2] M. Yuan *et al.*, "Large cooperativity and microkelvin cooling with a three-dimensional optomechanical cavity", Nat. commun. **6**, 8491 (2015)

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