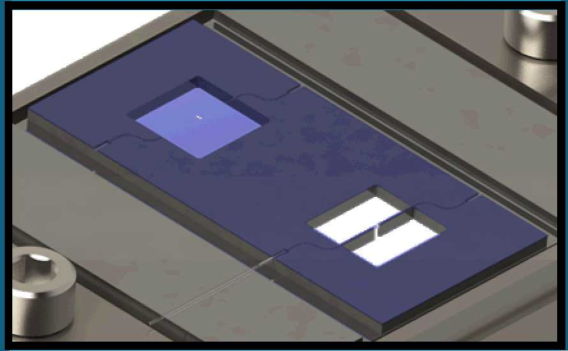
SAND2020-5544C

Integrated atomic waveguides for atom interferometry (AI)



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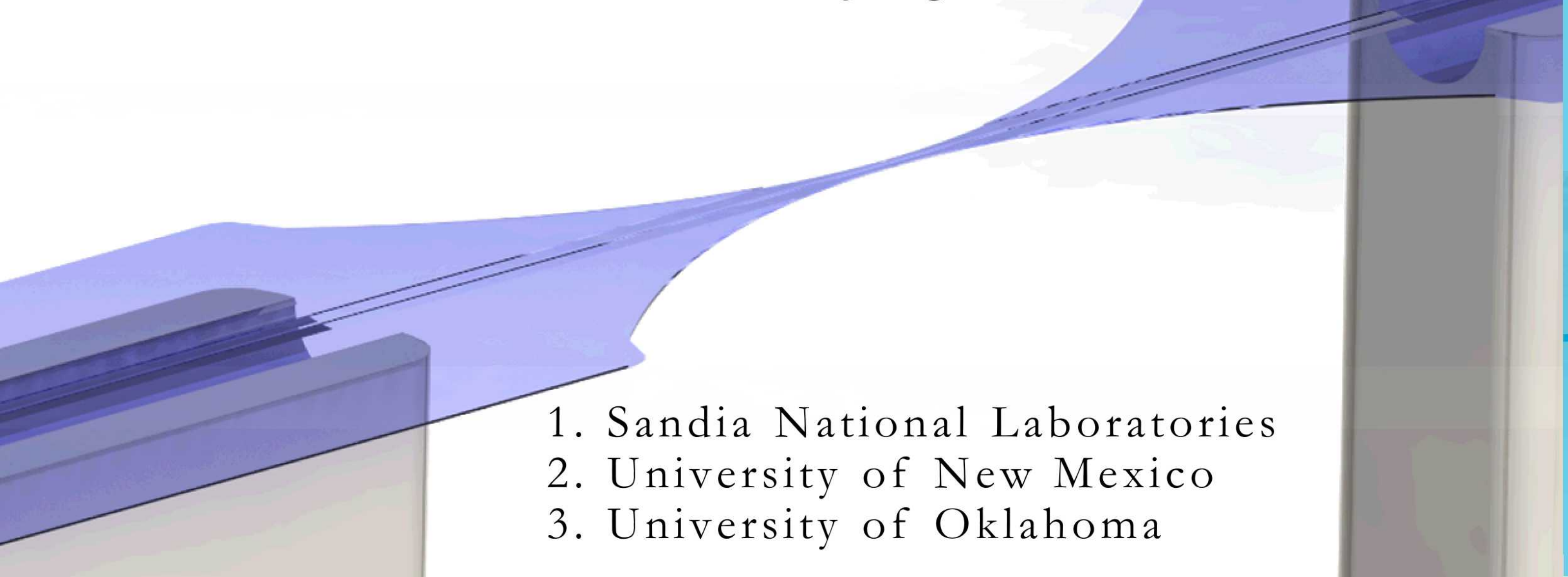

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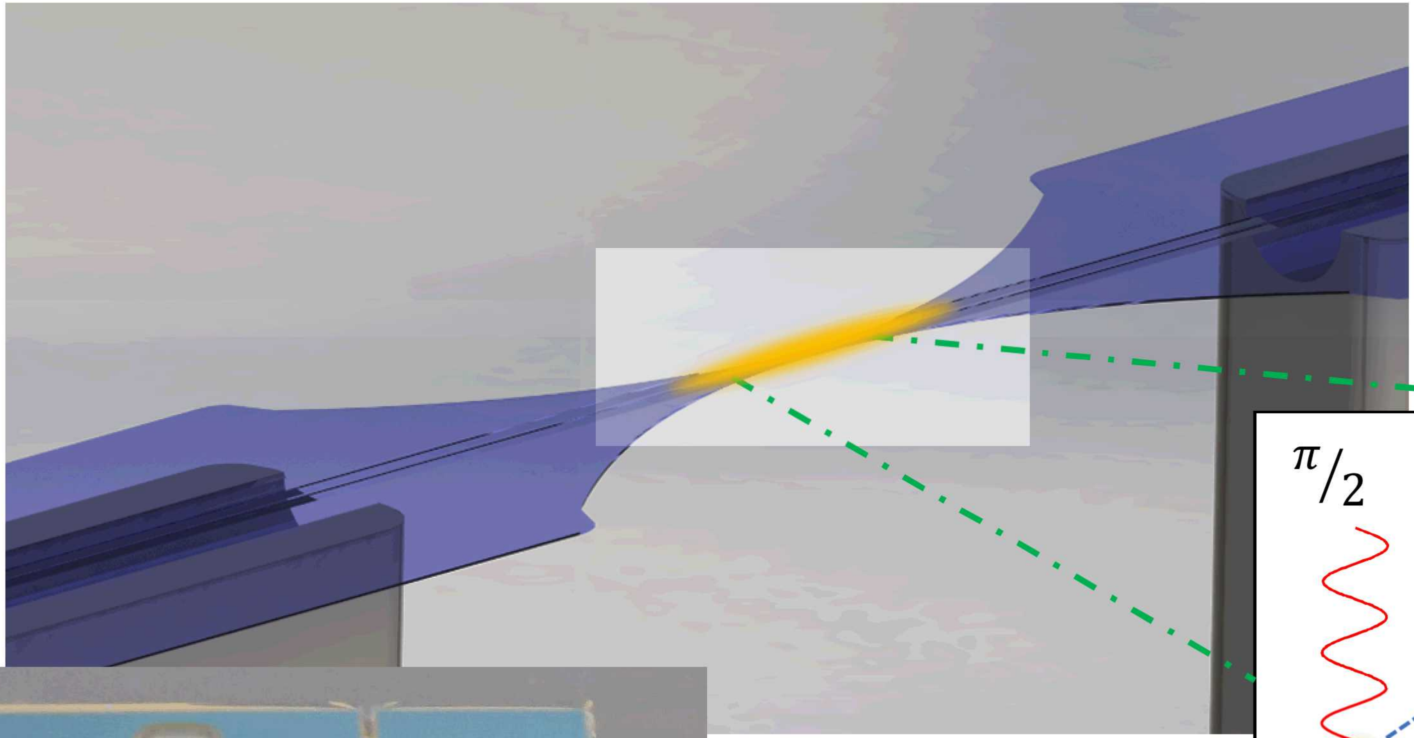
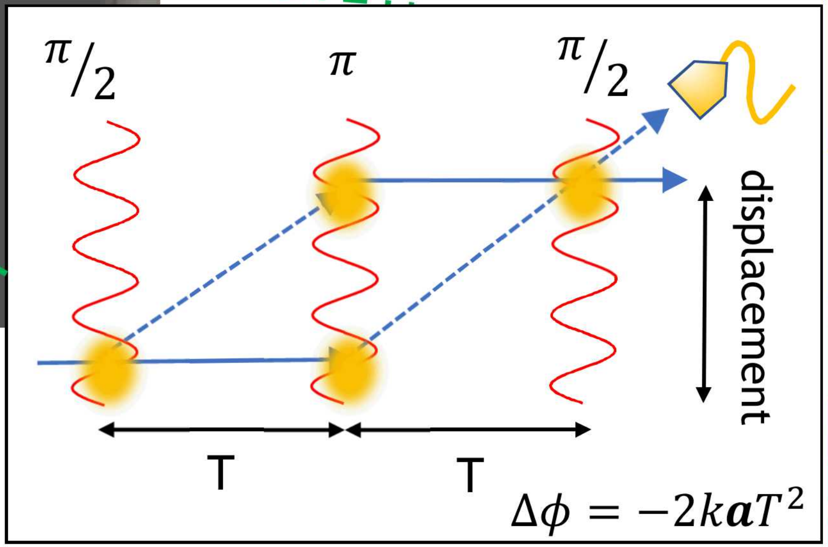
We are making integrated photonic waveguides for atom interferometry



Measurement sequence

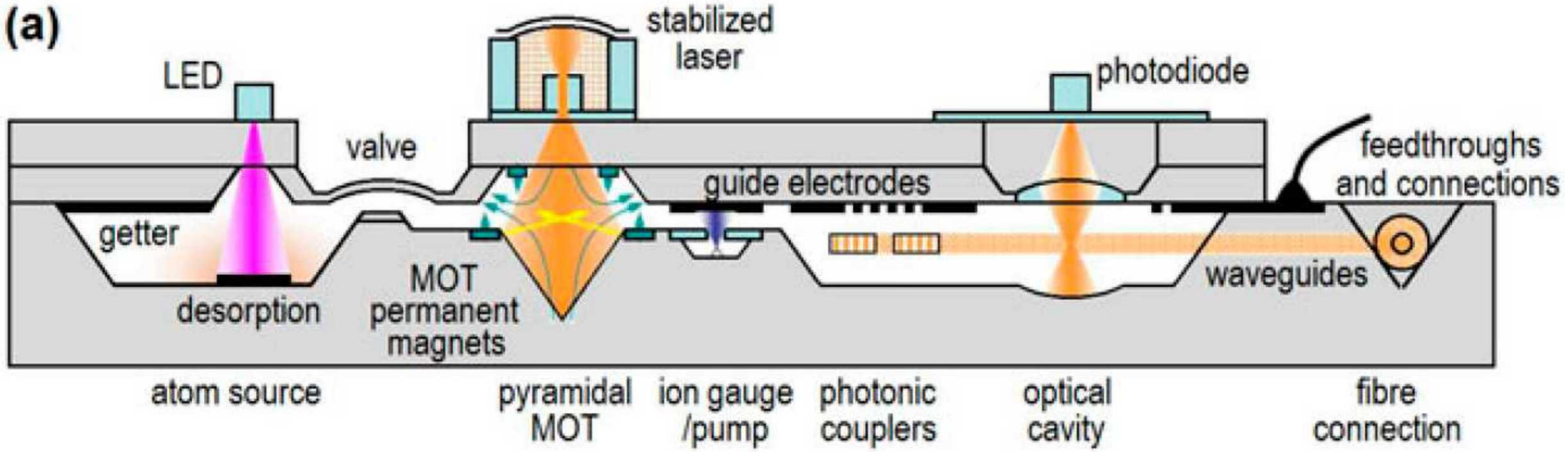


focused on

making the photonic device and
overcoming heat dissipation

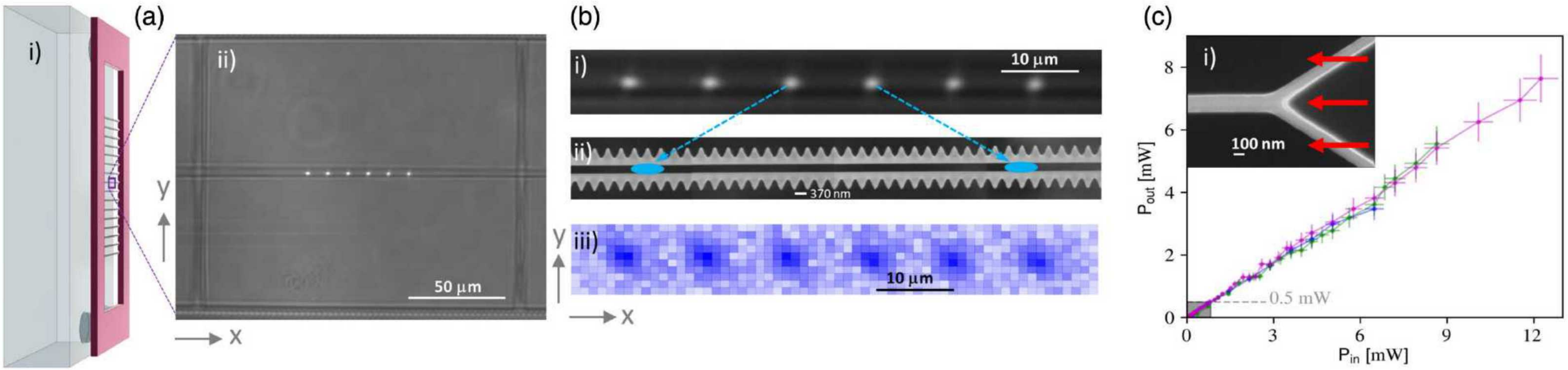
Neutral-atom photonic devices bring fieldable technology and new physics

Concept:
fully integrated atomic devices



Fifteen years of coldmatter on the atom chip: promise, realizations, and prospects, M Keil et. la., JOURNAL OF MODERN OPTICS VOL. 63, NO. 18, 1840–1885 (2016)

Photonic device for
cold atom experiments



Advanced apparatus for the integration of nanophotonics and cold atoms,
J. B. Beguin, et al, Optica Vol 7, No 1,, 1 (2020)

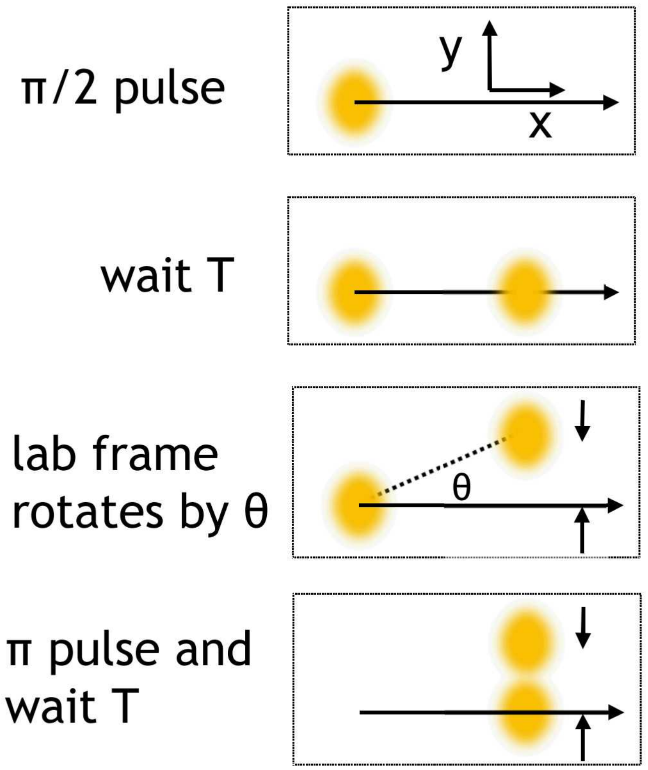
Guided atom interferometry on chip would bring new capabilities

- 1-D atoms guide ensures atoms pass through each other
- Compact and potentially integrable was photonics and electrical systems
- Parallel systems on same chip
- Strong light-atom interactions
- Low power Raman beams

waveguide mode	free space mode
1 um scale	3 mm waist
~ 1 um^2 area	~ 10^7 um^2 area

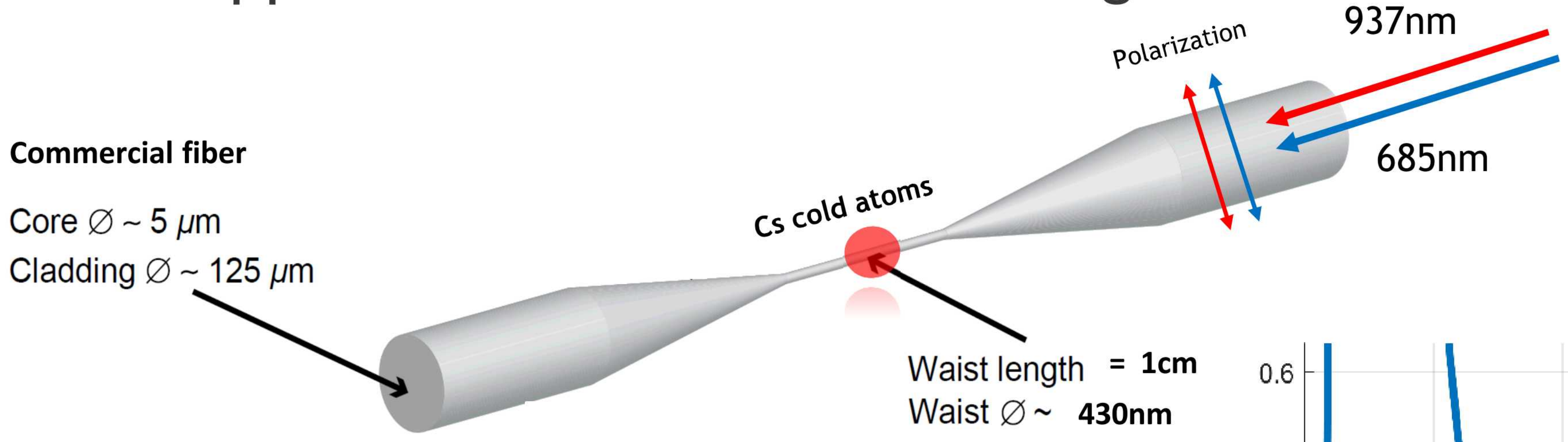
Waveguide needs 10^7 less power for same intensity!

Sequence with deleterious rotation.
Off axis motion reduces signal.



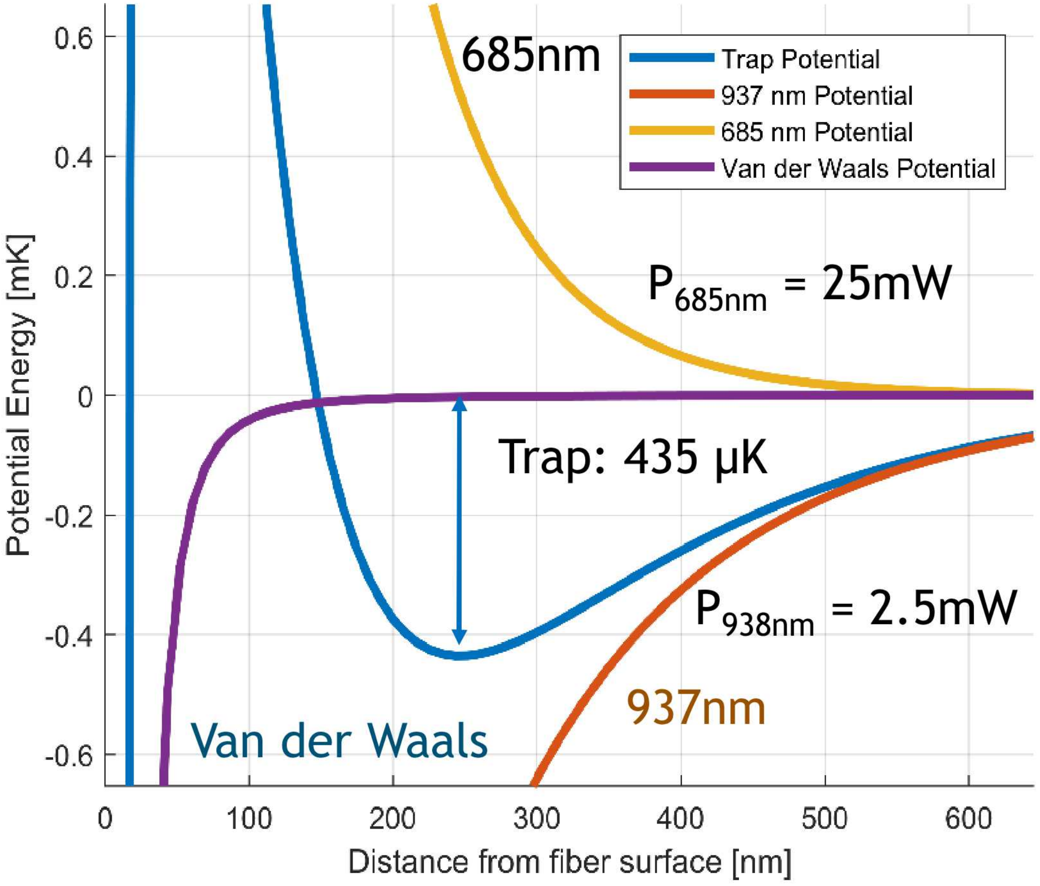
no signal!

Trapped 38 Cs atoms with atom guide



(See S02.9 Friday 9:36 am for more details)

- Two-color evanescent fields provide repulsive/attractive forces to trap atoms.
- 1-D dipole trap configuration with Cs magic-wavelengths
- Trap depth = 435 μK
- Trapped 38 Cs Atoms



Steps to making AI photonic platform

Waveguide overlaps with MOT

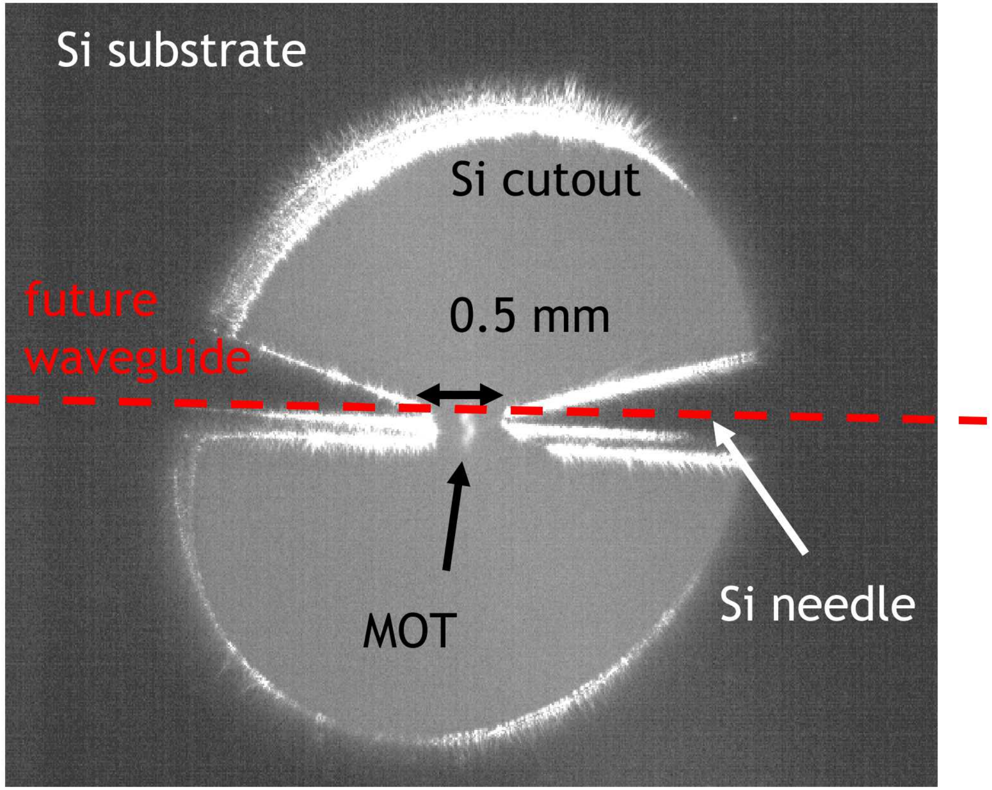
Waveguide for two color atoms trap → Atoms trapped on waveguide for AI

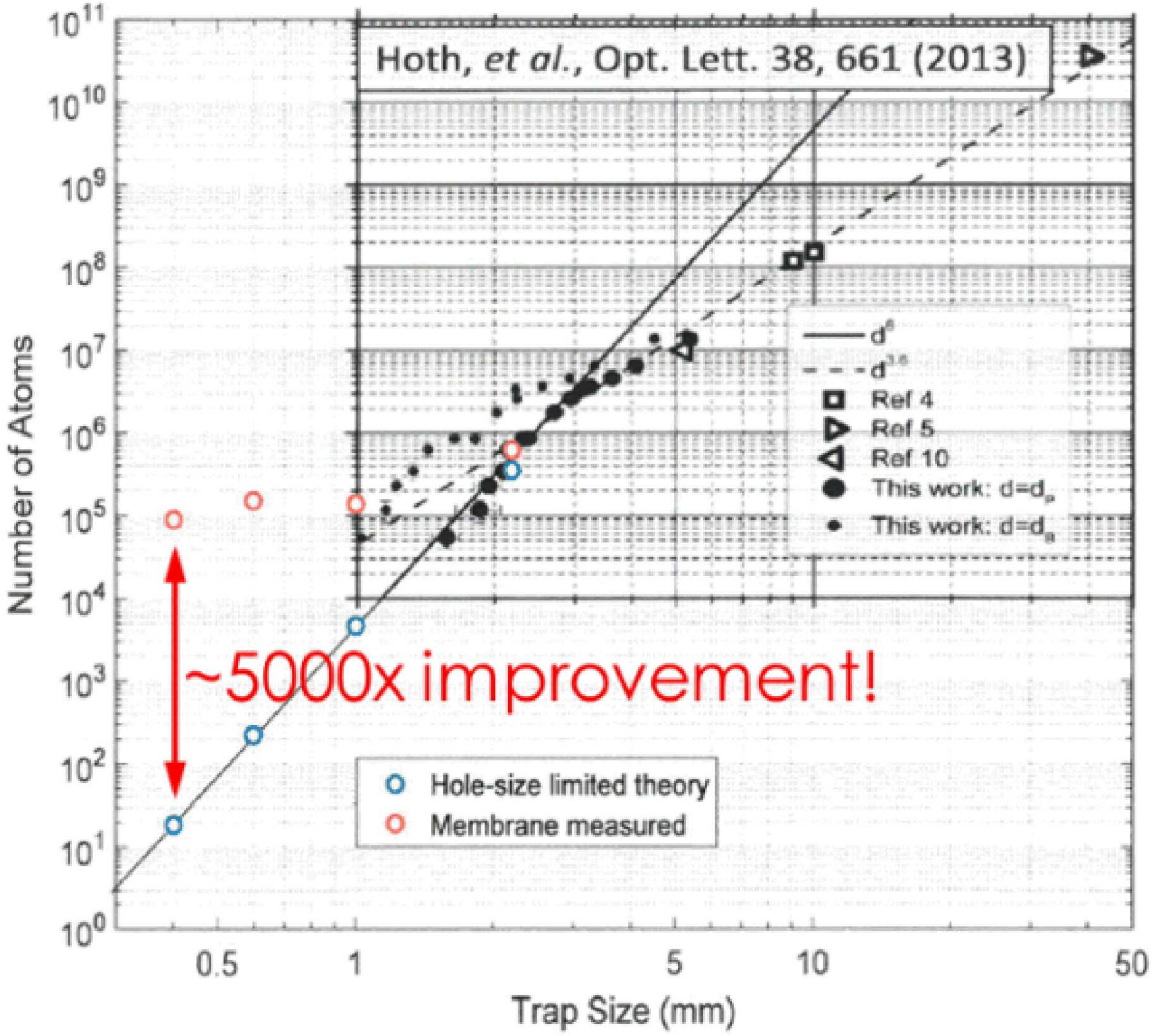
Waveguide power handling for deep trap

Use nanofiber as guide

435 μK deep trap for order 50 Cs atoms

We have previously demonstrated from MOT on chip cut out

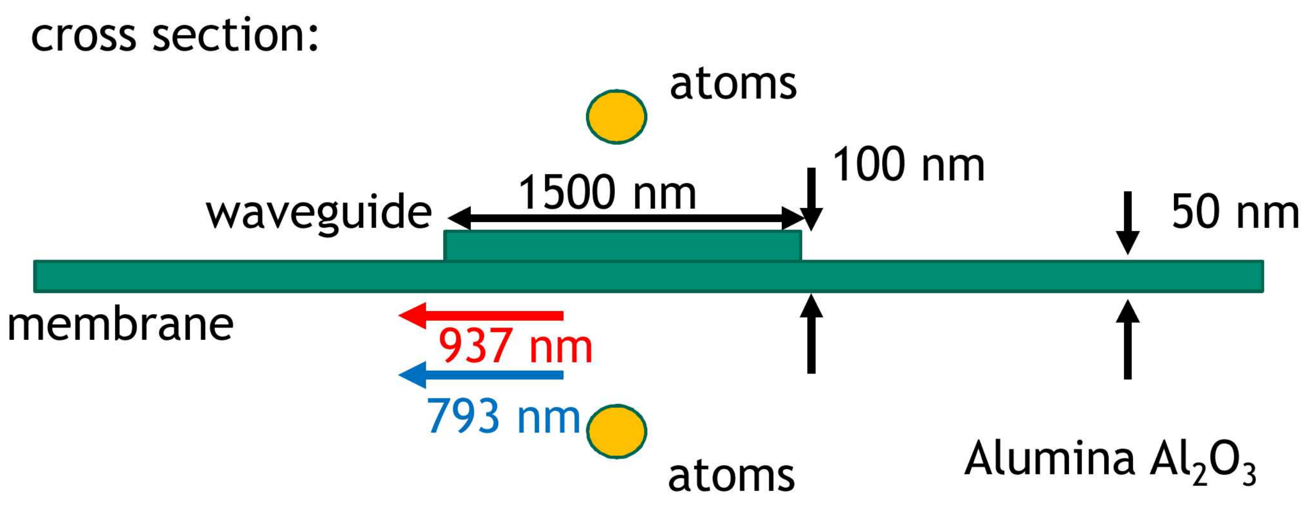


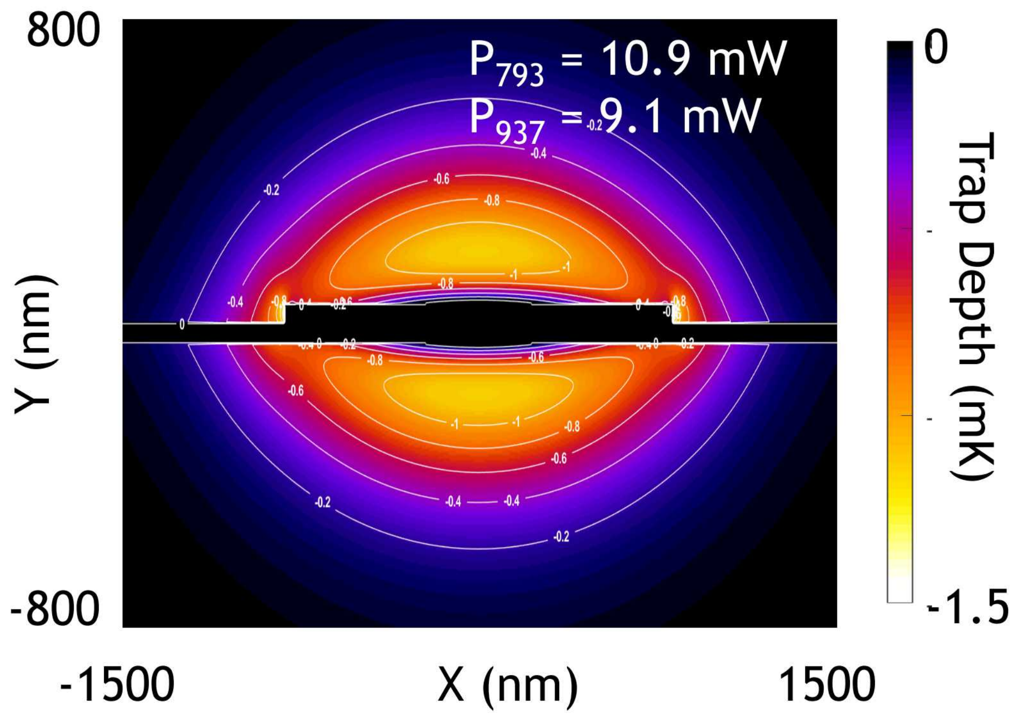


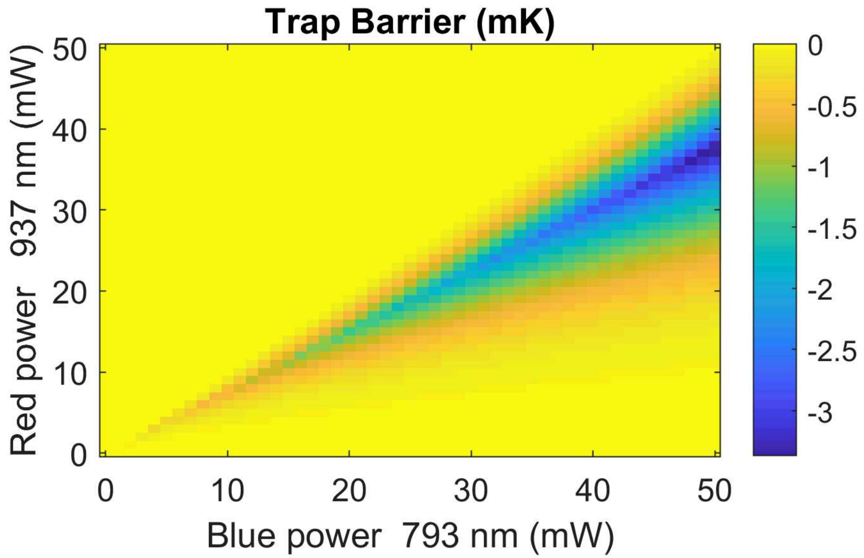
0.5 mm diameter membrane cutout

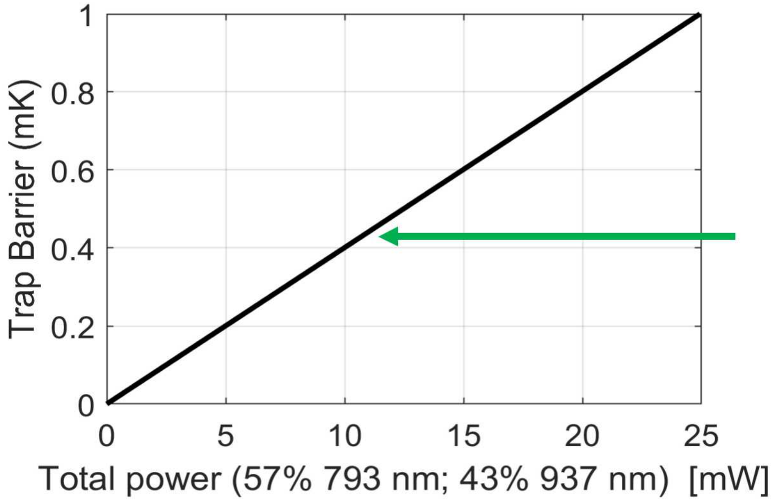
→ N ~ 10^5 atoms in MOT

Designing the photonic waveguide form the atom trap



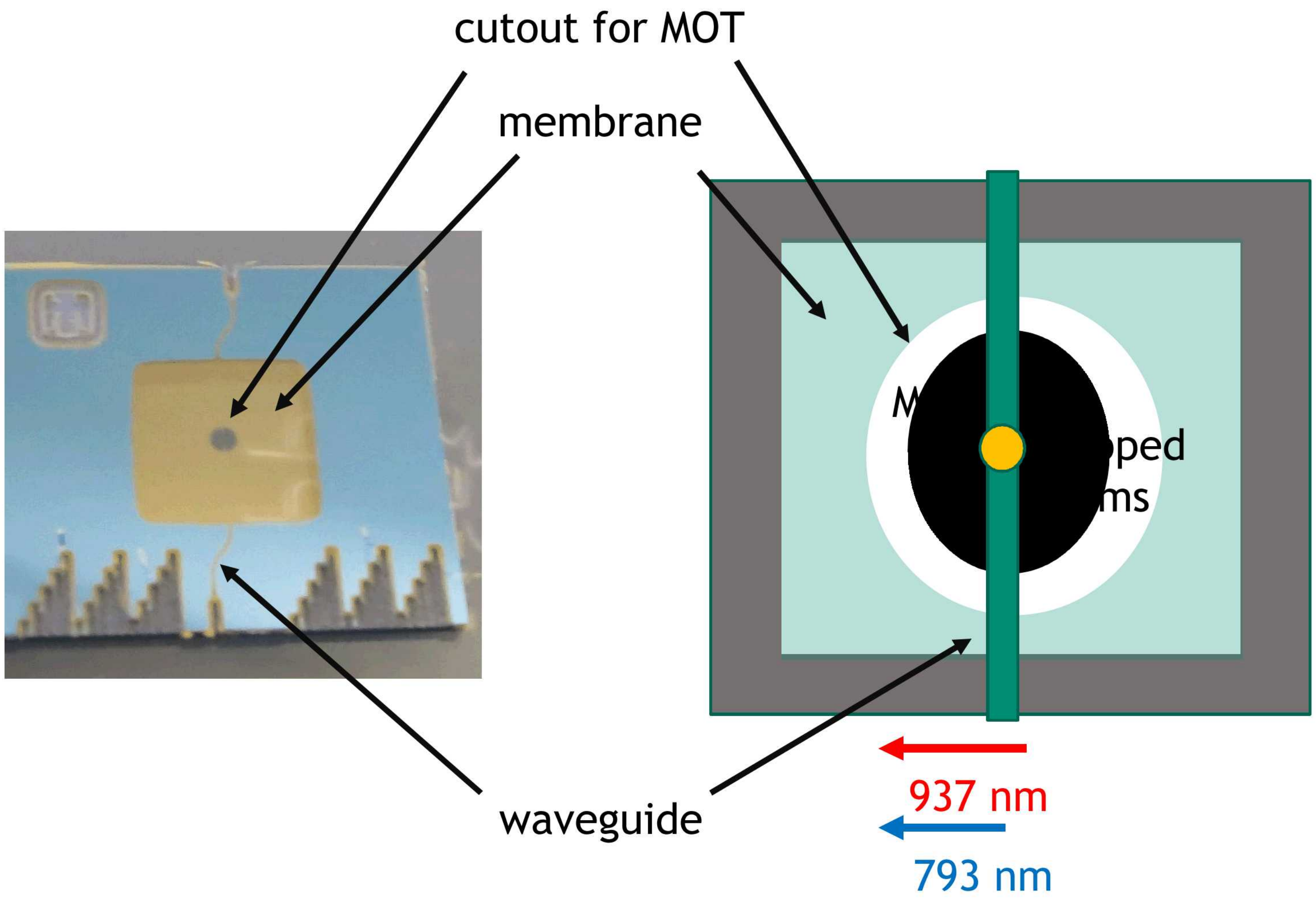






11 mW for
0.435 mK trap
(match nanofiber)

We fabricate a photonic waveguide chip for atom trapping



Experimental sequence

Turn on 793nm & 937nm trap

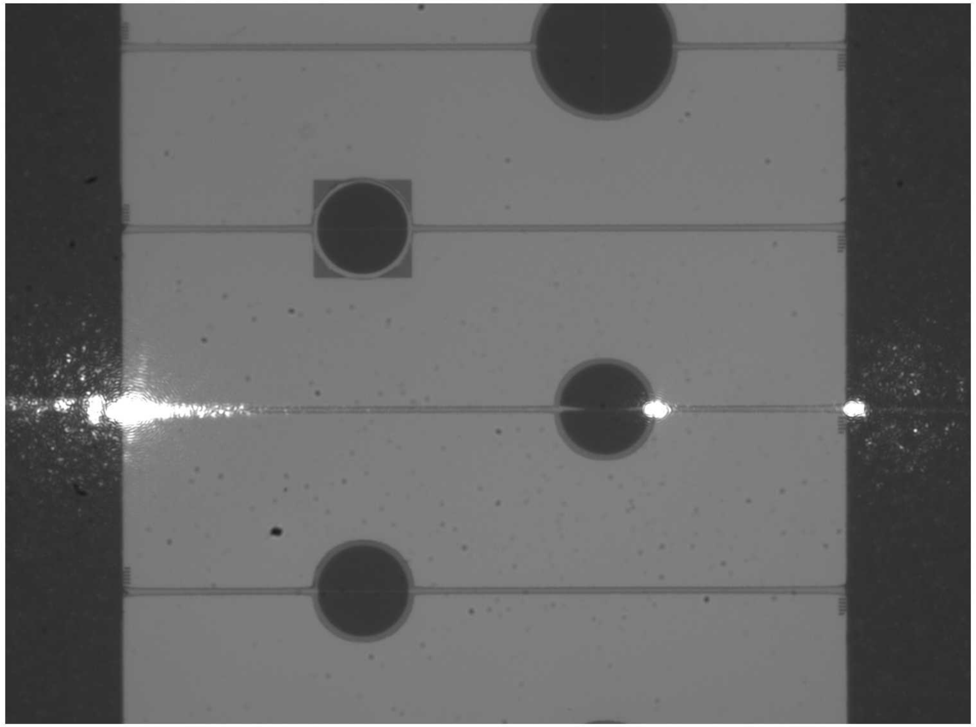
Generate MOT around waveguide

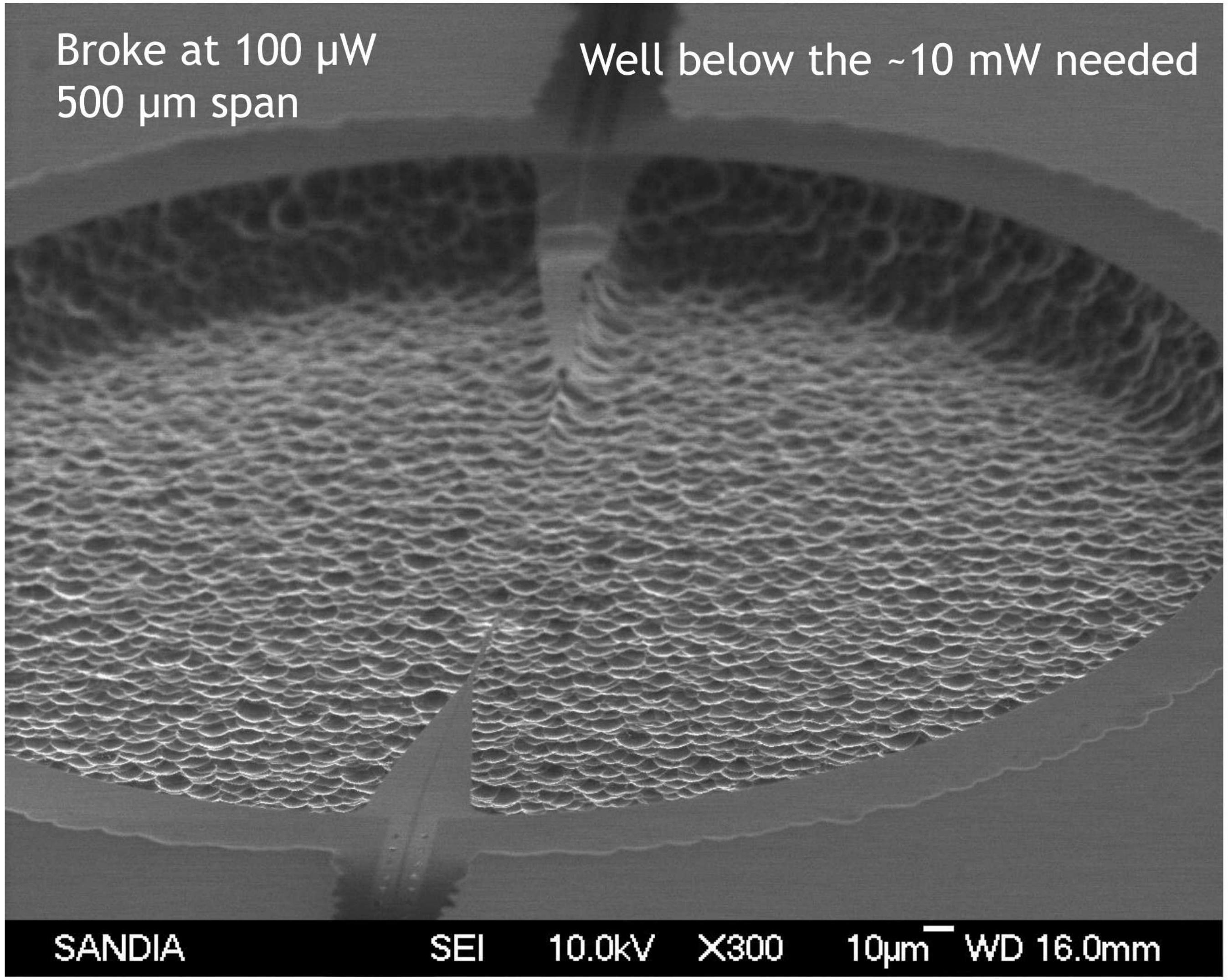
Sub-doppler cool

Cs atoms cooled into the trap

Major problem is heat dissipation on deep traps

Propagation loss:
1.0 to 4.5 dB/cm at $\lambda = 935$nm
Expected 0.1 dB/cm from previous alumina quality





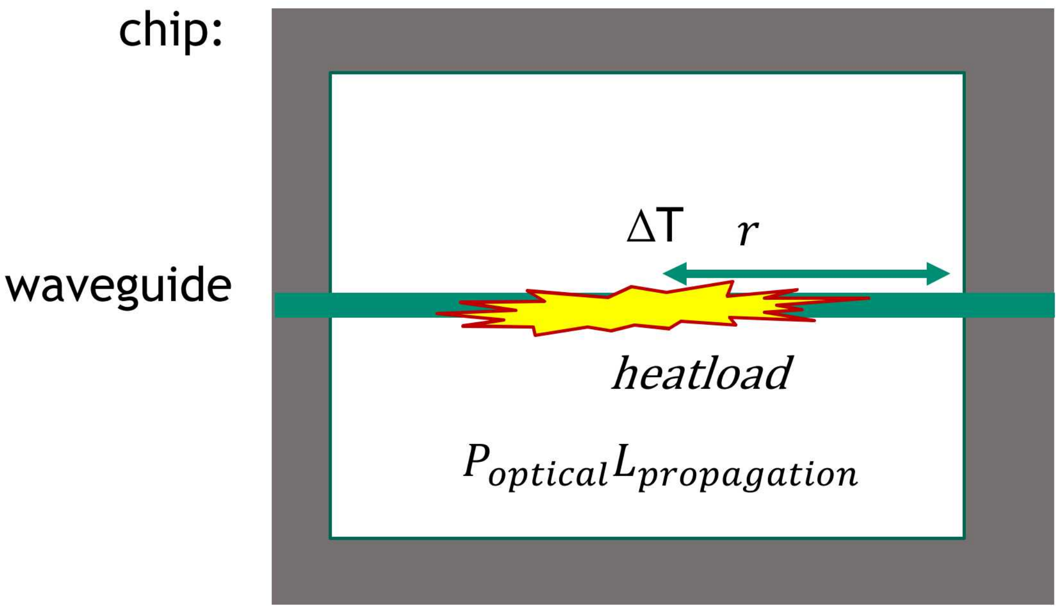
The waveguides are poor heat sinks

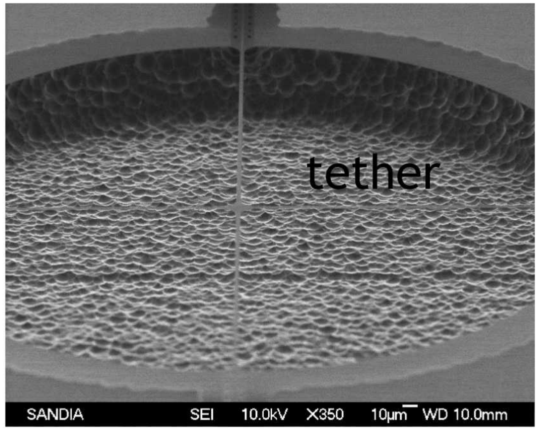
$$\Delta T = \frac{P_{optical} L_{propagation}}{k} \; \frac{r^2}{A}$$

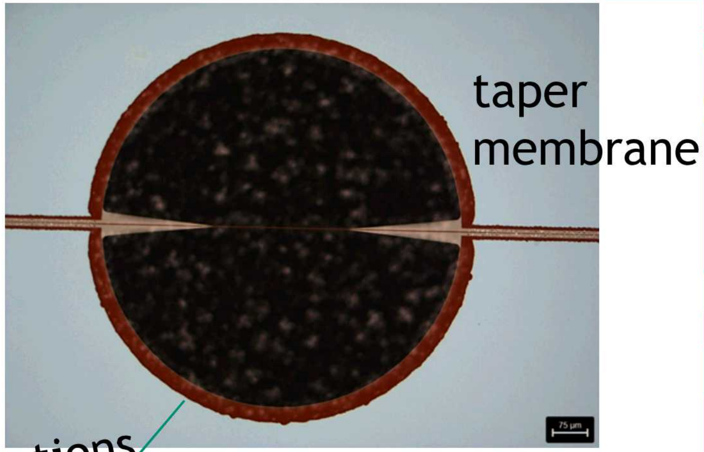
r^2 ~ (100s μm)^2

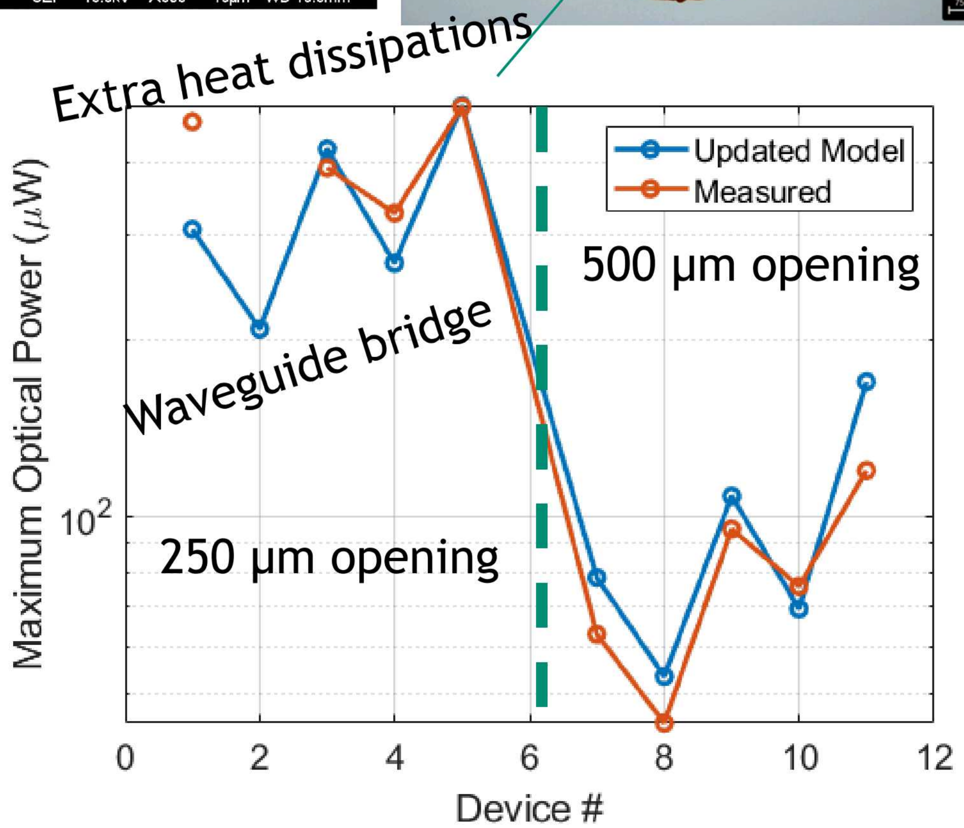
A ~ 0.1 (μm)^2

Waveguide bridge







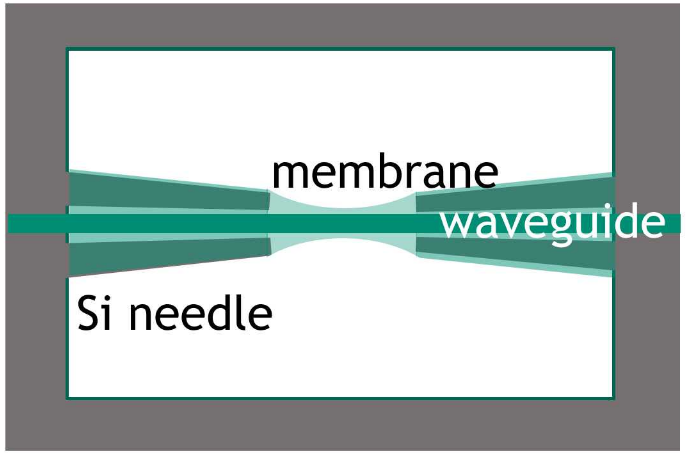


Engineered structures to heat sink

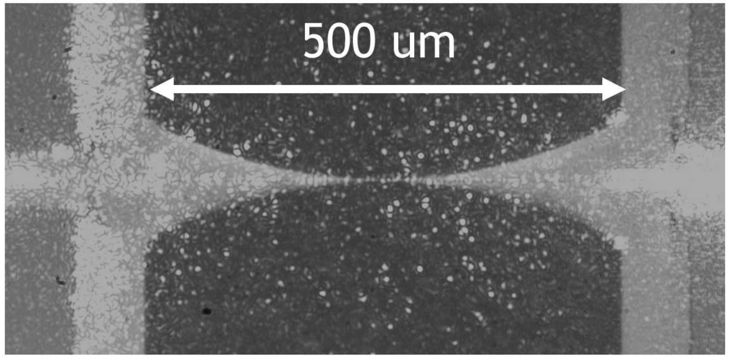
Add

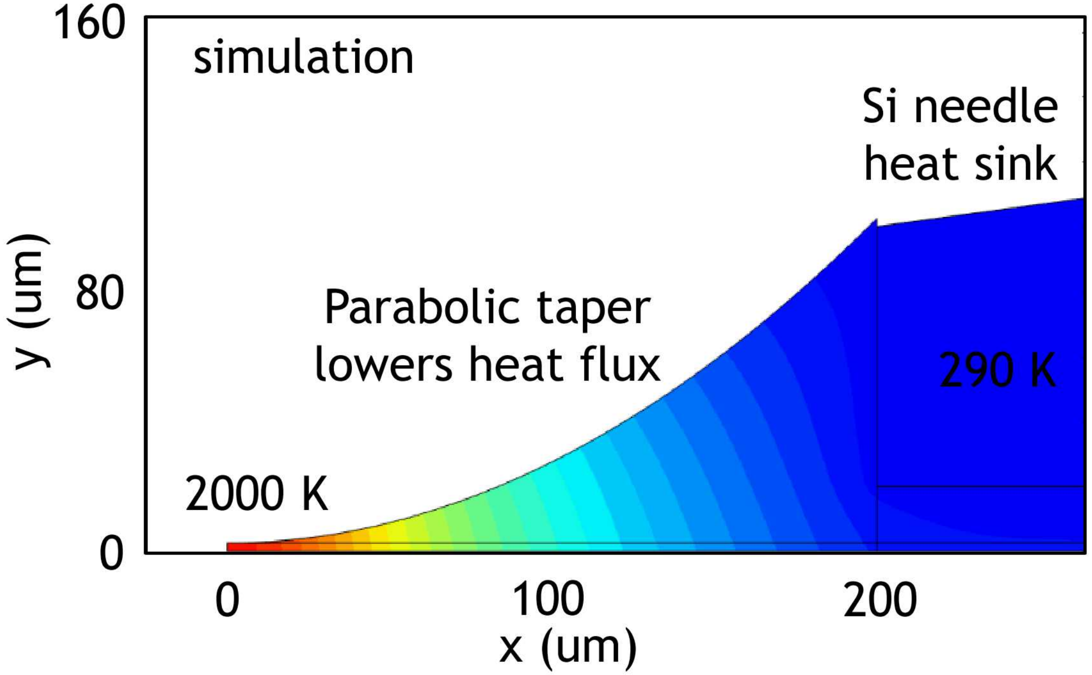
- Si needle
- Parabolic membrane tapper

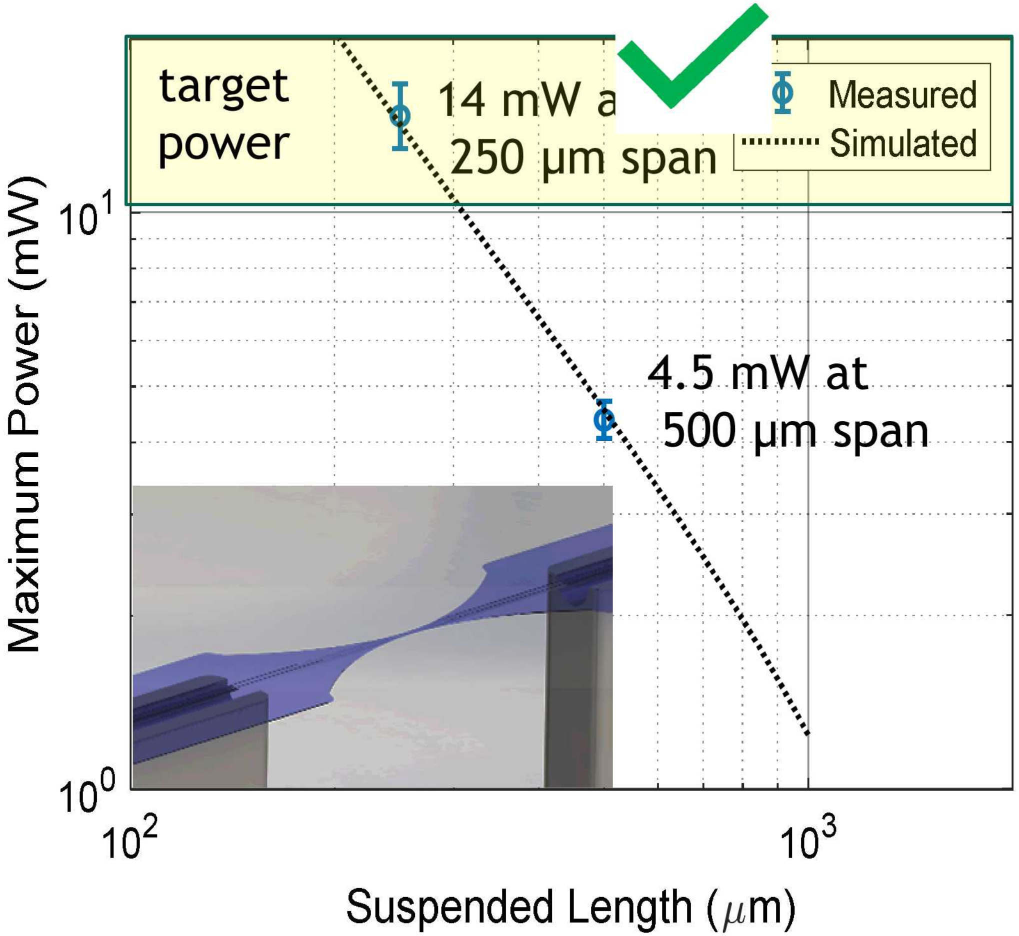
chip



test structure







Back of the envelop calculation: Estimating number of trapped atoms at a given power

$$\frac{dN}{dt} = R_0 \exp(\gamma_{MOT} t) - \Gamma N - \beta N^2 = 0$$

$$N_{max} = R/\Gamma = C\, V_{loading}(U_{barrier} - k_B T_{MOT})$$

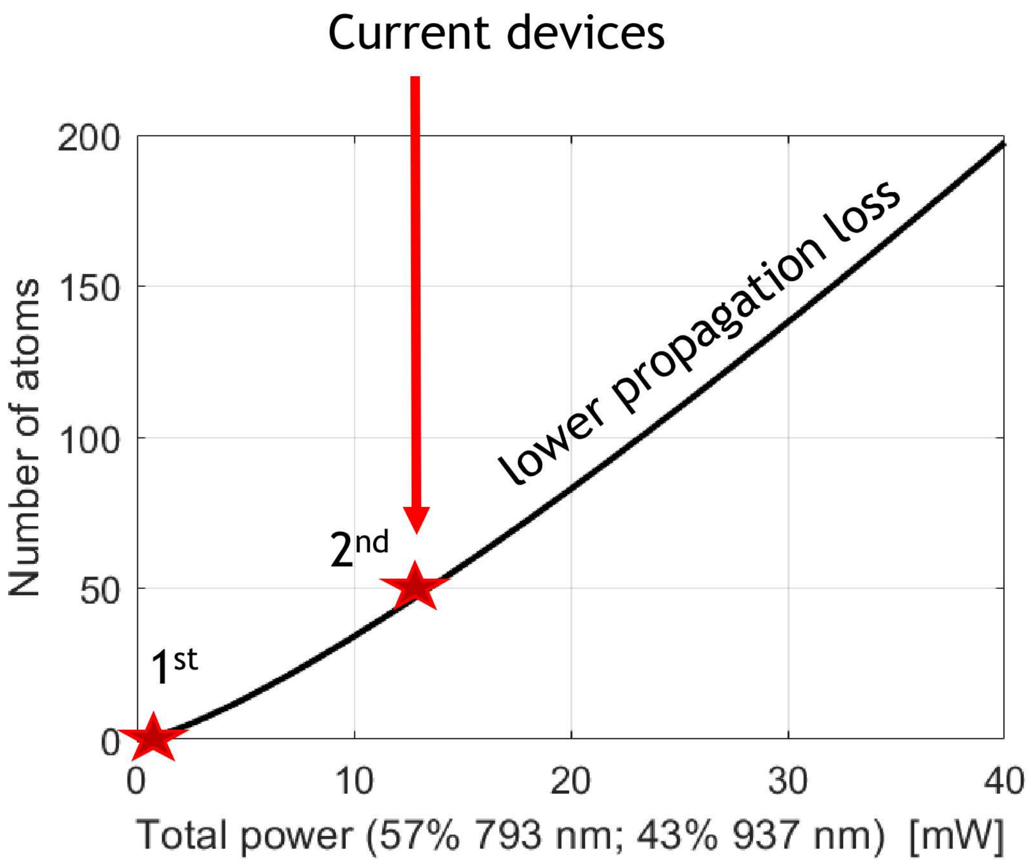
calculate from nanofiber

Loading volume

$$R \propto \int_{V(U_{trap} < T_{MOT})} dV\, \rho_{MOT}$$

Barrier height

$$\frac{1}{\Gamma} = \frac{U_{trap} - k_B T_{MOT}}{\frac{dQ}{dt}}$$

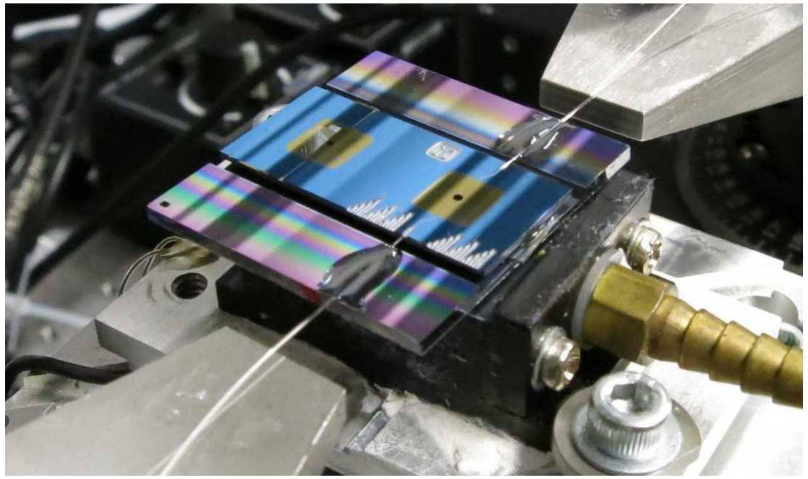


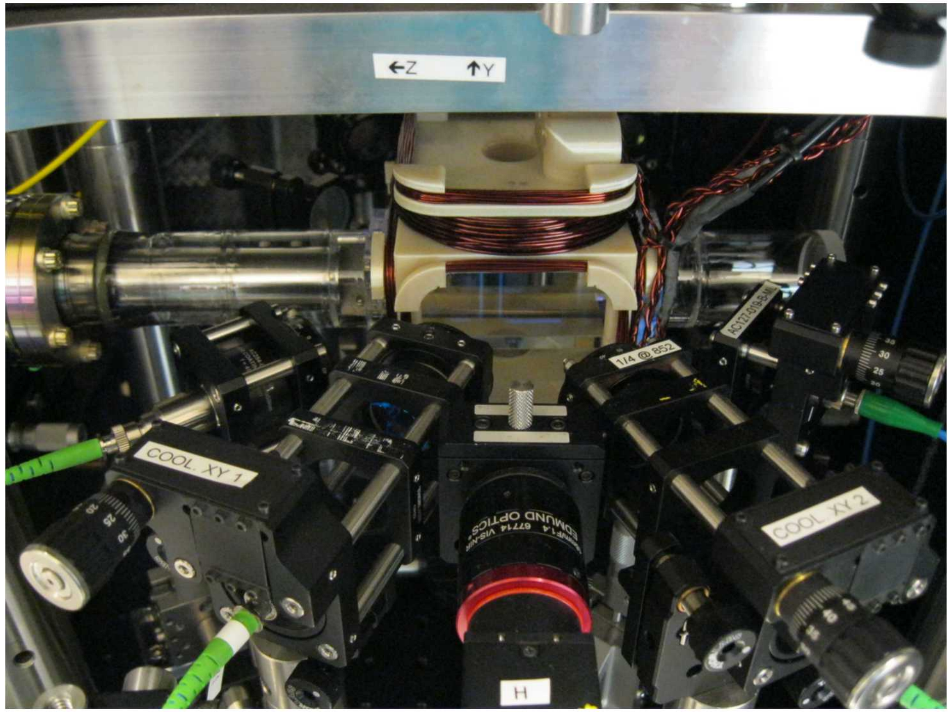
Assumes:

- steady state loading
- low density of atoms trapped
- decay set by fixed heating rate (big assumption)
- same MOT and MOT-waveguide overlap as nanofiber

Conclusion: we are in a position to trap atoms and perform guided AI on a photonic chip

- Waveguide fabricated for two color atoms trap
- Waveguide exceed power handling needed for trapping
- Chips designed to accommodate MOT formation on trap
- Ready to fabricate for testing with MOT





Acknowledgements

AMO Team

William Kindel[1]

Adrian Orozco[1,2]

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Fabrication Team

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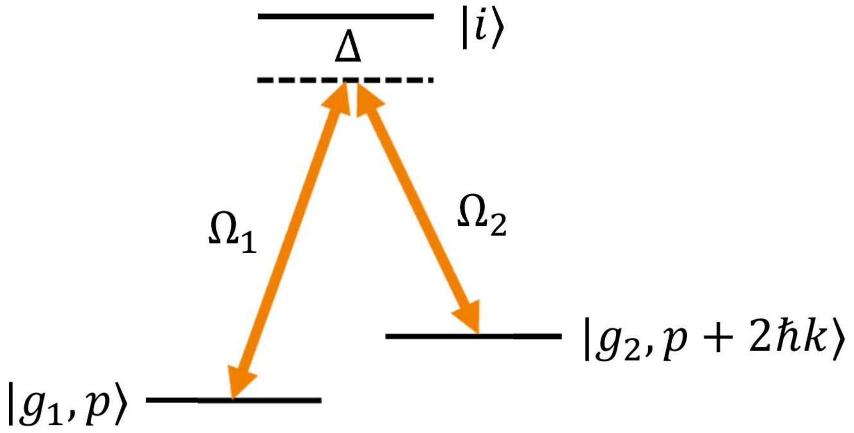
THANK YOU

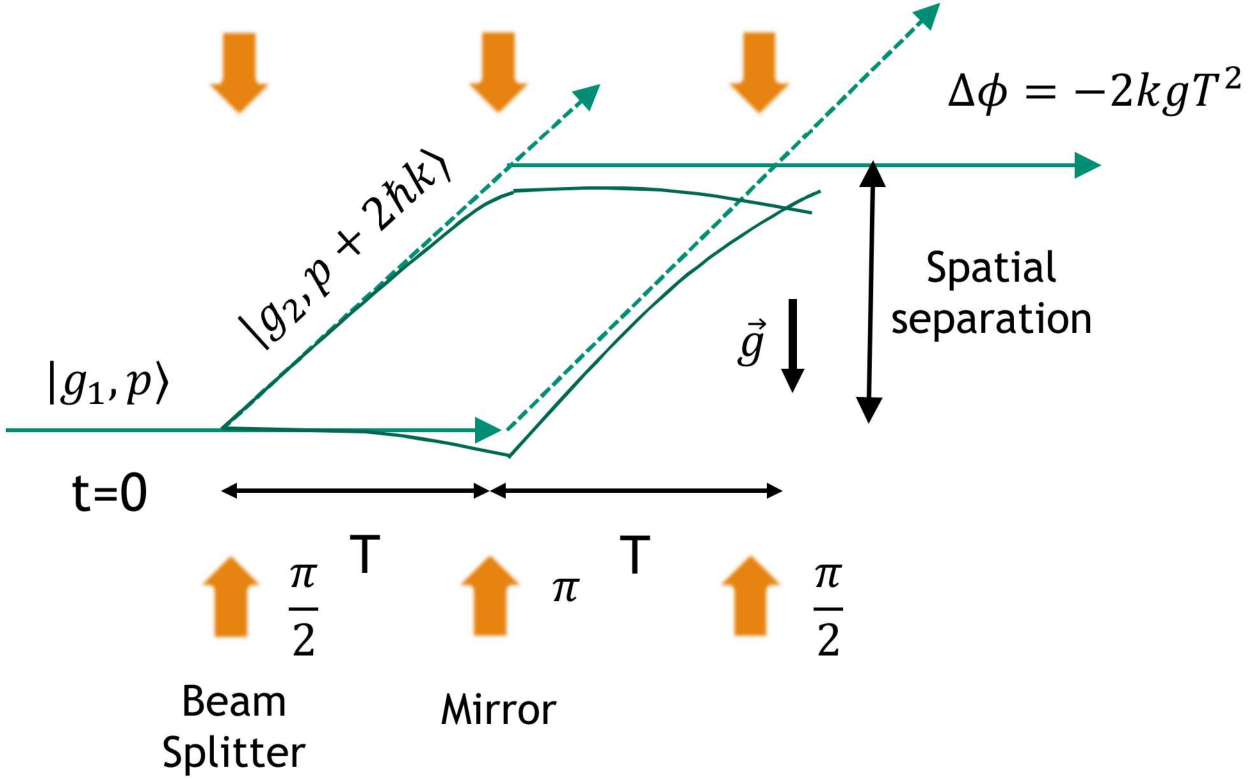
Appendix

Mach-Zehnder Atom Interferometer sense acceleration

- Doppler sensitive Raman transitions impart a momentum of $\sim 2\hbar k$ onto atom
- Three pulse sequence splits, redirects, and recombines atomic wavepackets
- Laser phase is imprinted onto the wavepacket resulting in precise measurement of spatial phase shift between arms
- Sensitivity can be increased by
  - Longer interrogation time T
  - Large momentum kick

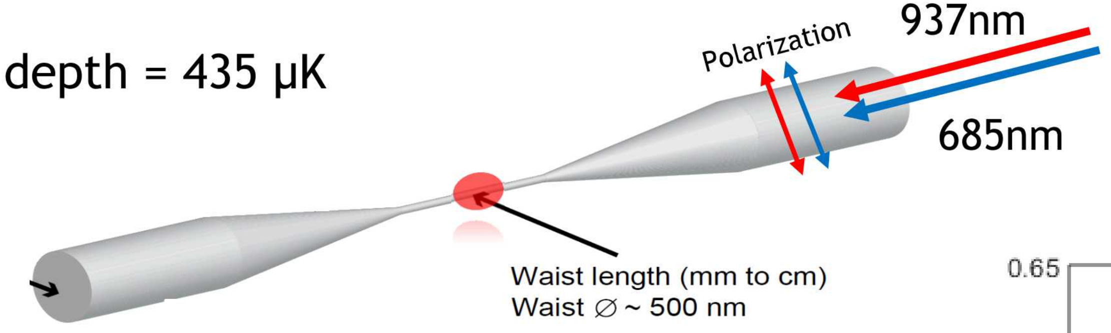


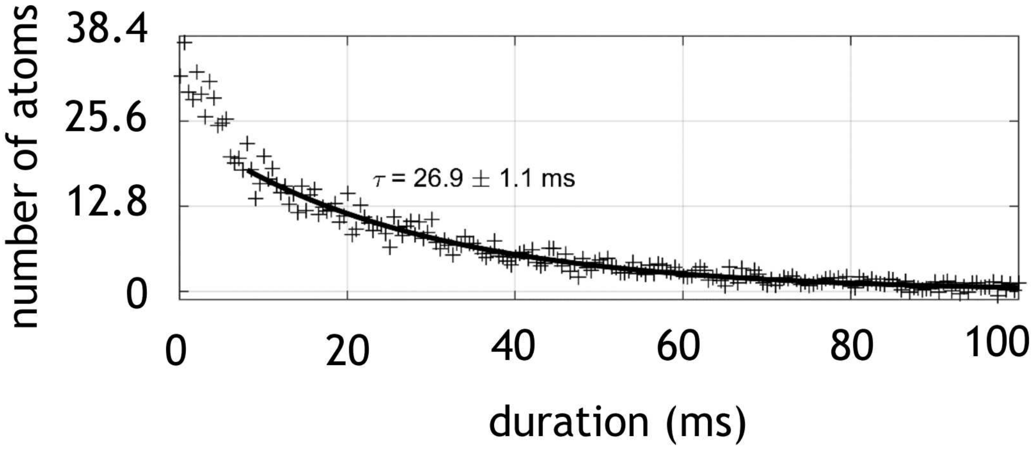
$$\Omega_{Raman} = \frac{\Omega_1 \Omega_2}{2\Delta}$$



Nano fiber trapping guides our development

Trap depth = 435 μK





Doppler-free Raman beam