Microfabrication of large area high-stress silicon nitride membranes for optomechanical devices

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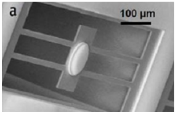
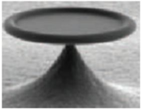
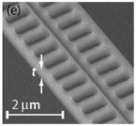
http://arxiv.org/abs/1601.02669

Diavolezza cQOM workshop
02 February 2016

Motivation







- low losses mechanical resonator for optical cavities
- SiN membranes

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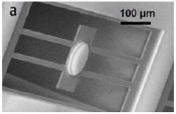

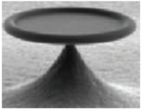
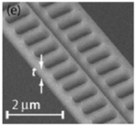

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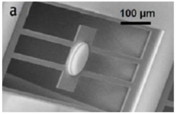
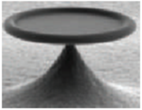
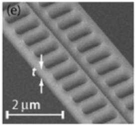


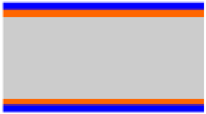
- low losses mechanical resonator for optical cavities
- SiN membranes

- freely selectable shape
- controlled high internal stress

Microfabrication process

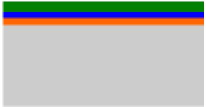
1) LPCVD TEOS (200 nm)

2) LPCVD SiN (100 nm)

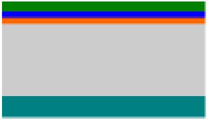


3) Back-side etching (RIE)

4) Sputtering pure-Al (1 μm)



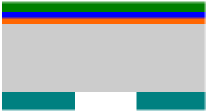
5) PECVD SiO2 back-side (6 μm)



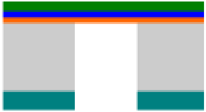
6) Back-side litography

Microfabrication process

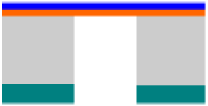
7) Back-side dry etching (SiO2)



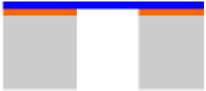
8) DRIE silicon etching



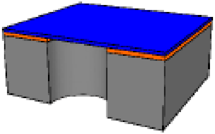
9) Pure-Al wet etching (PES)



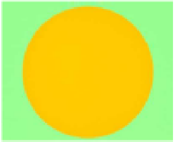
10) TEOS wet etching (HF)



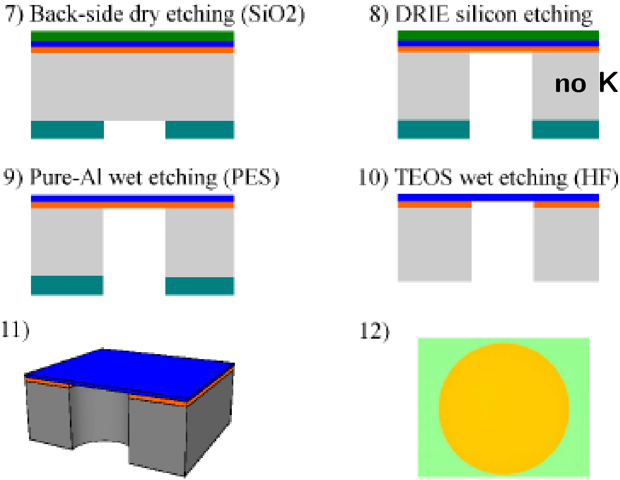
11)



12)



Microfabrication process



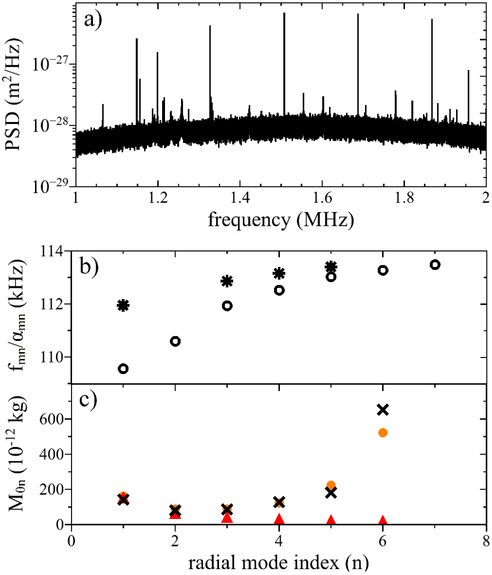
no KOH etching!

Resonance frequencies of circular membranes

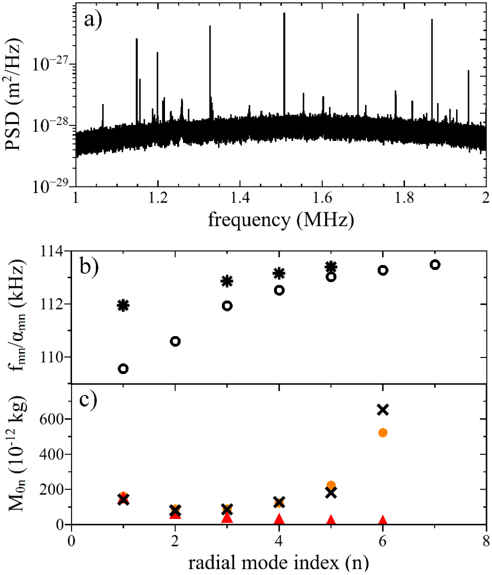
- resonance frequencies

$$f_{mn} = f_0 \alpha_{mn}, \quad f_0 \equiv \frac{1}{2\pi R}\sqrt{\frac{T}{\rho}}, \quad J_m(\alpha_{mn}) = 0$$

Resonance frequencies of circular membranes

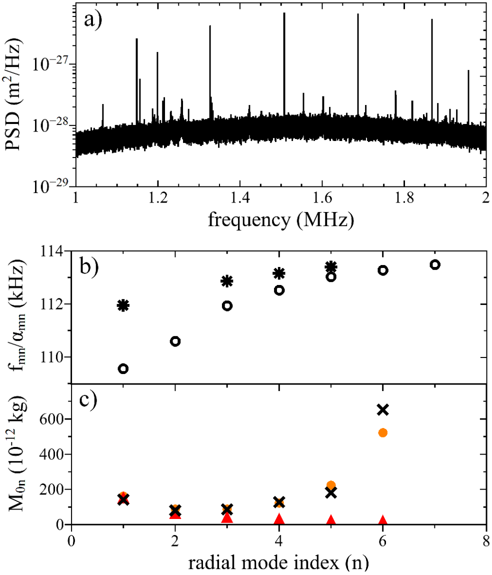


Resonance frequencies of circular membranes



$f_0 \simeq 114$ kHz

Resonance frequencies of circular membranes



$f_0 \simeq 114$ kHz

$R = 0.75$ mm
$T = 1$ GPa
$\rho = 3200$ kgm^{-3}

$f_0 = 118.6$ kHz

Effective mass

- effective mass dependent on modal index
  - pointlike readout:

$$M_{0n} = M J_1^2(\alpha_{0n})$$

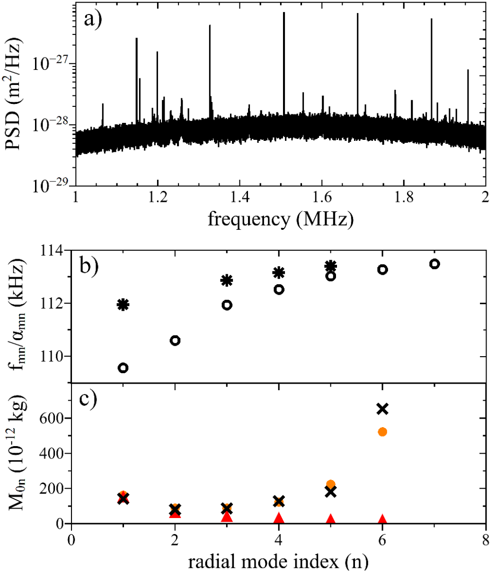
  - Gaussian readout:

$$M_{0n} = M \left(\frac{J_1(\alpha_{0n})}{\frac{4}{w^2} \int J_0(\alpha_{0n} r/R) \exp\left(-\frac{2r^2}{w^2}\right) r dr} \right)^2$$

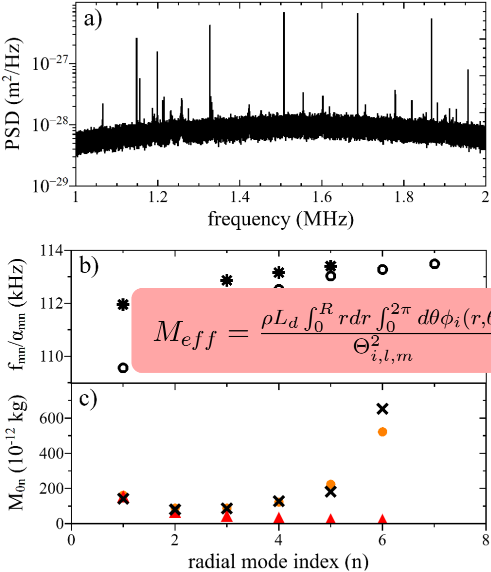
- experimentally obtained from the areas of the thermal peaks

$$A_{0n} = \frac{kT}{M_{0n}(2\pi f_{0n})^2}$$

Effective mass



Effective mass



$$M_{eff} = \frac{\rho L_d \int_0^R r dr \int_0^{2\pi} d\theta \phi_i(r,\theta)}{\Theta^2_{i,l,m}}$$

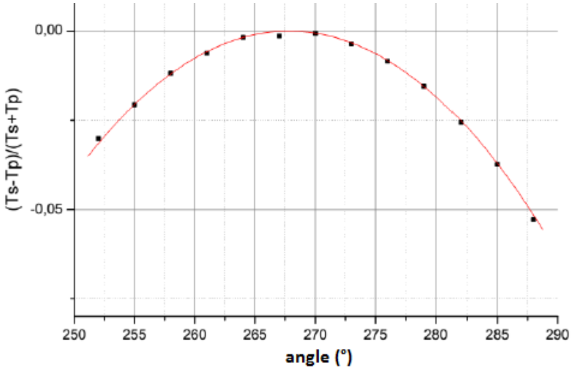
Q-factor

- at room temperatures ranging from few thousands to 2×10^5
- at cryogenic temperatures globally higher:

$R = 0.75$ mm, 5 mm side frame — $Q_{max} = 0.65 \times 10^6$ @ 8 K

$a = 1$ mm, 5×20 mm^2 frame — $Q_{max} = 1.3 \times 10^6$ @ 13 K

Optical properties of circular membranes



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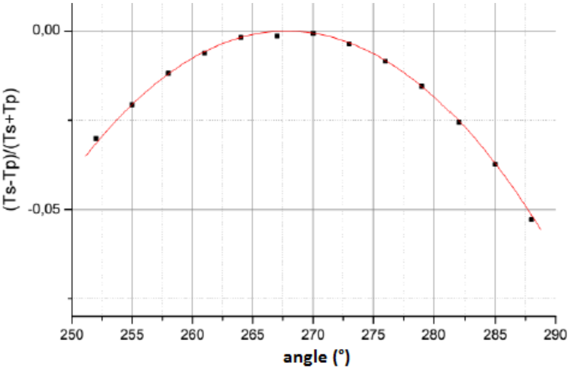


$$L_d = 97.27 \pm 0.01 \text{ nm}$$
$$n_R = 2.0210 \pm 0.0005 \text{ @ } \lambda = 1064 \text{ nm}$$

Optical properties of circular membranes

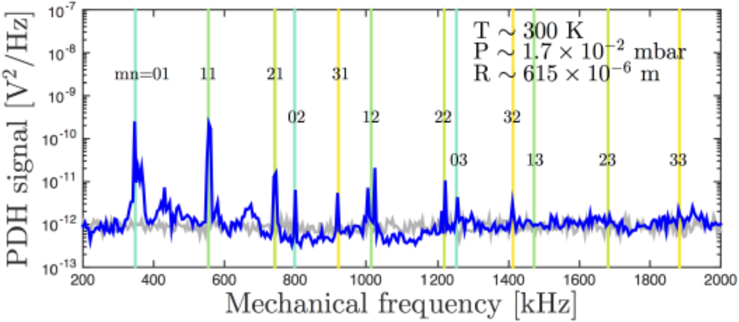
- reflection and transmission coefficients of the membrane, $\beta \equiv nkL_d$

$$r_d = \frac{(n^2-1)\sin\beta}{2in\cos\beta + (n^2+1)\sin\beta}$$

$$t_d = \frac{2n}{2in\cos\beta + (n^2+1)\sin\beta}$$

$$\Rightarrow |r_d|^2 = 0.355 \pm 0.002$$

Optical properties of circular membranes



$f_{01} \sim 348.5$ kHz

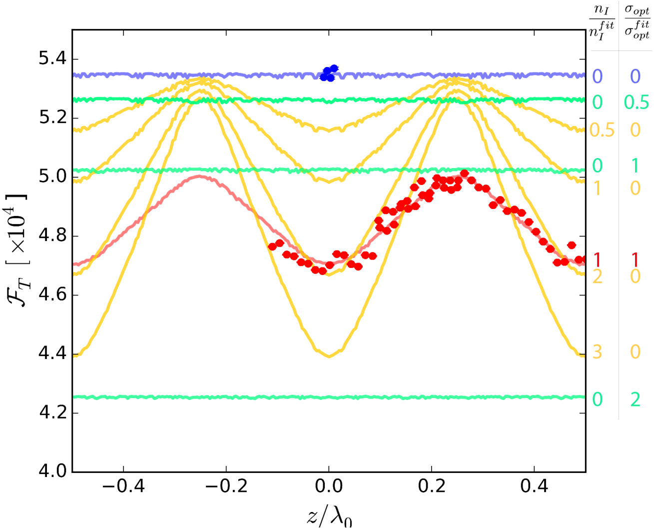
Finesse measurement

- ringdown technique, $\mathcal{F} = \pi c \tau / L$
- intensity transmission of the cavity assuming $r_1 = r_2 = \sqrt{\mathcal{R}}$ and $t_1 = t_2 = \sqrt{\mathcal{T}}$

$$\mathcal{T}_c = \frac{|\mathcal{T} t_d|^2}{\left|1 + 2 r_d \sqrt{\mathcal{R}} \cos(2kz) \mathrm{e}^{ikL} + \mathcal{R}(t_d^2 + r_d^2) \mathrm{e}^{2ikL}\right|^2}$$

- optical roughness $\sigma_{opt} \Rightarrow \sqrt{\exp\left[-(2k\sigma_{opt})^2\right]}$
- $L_d = 97$ nm, $n_R = 2.021$, $L = 9.03$ cm, $\lambda = 1064$ nm, $\mathcal{F}_v = 53520$

Finesse measurement



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- $n_I = (1.97 \pm 0.08) \times 10^{-6}$
- $\sigma_{opt} = (287 \pm 4)$ pm

- Norcada 1 mm side, 50 nm thickness membrane: $n_I = (1.0 \pm 0.01) \times 10^{-5}$, $\sigma_{opt} = (280 \pm 10)$ pm

Auxiliary slides

- intensity reflection and transmission coefficients

$$R_P = \left(\frac{n\cos\theta_i - \cos\theta_t}{n\cos\theta_i + \cos\theta_t}\right)^2, \quad R_S = \left(\frac{\cos\theta_i - n\cos\theta_t}{\cos\theta_i + n\cos\theta_t}\right)^2$$

$$T_{S,P} = \left(1 + \frac{4R_{S,P}}{(1-R_{S,P})^2}\sin^2(\beta\cos\theta_t)\right)^{-1}, \quad \beta \equiv nkL_d$$

Auxiliary slides