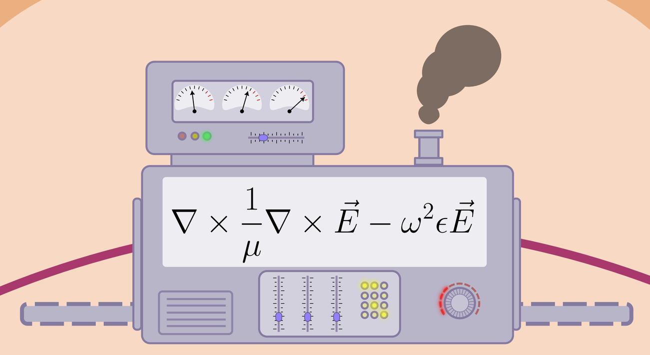
Inverse Design of Release-free Optomechanical Crystals

David Hambraeus[1*], Paul Burger[1], Johan Kolvik[1], Philippe Tassin[2] and Raphaël Van Laer[1]

*Contact: davham@chalmers.se

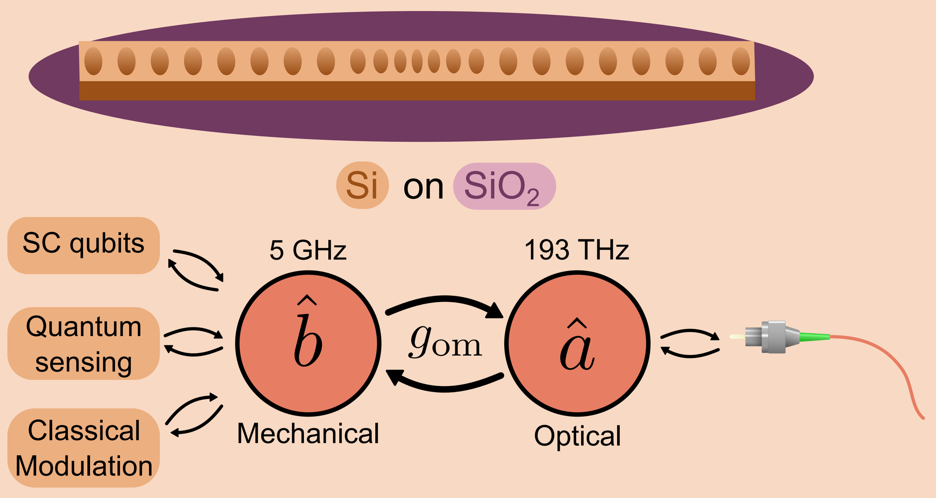
[1] Department of Microtechnology and Nanoscience, Chalmers.

[2] Department of Physics, Chalmers



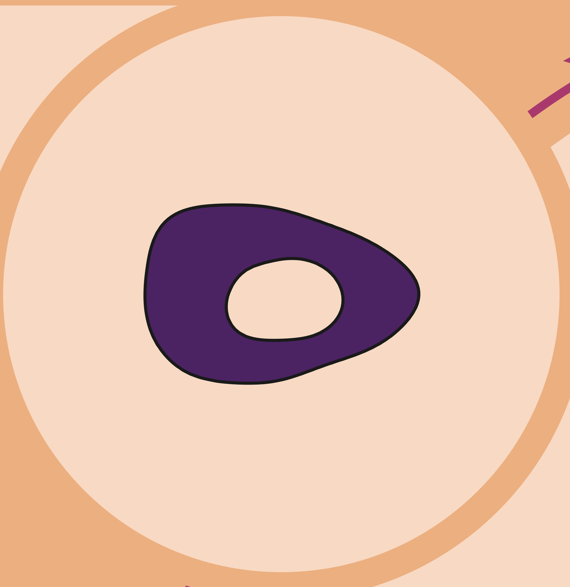
Forward Simulation

Optomechanical crystals



1. Geometry

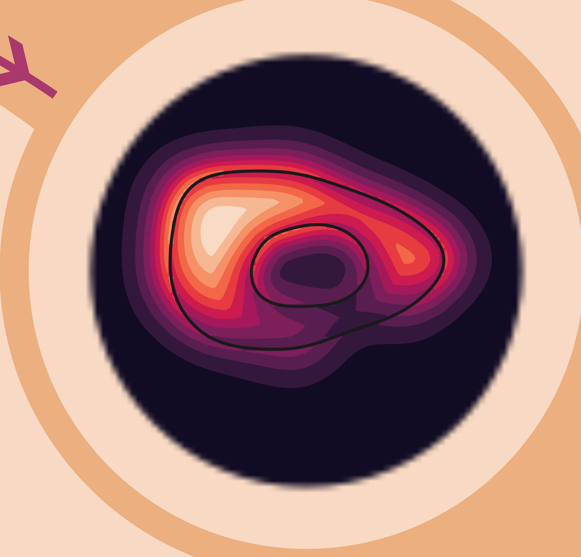
Stored as a Signed Distance Function (SDF)



2. Forward field

COMSOL eigenmode simulation

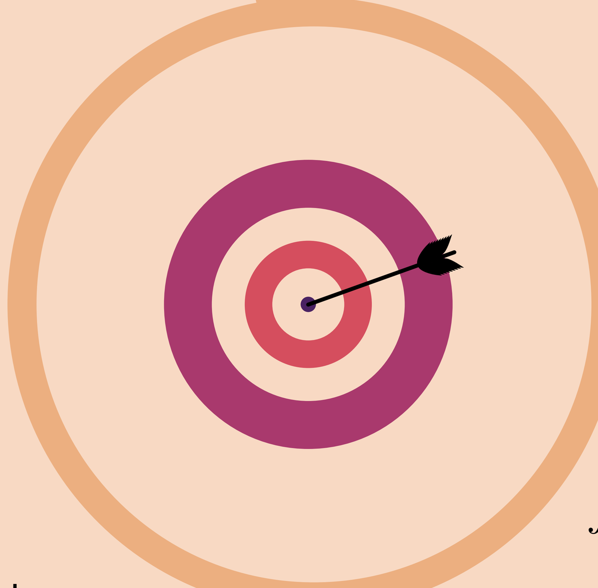
$$\int \left[\nabla \times \frac{1}{\mu}\nabla \times \vec{E} - \omega^2\epsilon\vec{E}\right] \cdot \vec{t}\, dV = 0$$



3. FOM

Figure of Merit (FOM) can be function of field, frequency and Q

$$\int \tanh[(a(r-r_0)]\epsilon E^2$$



Conventional design

+ Optimizing is easy
- Might miss out on performance

More tunable parameters

- Optimizing is dificult
+ Better chance of high performance at optimum

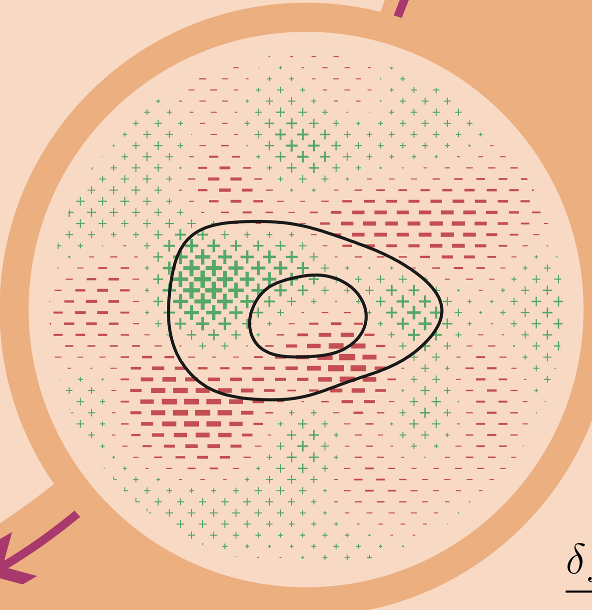
Inverse design

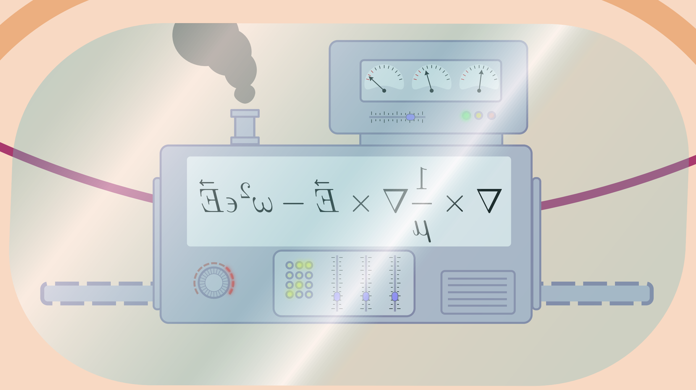
+ Easily optimize 10k parameters
+ Very large space of designs for a better optimum

4. FOM gradient

Analytical gradient of FOM w.r.t. field

$$\frac{\delta f_{\mathrm{FOM}}}{\vec{E}(\vec{r})} = \tanh[a(r-r_0)]\epsilon\vec{E}$$



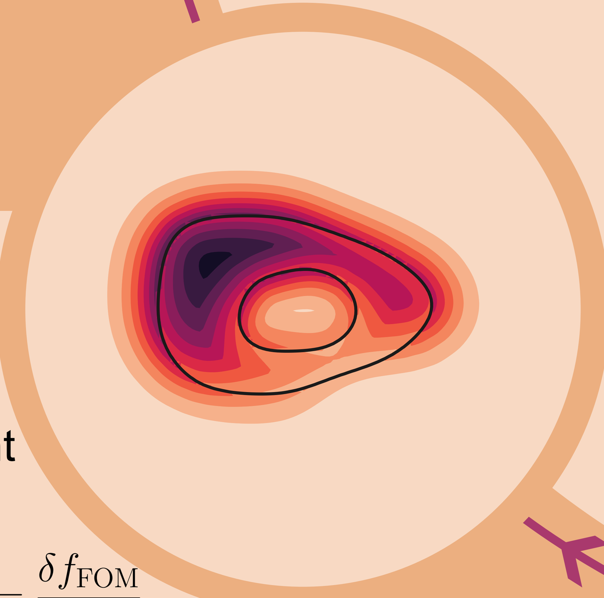


Adjoint Simulation

5. Adjoint field

Obtained through an adjoint simulation with FOM gradient as source

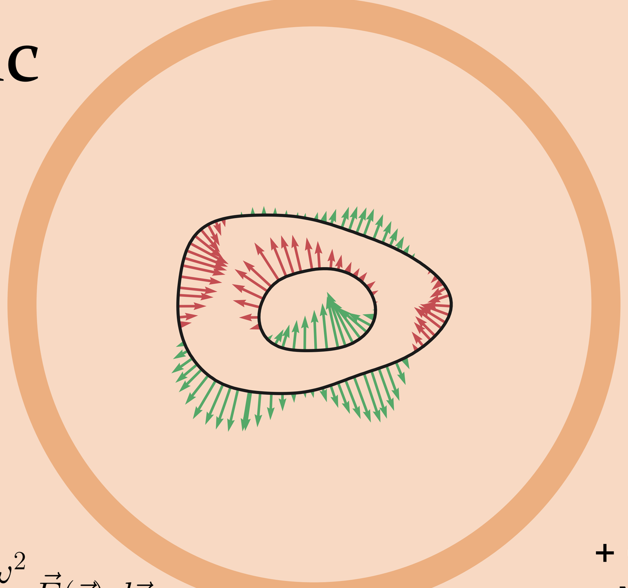
$$\int \left[\nabla \times \frac{1}{\mu}\nabla \times \vec{t} - \omega^2\epsilon\vec{t}\right] \cdot \tilde{E}\, dV = \frac{\delta f_{\mathrm{FOM}}}{\vec{E}(\vec{r})}$$



6. Geometric gradient

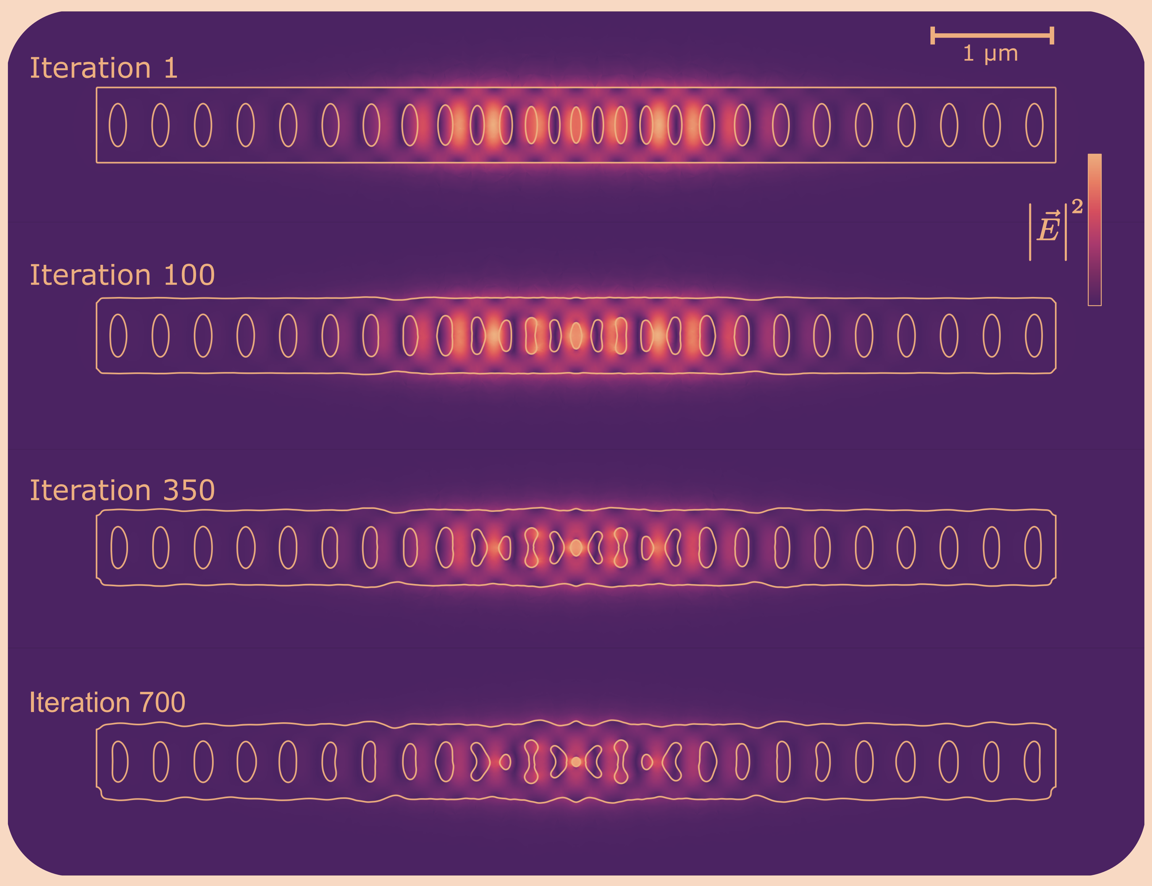
Indicates where to add / subtract material to increase FOM

$$\frac{\delta f_{\mathrm{FOM}}}{\vec{\epsilon}(\vec{\rho})} = \omega^2\tilde{E}(\vec{\rho}) \cdot \vec{E}(\vec{\rho}) + \int \tilde{E}(\vec{r}) \cdot \epsilon\frac{\delta\omega^2}{\epsilon(\vec{\rho})}\vec{E}(\vec{r})\, d\vec{r}$$



Results and outlook

Progression of mode profile during optimization



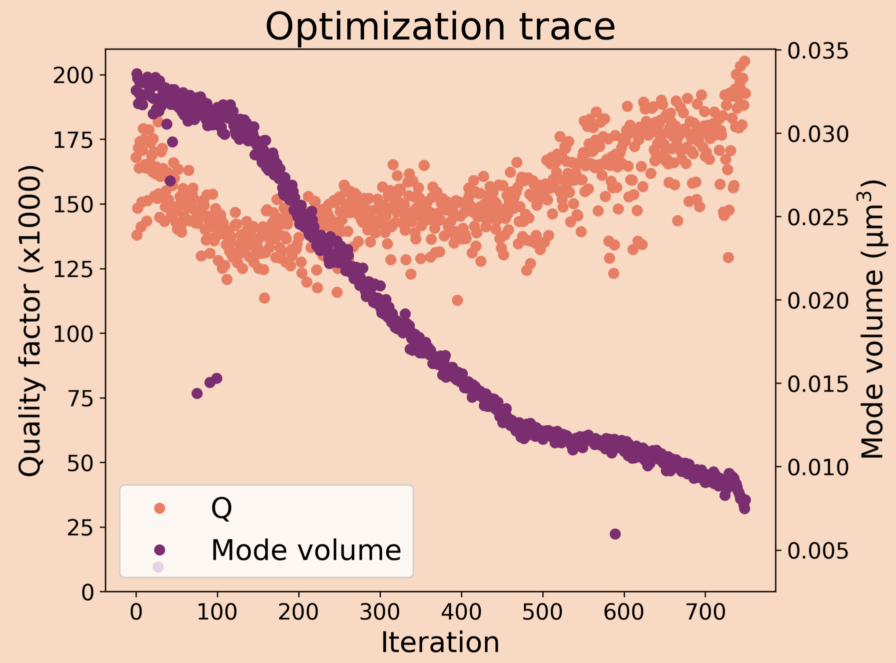
Minimizing mode volume

- Mode volume reduced by >70 %
- Field is concentrated in center
- Q-factor stays above 100k

Open questions

- Robustness to fabrication imperfections
- Hole seeding and removal
- Optimizing optomechanical interaction

Optimization trace



References

[1] J. Kolvik, P. Burger, J. Frey, and R. V. Laer, “Clamped and sideband-resolved silicon optomechanical crystals,” Optica, OPTICA, vol. 10, no. 7, pp. 913–916, Jul. 2023

[2] S. Molesky, Z. Lin, A. Y. Piggott, W. Jin, J. Vucković, and A. W. Rodriguez, “Inverse design in nanophotonics,” Nature Photon, vol. 12, no. 11, Art. no. 11, Nov. 2018

[3]s O. Sigmund and K. Maute, “Topology optimization approaches,” Struct Multidisc Optim, vol. 48, no. 6, pp. 1031–1055, Dec. 2013

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