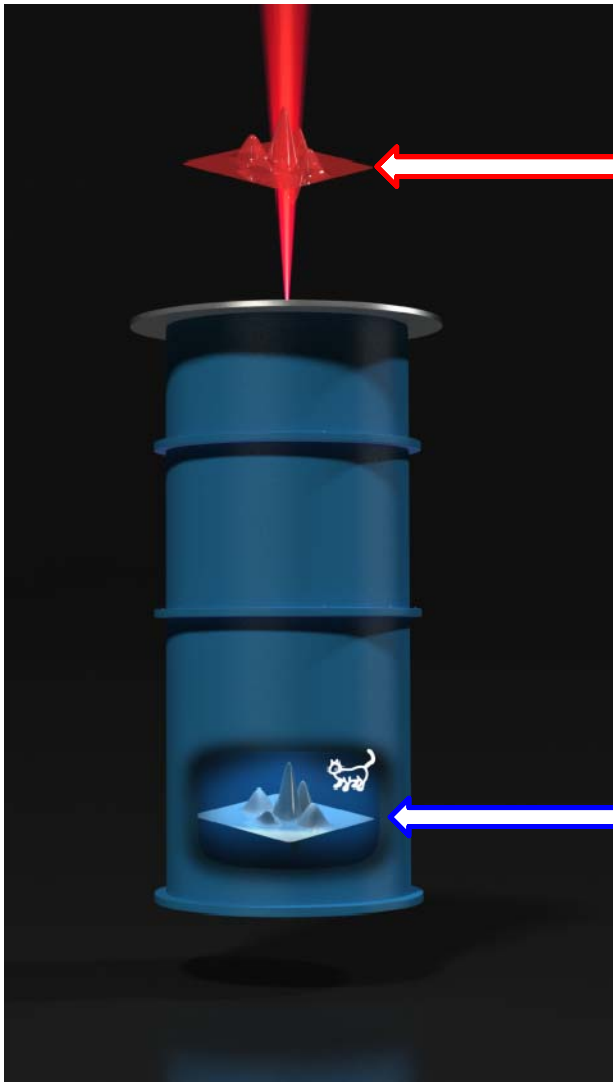
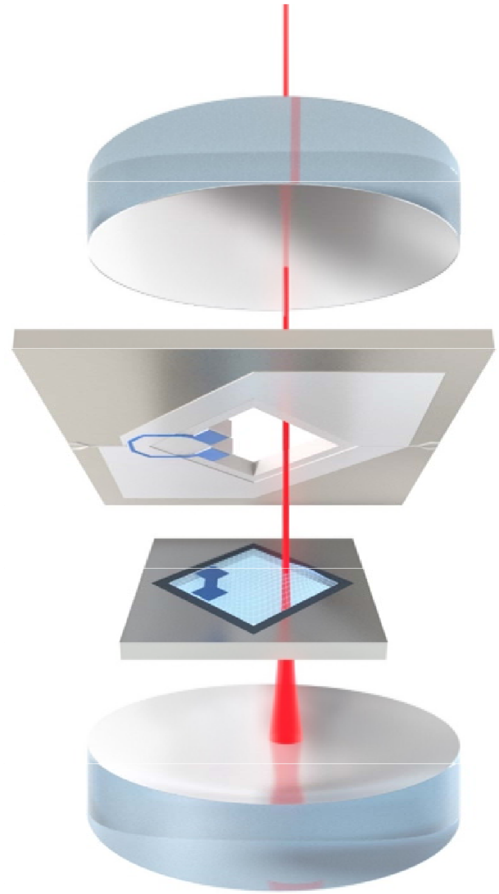
Towards a quantum interface between light and microwave circuits



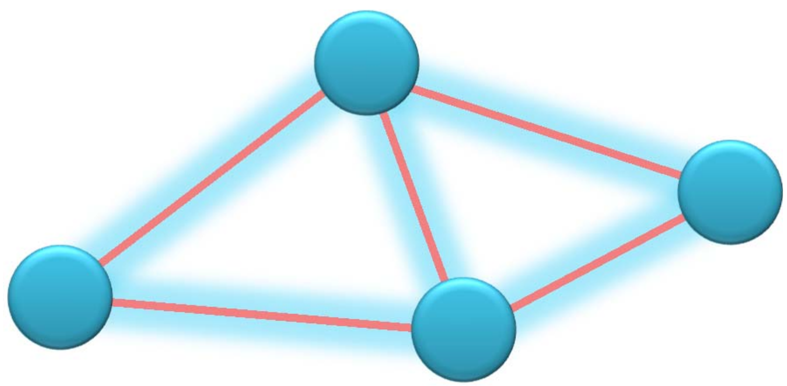
ambient light

ultracold microwaves

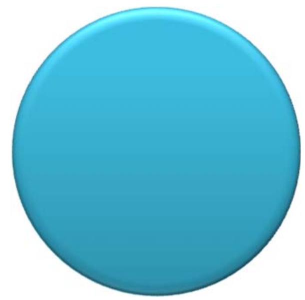


Quantum information network built from nodes linked by propagating modes

quantum network



nodes



process
and store

links

transmit

quantum network

physically secure communication

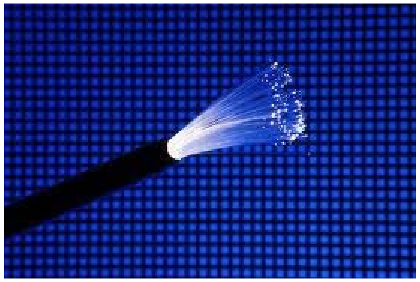
uncopiable information

Quantum transduction connects disparate physical systems

optical light:

long distance communication

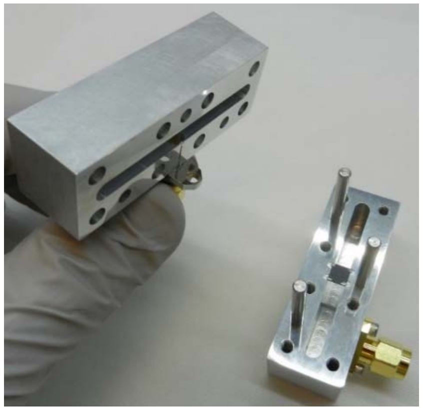
ambient temperature



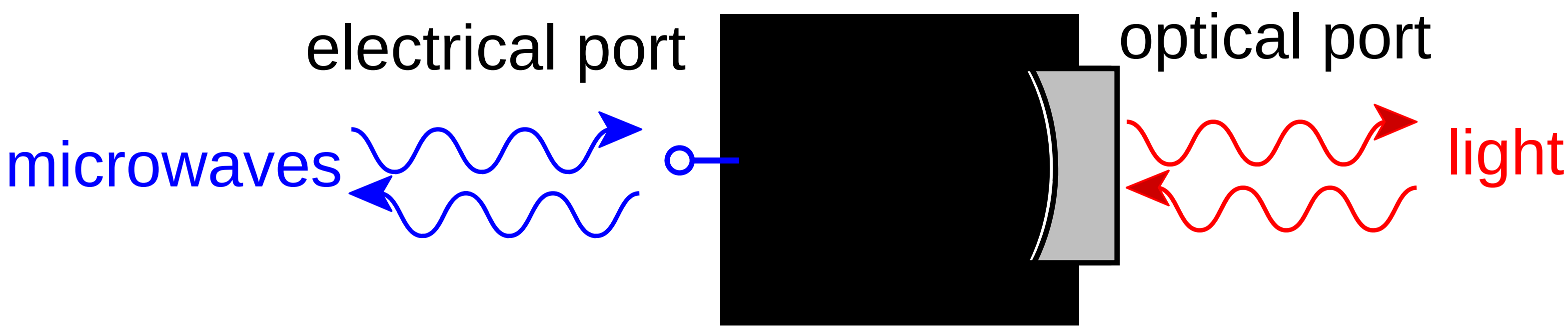
microwave circuits:

process quantum information

ultralow temperature $T < 250\ \mathrm{mK}$



Quantum state preserving convertor is a unitary device



quantum state preserving =>
bidirectional, lossless, reflectionless network

$$T_{up} = T_{down} = 1 \qquad R_{elec} = R_{opt} = 0$$

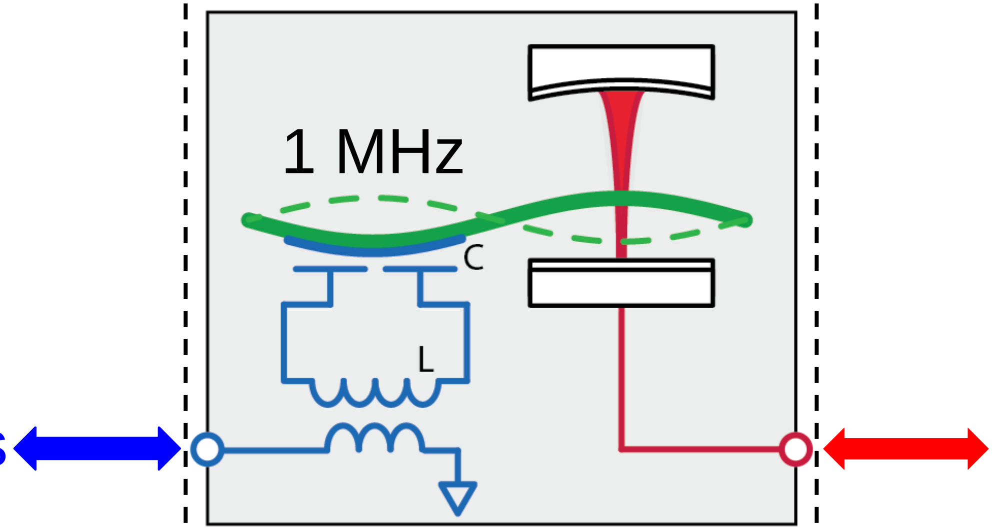
Mechanical oscillator creates coherent coupling between microwaves and light

electrical

mechanical

optical

7 GHz



280 THz

microwaves

light

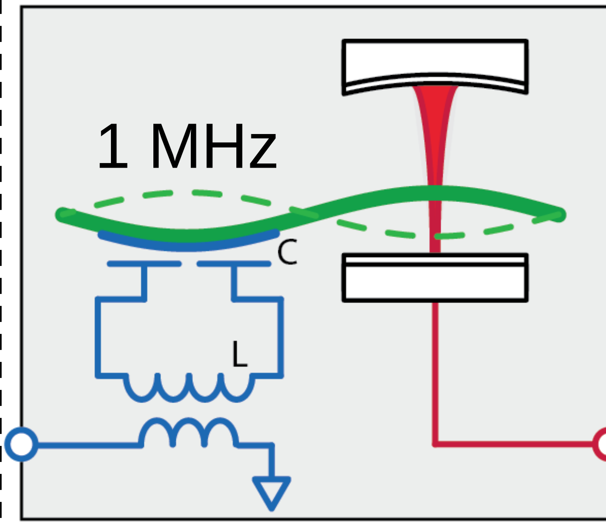
Mechanical oscillator creates coherent coupling between microwaves and light

electrical

mechanical

optical

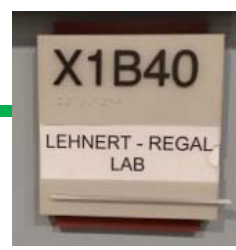
7 GHz



280 THz

microwaves

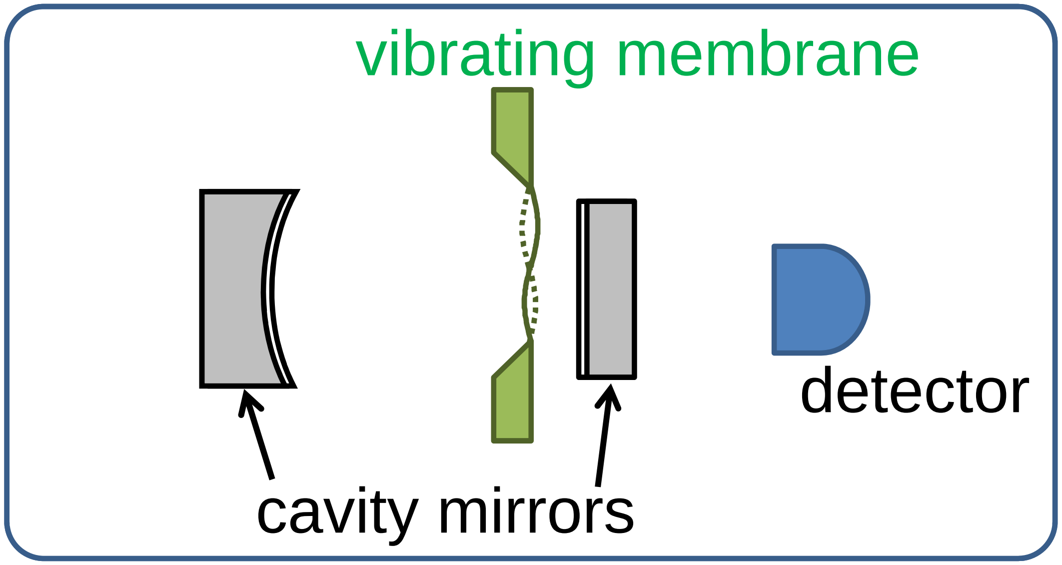
light



<u>Lehnert group</u>
quantum
electromechanics

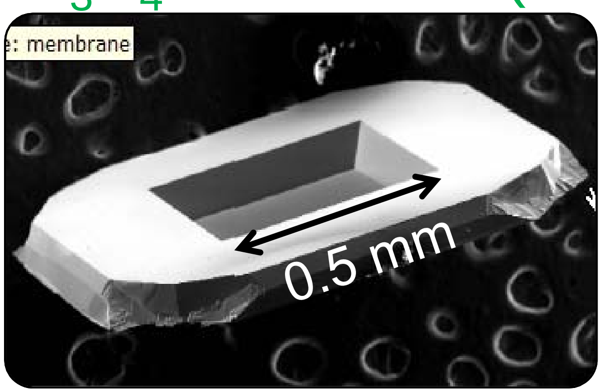
<u>Regal group</u>
quantum
optomechanics

Suspended membrane in optical cavity forms optomechanical system



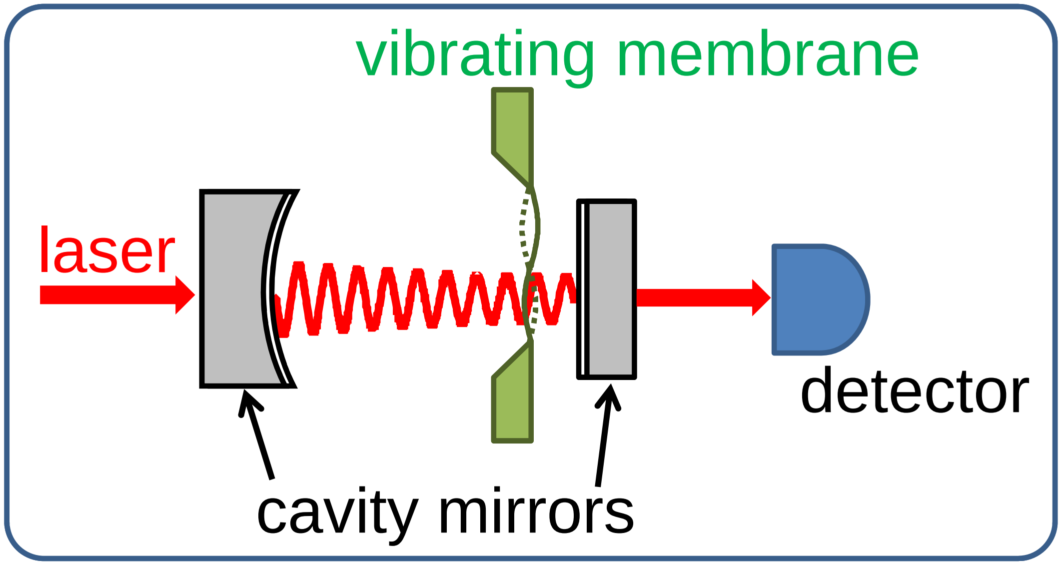
1 cm

Si_3N_4 membrane (50 nm)

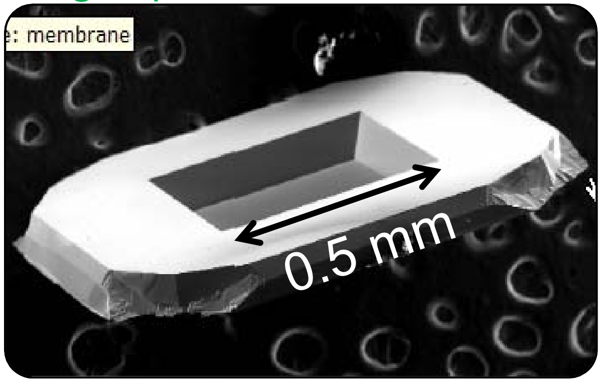


Harris group (YALE)

Suspended membrane in optical cavity forms optomechanical system



Si_3N_4 membrane (50 nm)



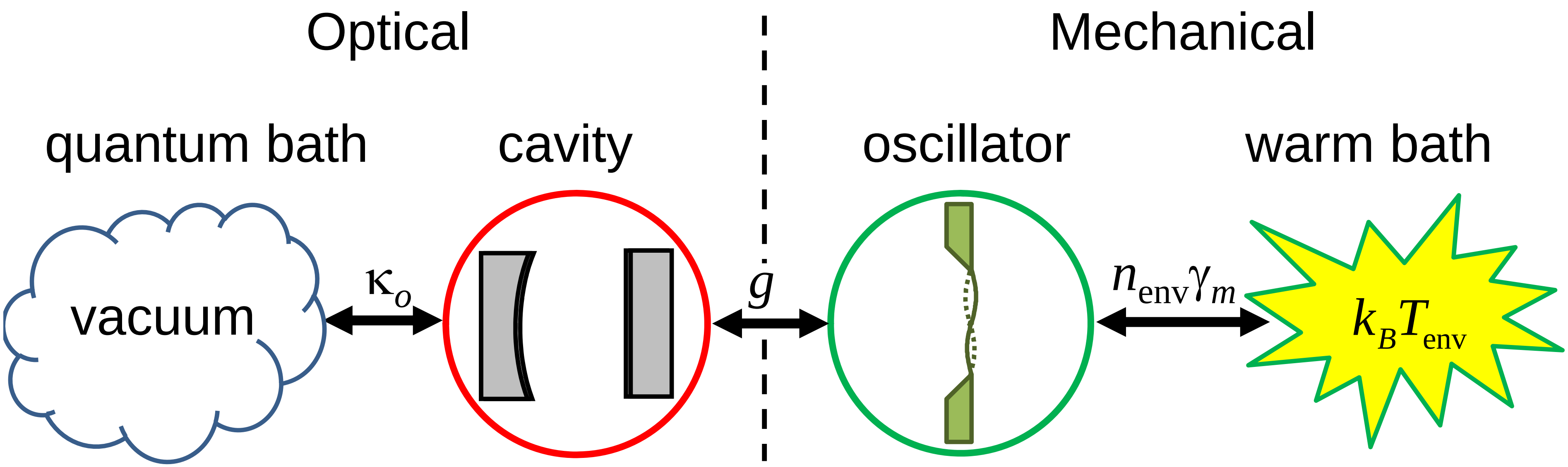
Harris group (YALE)

<u>optomechanical coupling</u> (g)

position alters optical phase

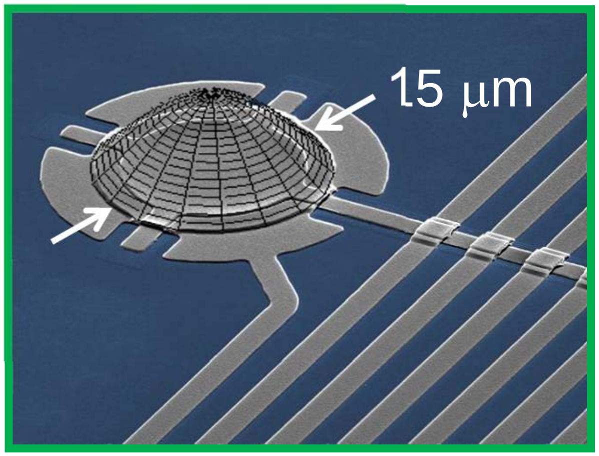
optical amplitude alters momentum

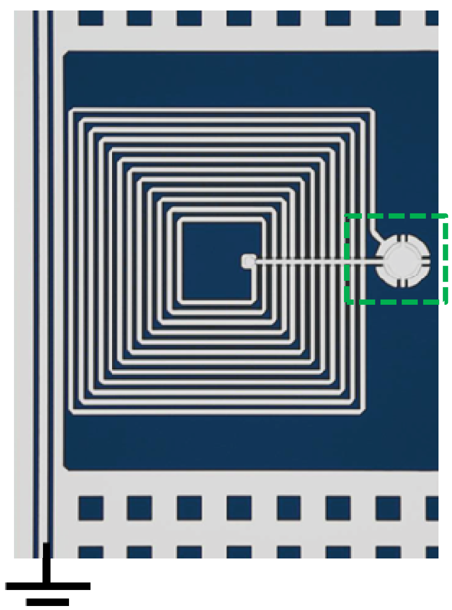
Superb coherent control creates optomechanical system in quantum regime



optomechanics in the quantum regime $\dfrac{g^2}{4\kappa_o} > n_{\mathrm{env}}\gamma_m$

Resonant circuit with compliant capacitor creates electromechanical system

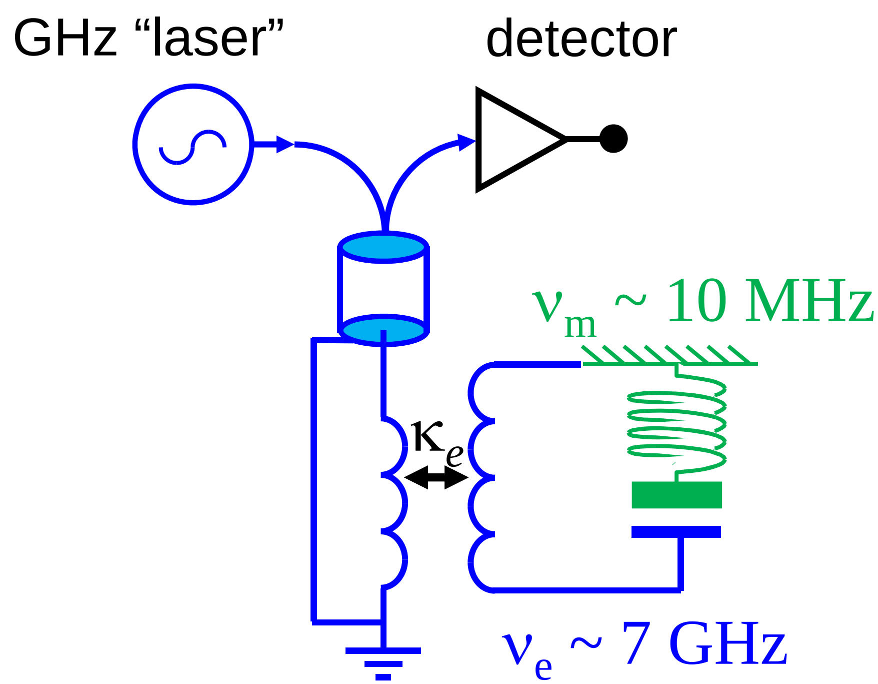




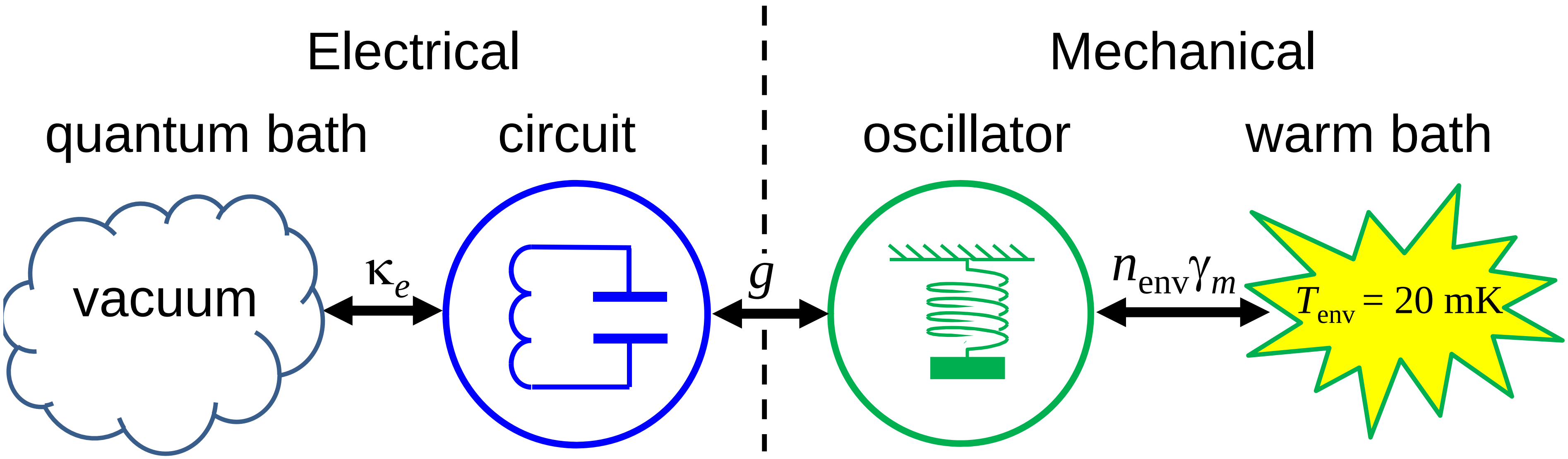
Electromechanical system

superconducting LC circuit

quantum circuit for $T < 250$ mK

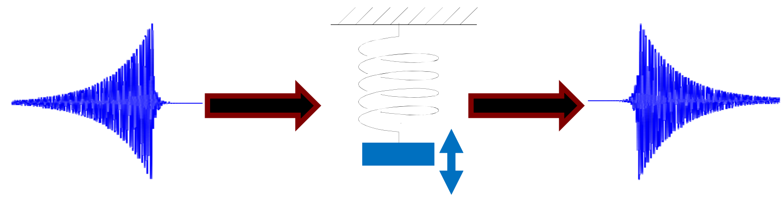


Microwave fields control the quantum state of a mechanical oscillator



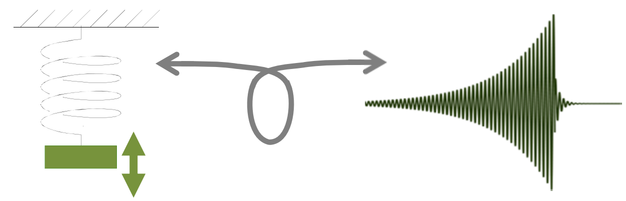
State transfer

Nature **495,** 210 – 214 (2013)

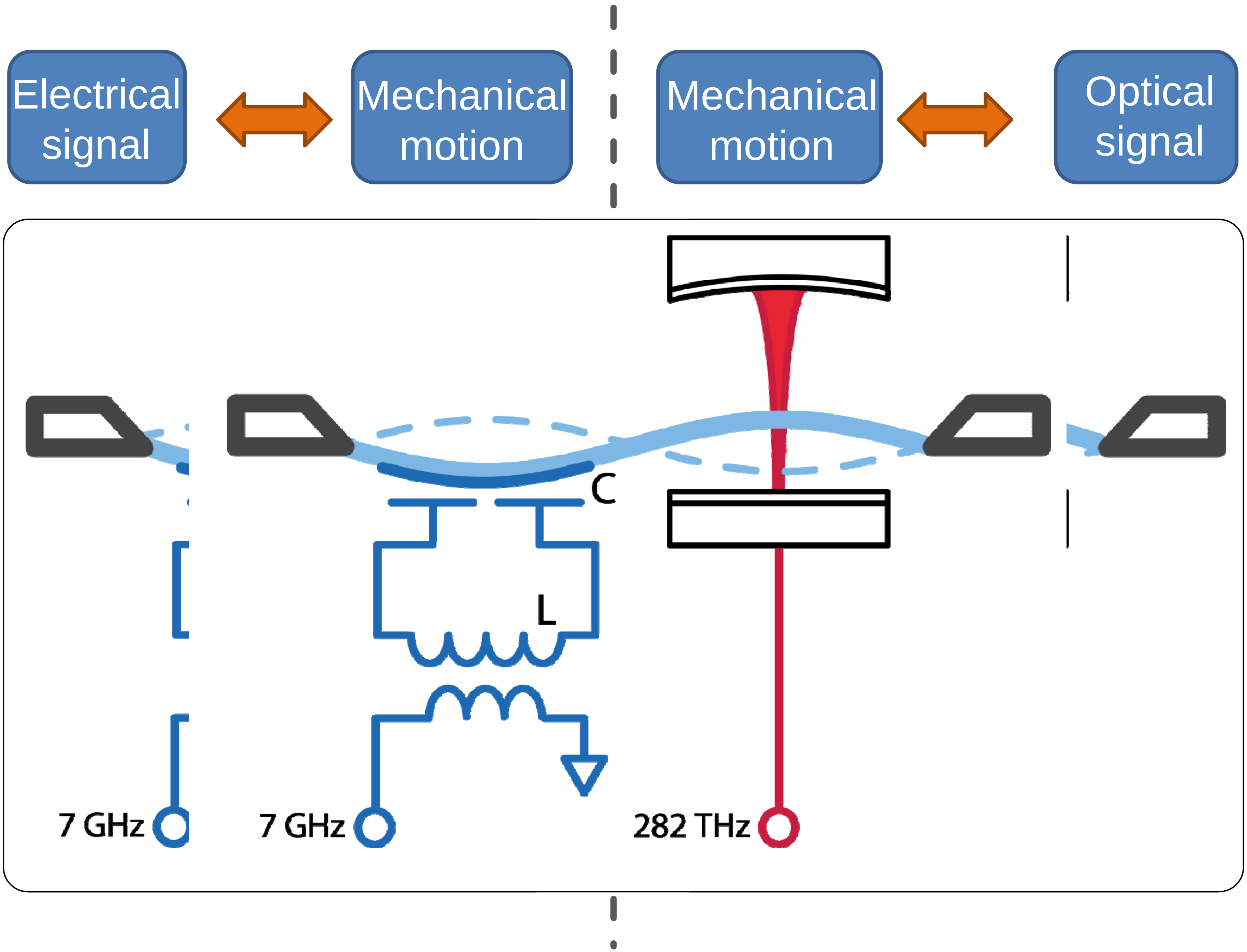


Entanglement

Science **342,** 710 – 713 (2013)

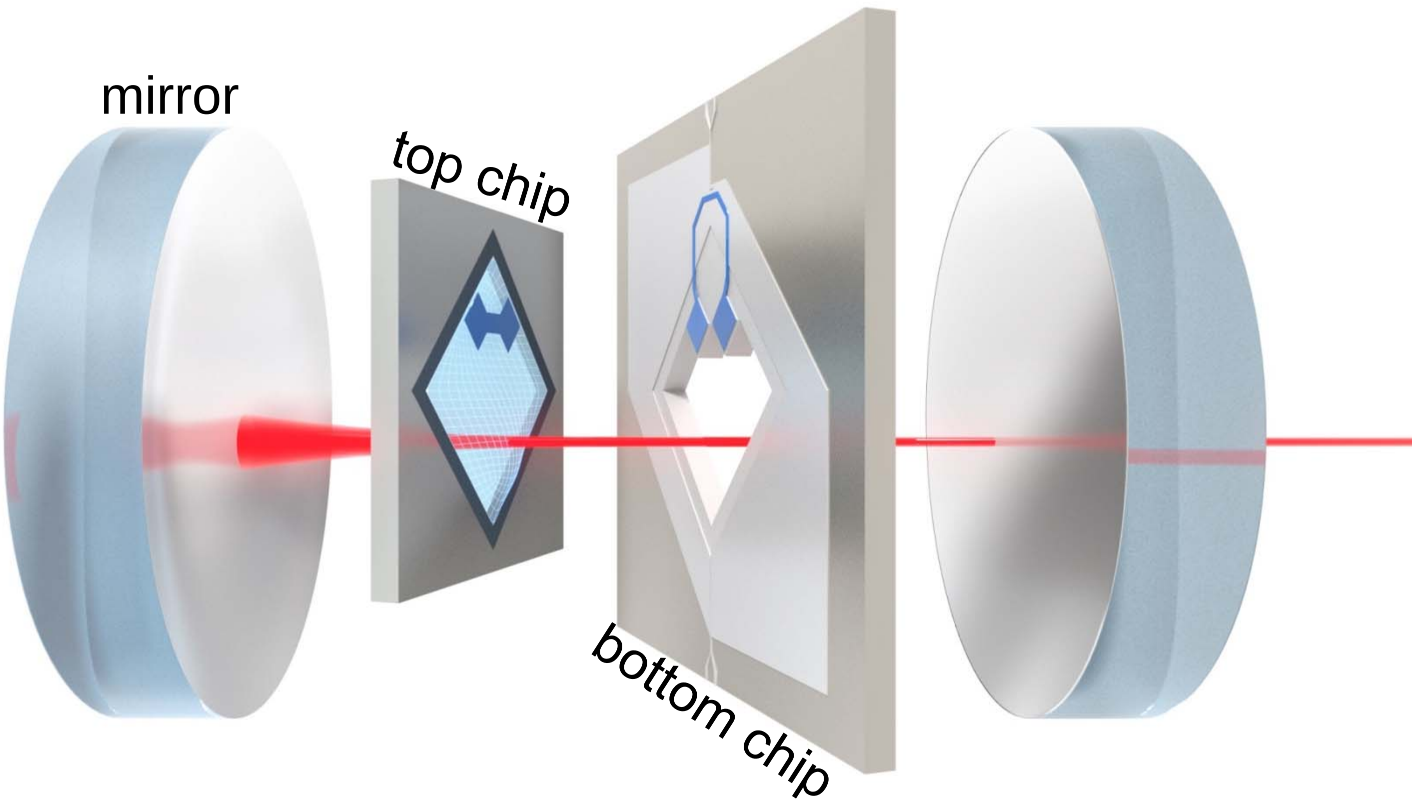


JILA NIST CU



Electrical signal
Mechanical motion
Mechanical motion
Optical signal
C
L
7 GHz
7 GHz
282 THz

Opto-electromechanical system formed from "flip-chips" in optical cavity



mirrors: high-finesse optical cavity

top chip: membrane and one plate of capacitor

bottom chip: remainder of electrical circuit

Image of assembled flip-chip structure

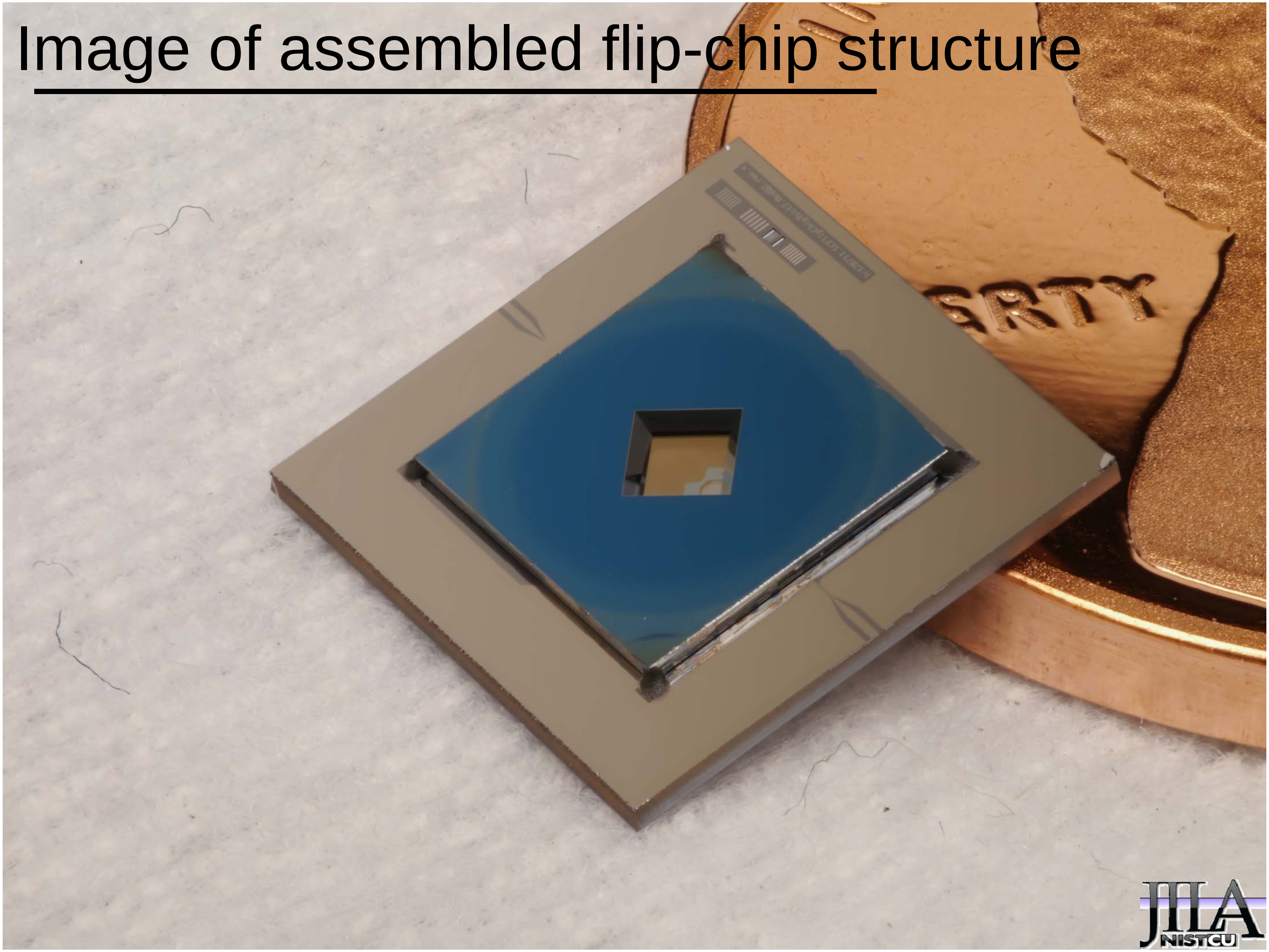


Diagram of optical cavity assembly

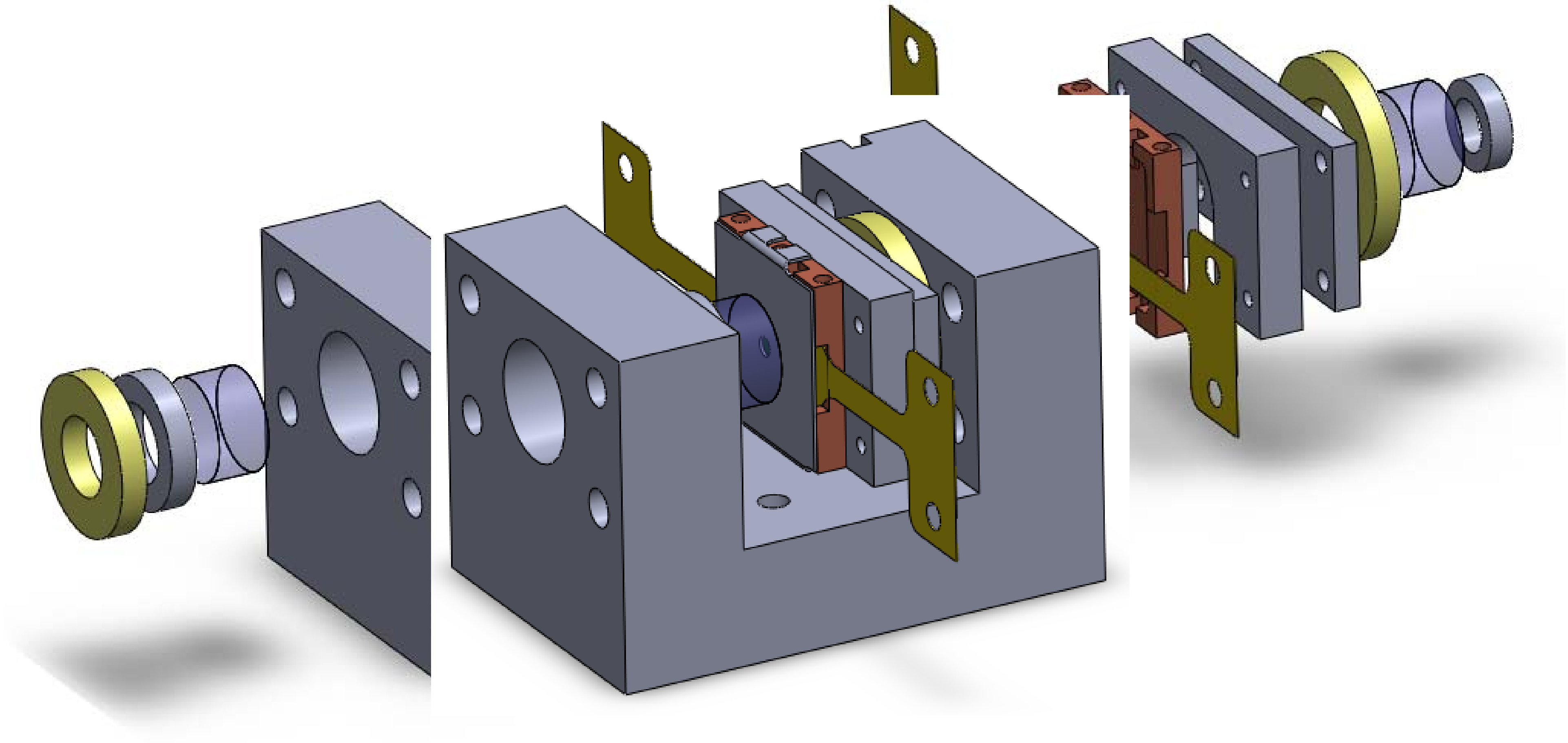
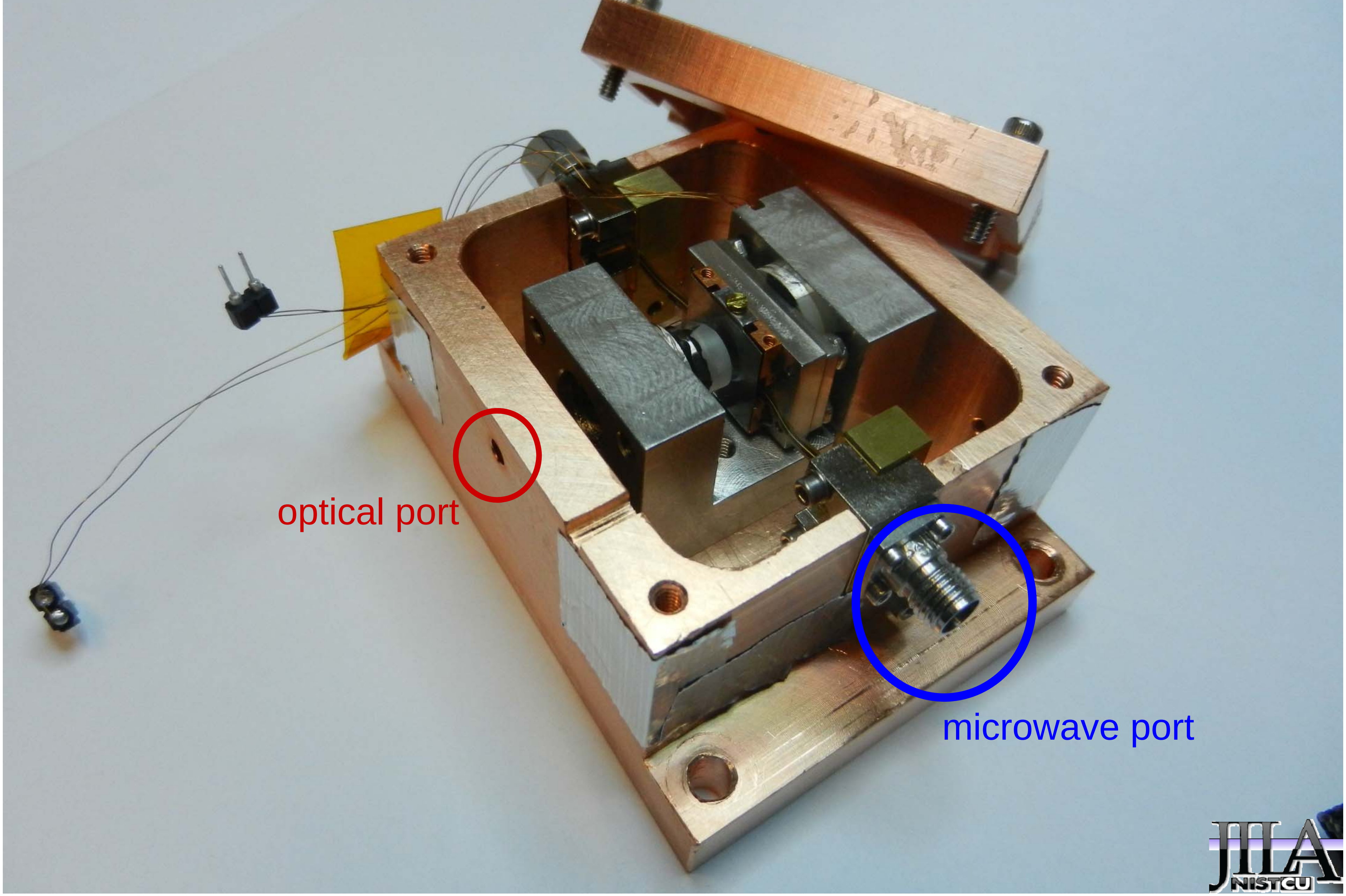
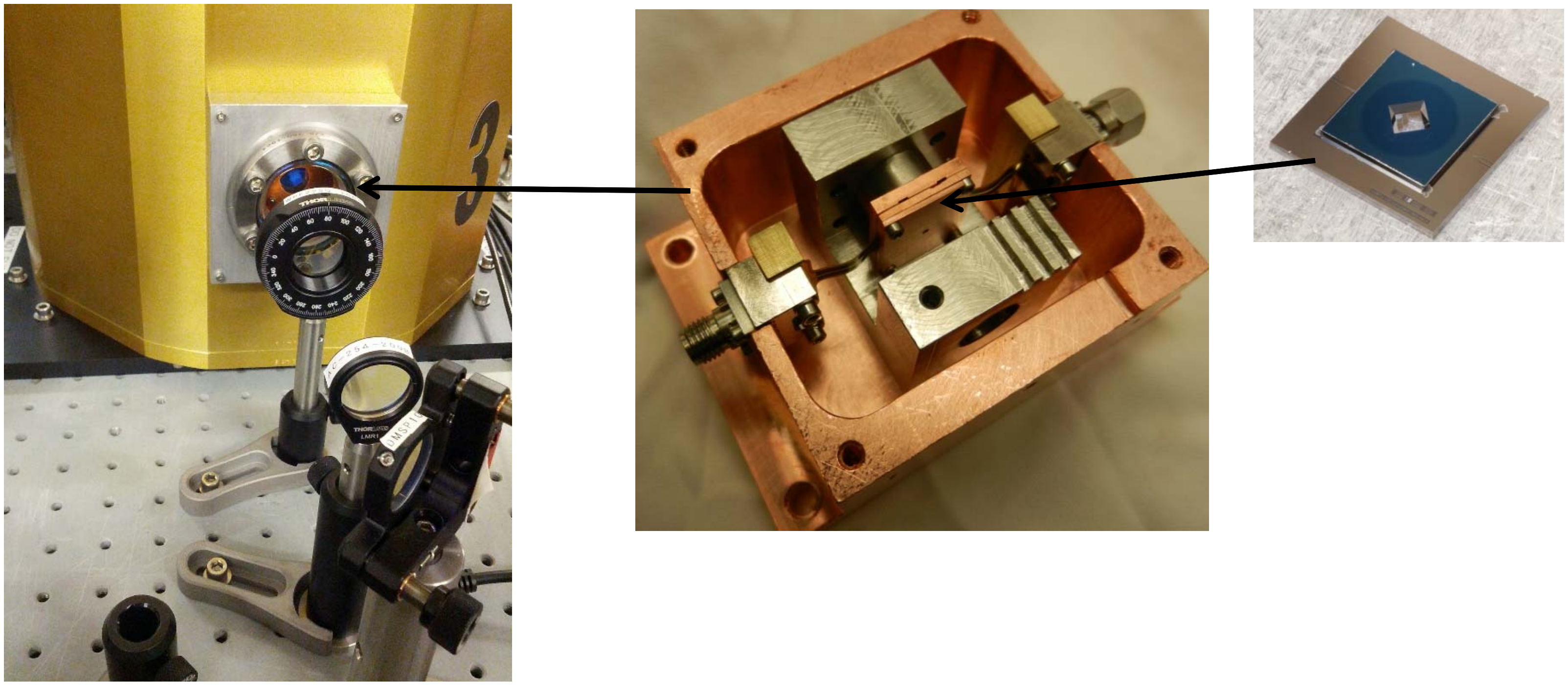


Image of optical cavity assembly



4 K sufficiently cold to test electro-optic conversion in a classical regime

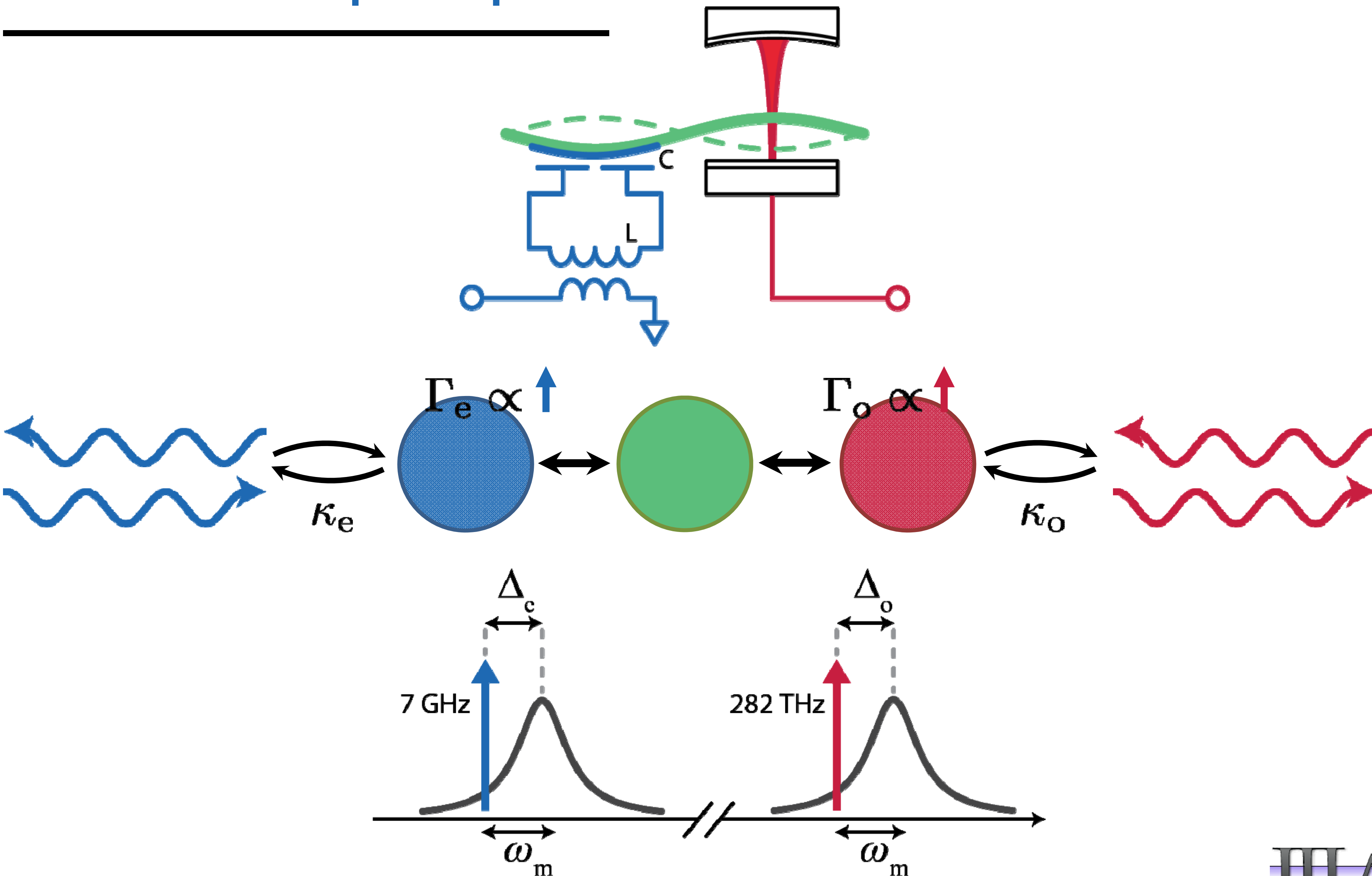


4 K cryostat with optical access

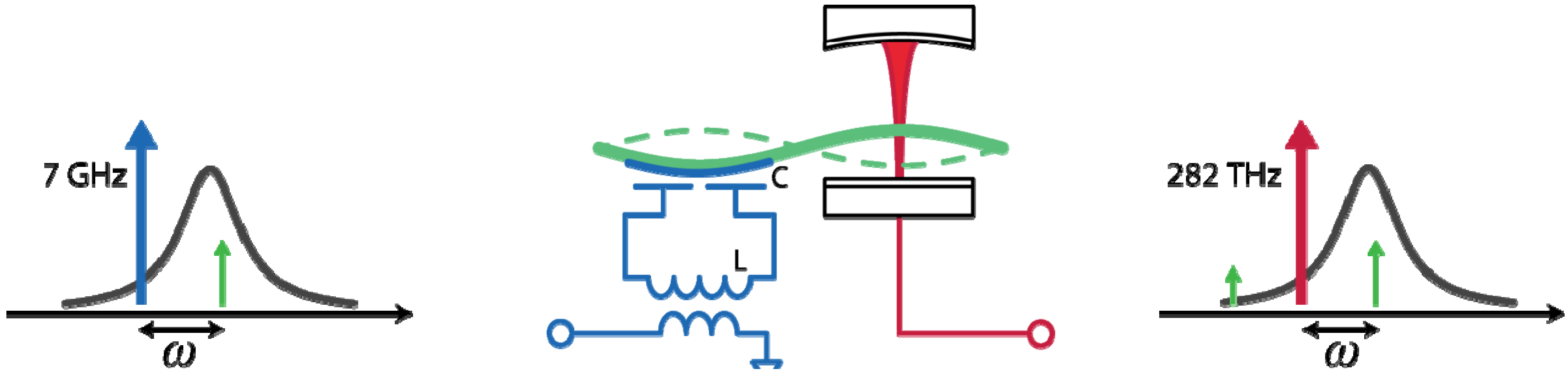
T_c of Nb: 9.2 K

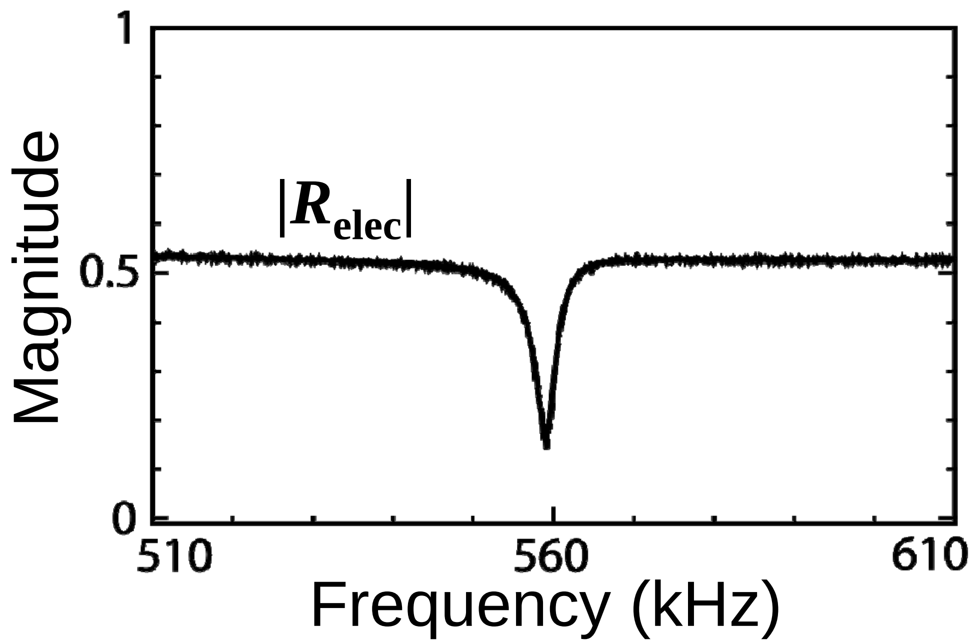
$$\frac{k_B T}{\hbar\omega_e} \approx 12$$

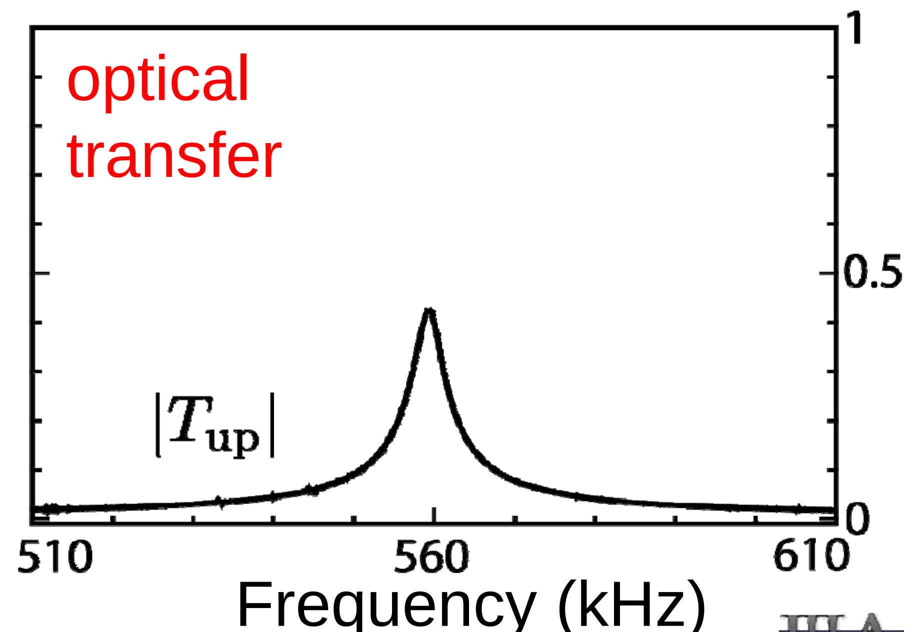
Conversion requires both optical and microwave pumps



Power absorbed at the microwave port is converted to optical light

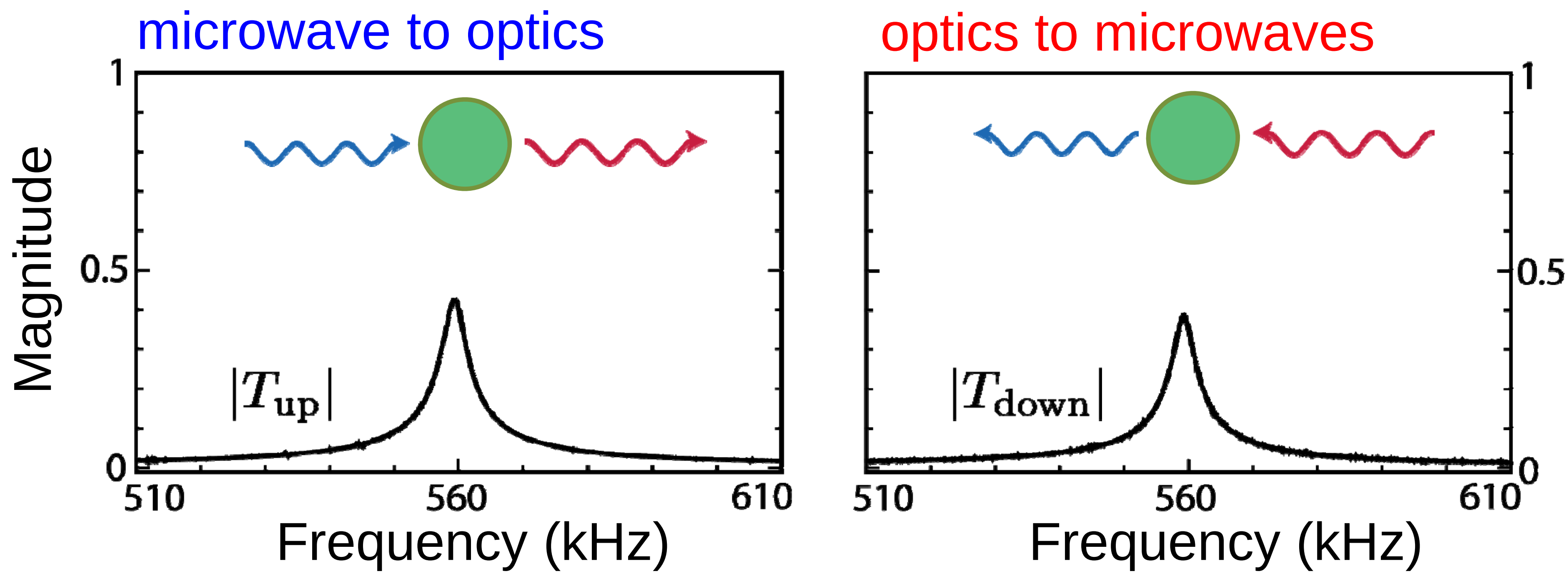






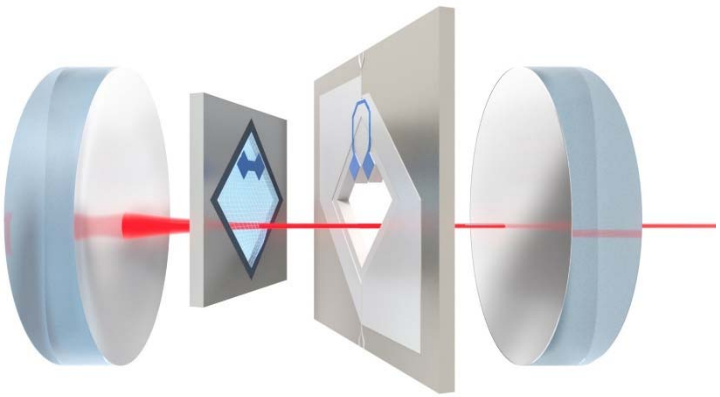
Bidirectional operation a prerequisite for quantum state transfer

$T = 4$ K



R. W. Andrews, C. A. Regal, KWL, et al.,
Nature Physics **10,** 321–326 (2014).

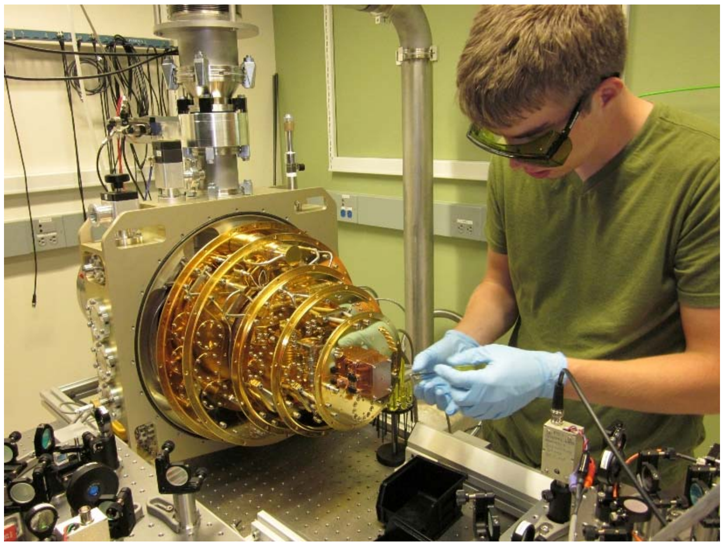
The future of mechanical systems in the quantum regime

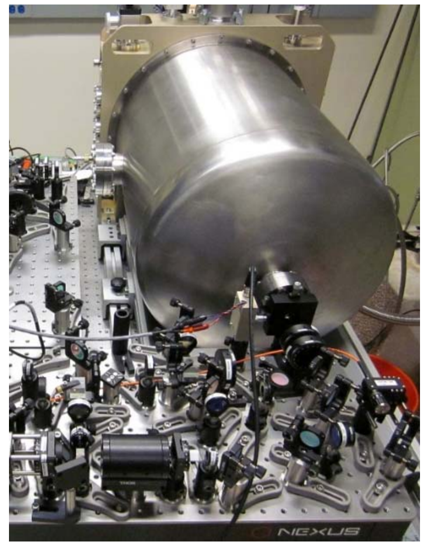


quantum operation of electro-optomechanical convertor

impact: create quantum networks

Reaching the regime of quantum state preservation: cooling the environment





optical access dilution refrigerator in low vibration environment

$$T < 100 \text{ mK}$$

Conclusions

transfer between microwave and optical fields

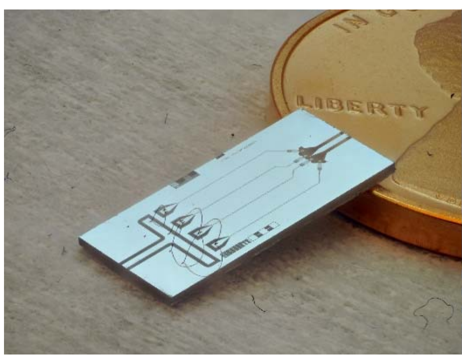
classical

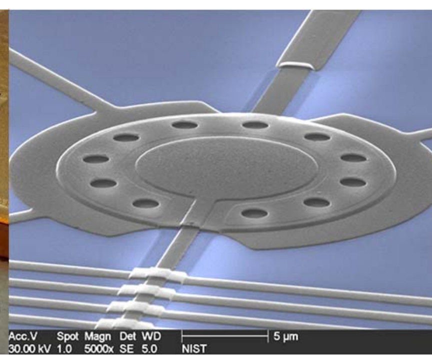
bidirectional

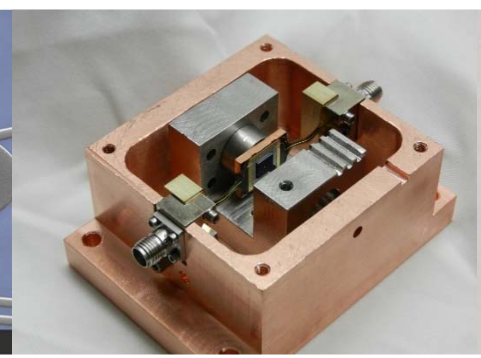
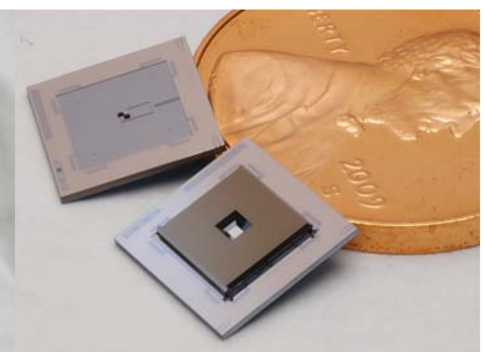
cryogenic

poised for quantum operation

microelectromechanics: a new quantum technology





Acknowledgements

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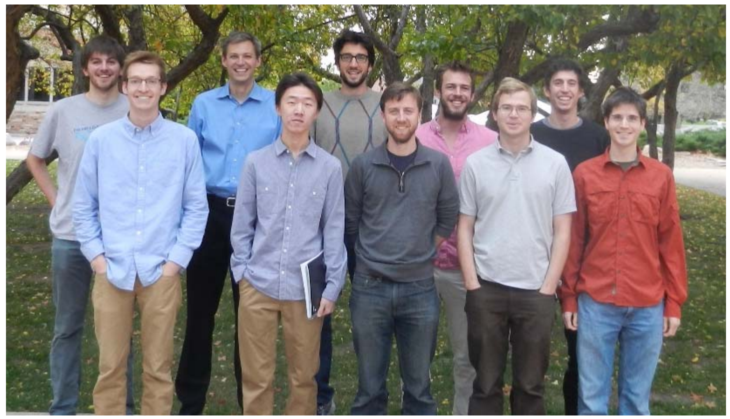

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