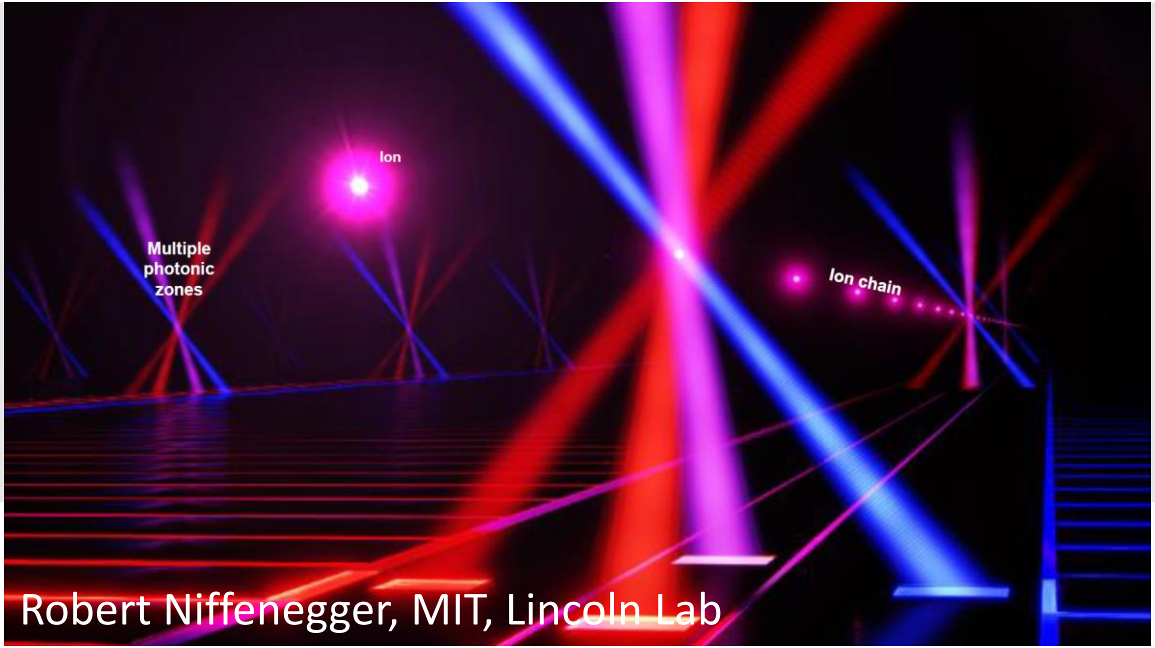
PAUL SCHERRER INSTITUT

PSI

ETH zürich

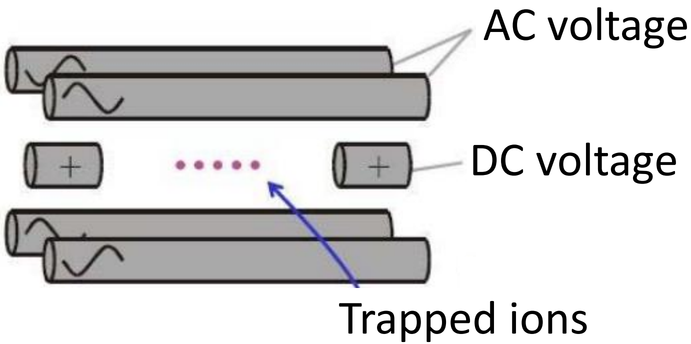


Flavia Timpu ::

Light delivery to trapped ions using integrated photonics

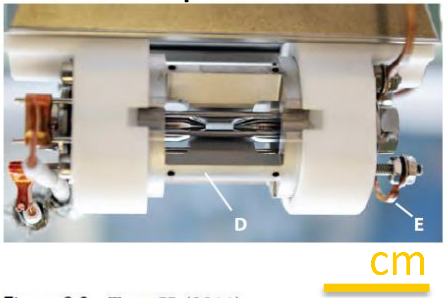
LNQ Meeting – 25.07.2022

Ion traps – 3D geometry



Use electrodes to create a potential well to trap charged particles

Blade trap @ Innsbruck



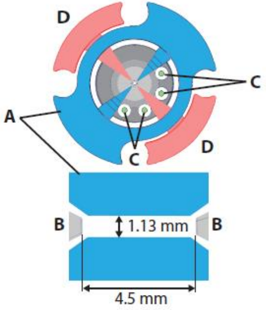
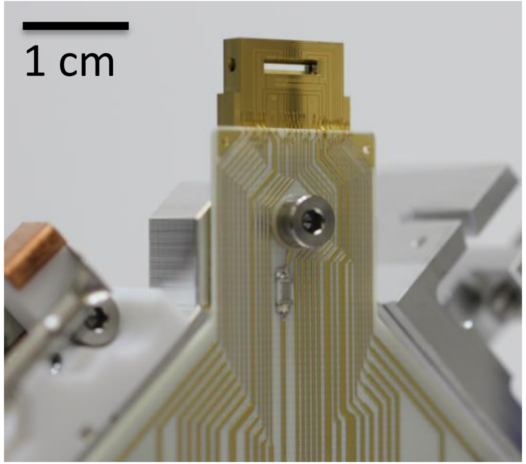


Figure 3.2.: Trap II (2011)

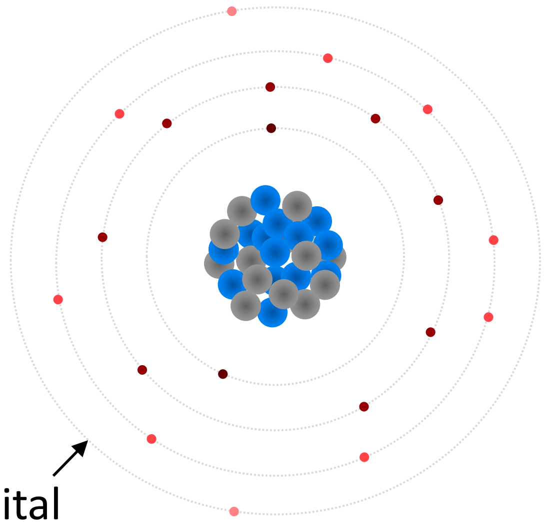
C. Hempel

Monolithic trap @ PSI



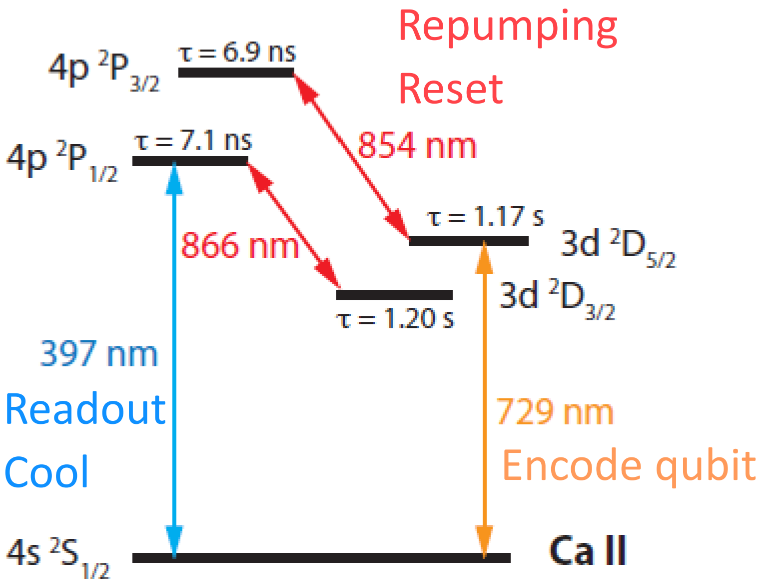
E. Brücke, made by FemtoPrint

The $^{40}Ca^+$ ion – energy levels



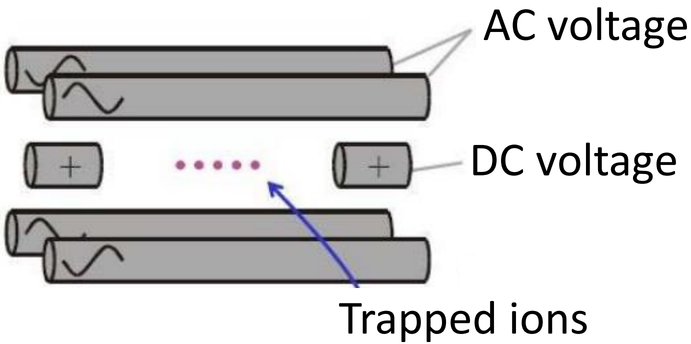
$4s^2$ orbital

Operations with trapped ions



Light delivery to the ions!

Ion traps – 3D geometry



Use electrodes to create a potential well to trap charged particles

Blade trap @ Innsbruck

Light access required!

Challenge: scaling up

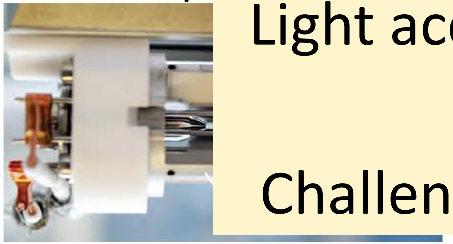
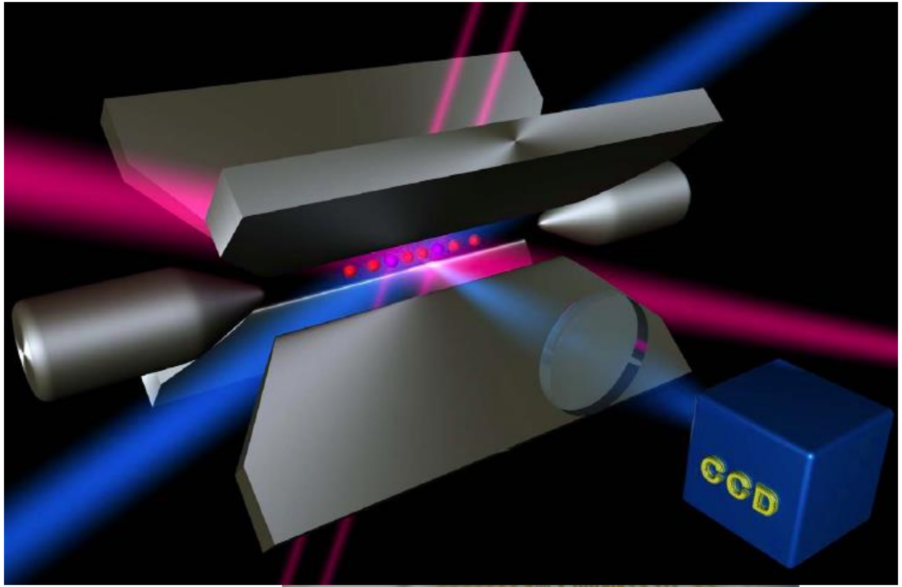
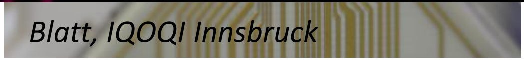


Figure 3.2.: Trap II (2011)

C. Hempel





Blatt, IQOQI Innsbruck

E. Brücke, made by FemtoPrint

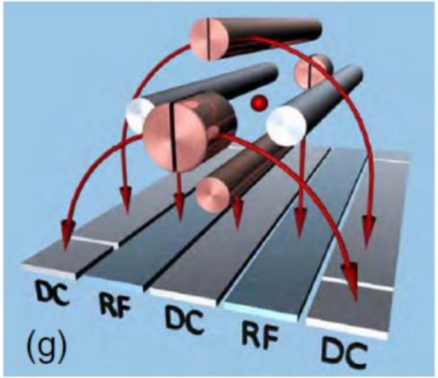
How to scale up ion traps?

2D ion traps

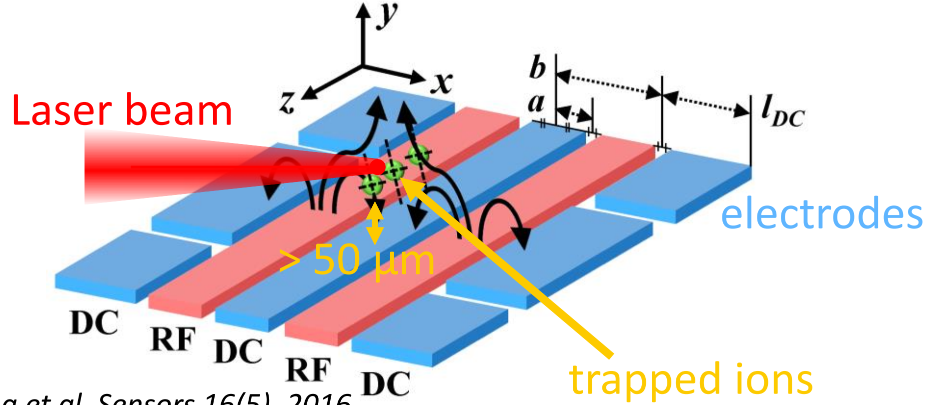
3D

to

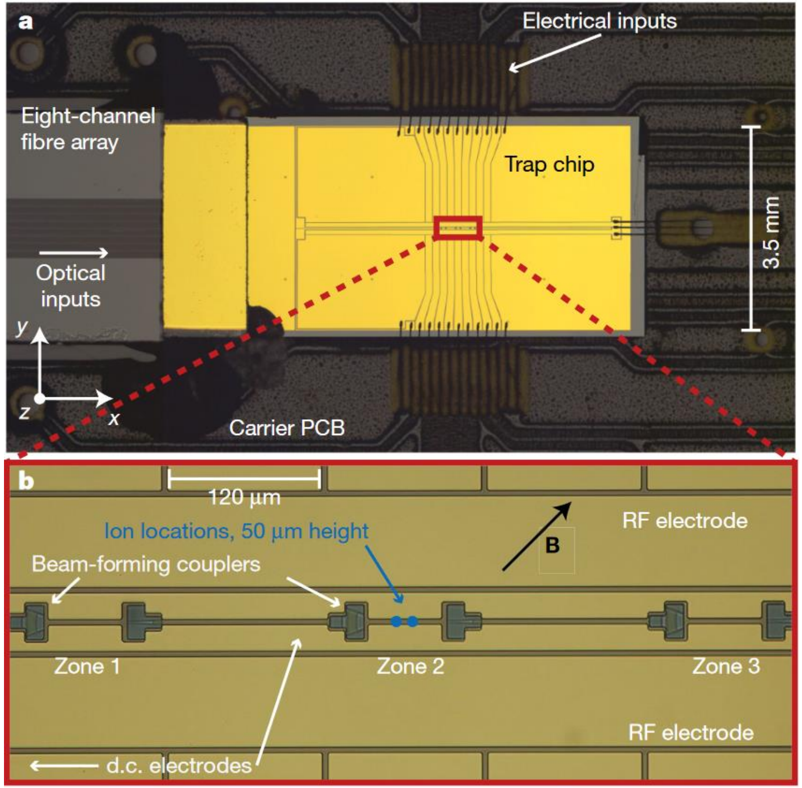
2D



Bruzewicz et al, APR 6, 2019



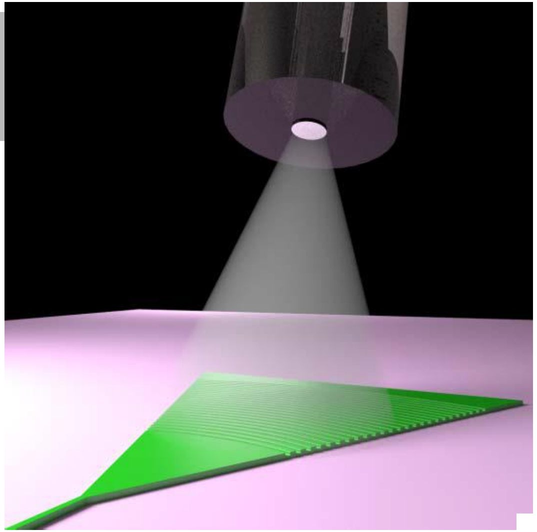
Hong et al, Sensors 16(5), 2016



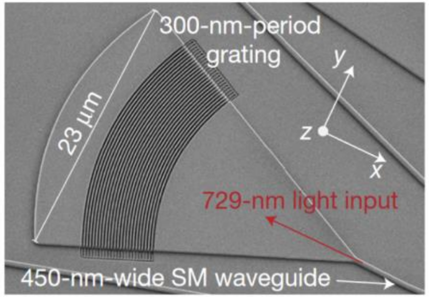
Mehta et al, Nature 586, 2020

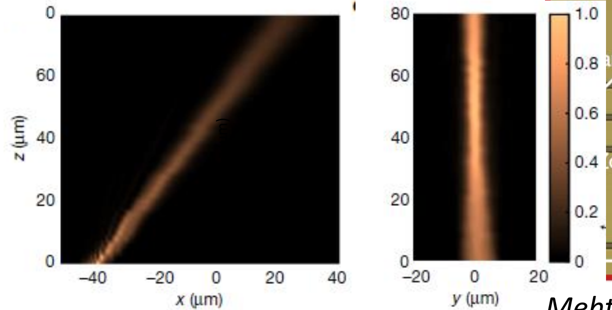
How to scale up ion traps?

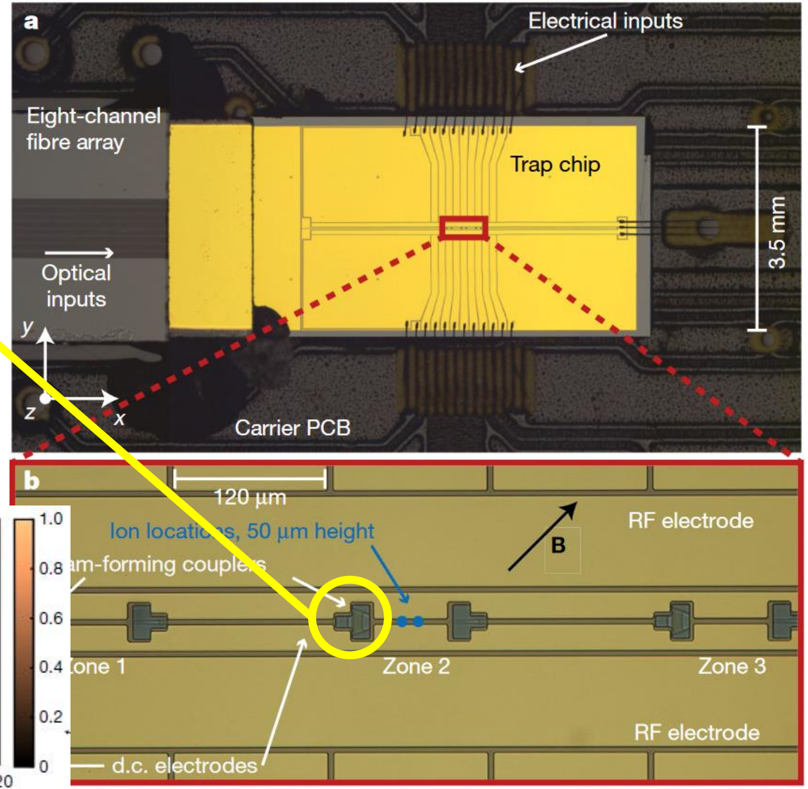
Integrated light delivery with grating outcouplers



Oton, IEEE Photonics Journal 8(1), 2016







Mehta et al, Nature 586, 2020

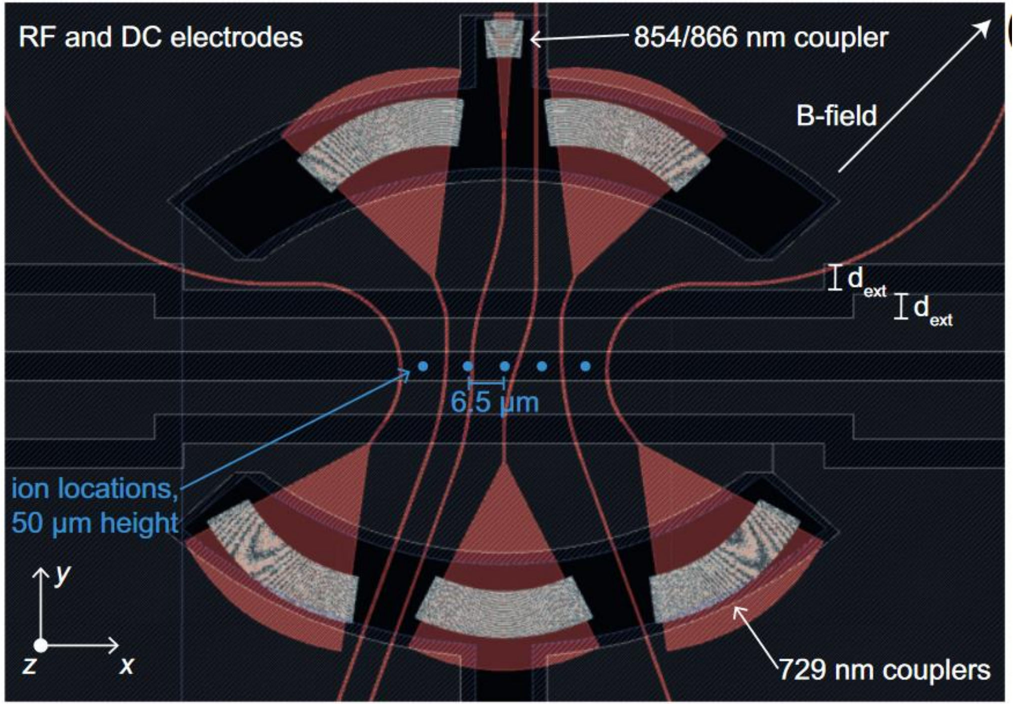
From the light source to the ion

Optical input: Fiber
coupled to the chip edge

Waveguide
from chip edge to trap position

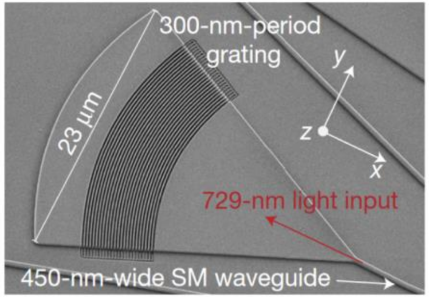
Taper

Grating outcoupler
patterned in taper



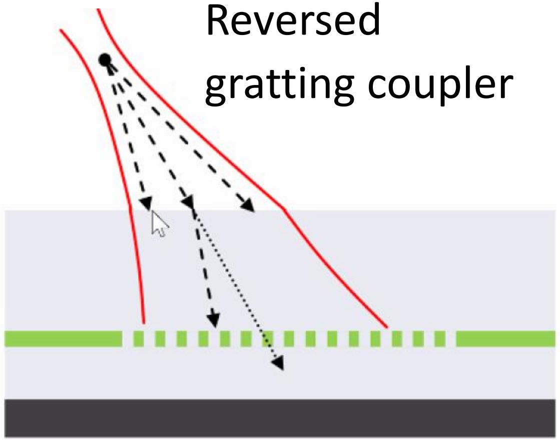
Mehta et al, Proc. of SPIE 10933, 2019

How does it work, how is it designed?



Mehta et al, Nature 586, 2020

Reversed
gratting coupler



Curved gratings used to couple light from a Gaussian beam into a waveguide.

$$R(z) \approx z, z \gg z_0$$

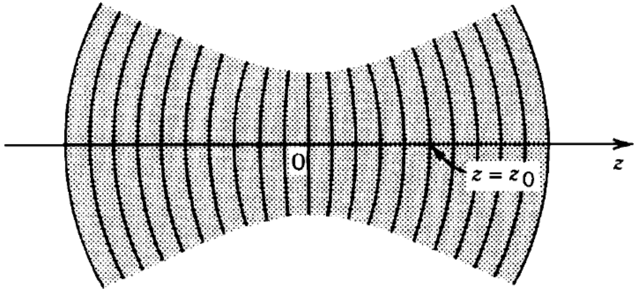
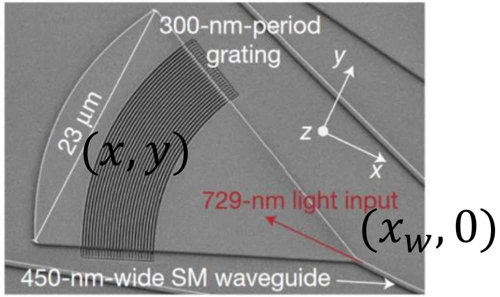


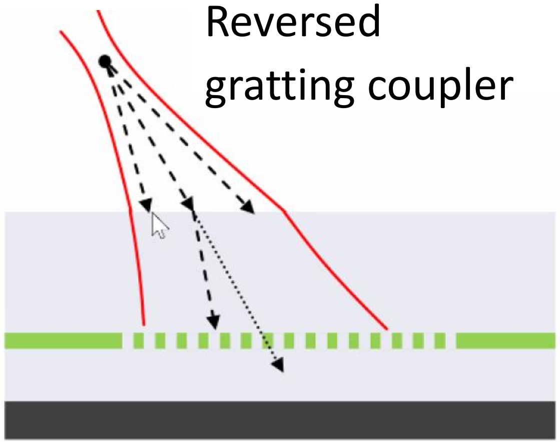
Figure 3.1-7 Wavefronts of a Gaussian beam.

Saleh, Teich, Fundamentals of Photonics

How does it work, how is it designed?



Mehta et al, Nature 586, 2020



1) At ion position – assume Gaussian beam source with known beam waist, propagation direction
2) Beam propagates to grating and couples to it
3) Beam focused to tip of taper and couples to the waveguide

For optimal coupling:

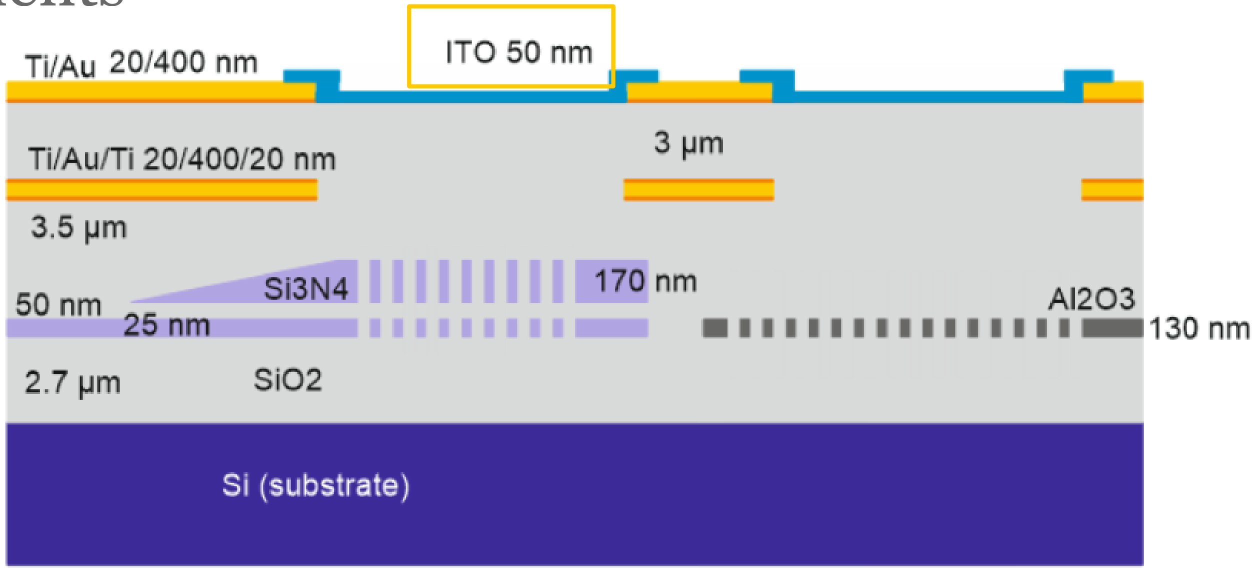
- Grating width and beam waist match
- Phase condition for grating stripe center
  $\Phi = 2\pi m$

Fabrication requirements

trapped ions

Electrodes layer for trapping

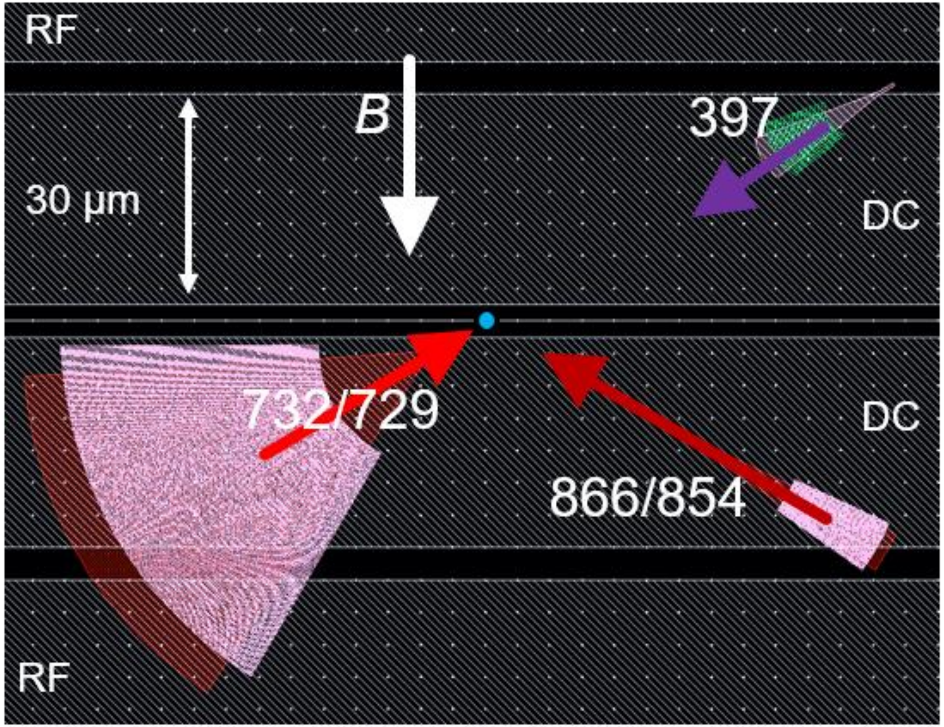
Integrated optics layer



K. Mehta and G. Beck, TIQI, ETH Zurich

- Layer-by-layer fabrication starting from a Si wafer
- Dielectric spacers between layers
- No unshielded dielectrics allowed – transparent metals for optical access

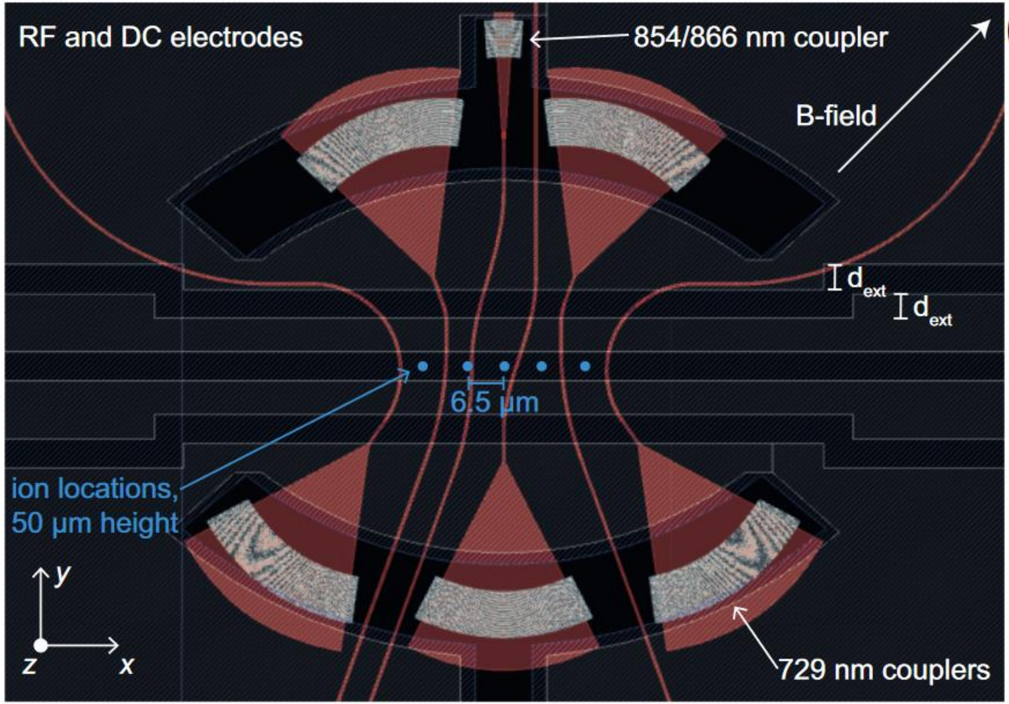
Fabrication requirements



K. Mehta and G. Beck, TIQI, ETH Zurich

- Gratings with variable period
- Diffraction limited features
- Grating width and aperture depends on wavelength and focus size

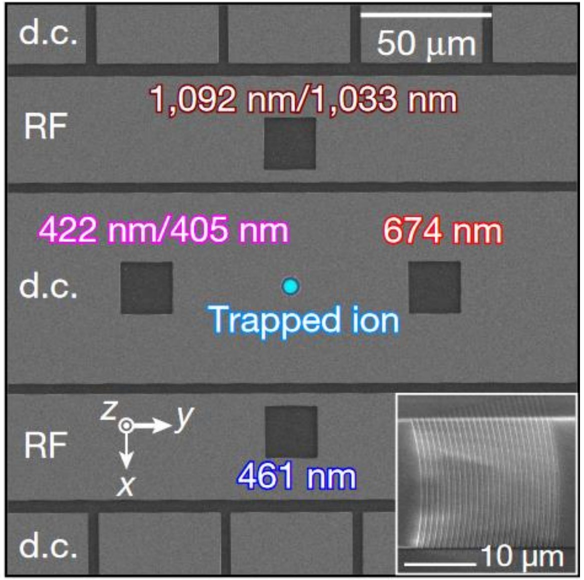
Fabrication requirements



Mehta et al, Proc. of SPIE 10933, 2019

- Single mode waveguides
- Waveguide bends optimized for low losses

What is next?



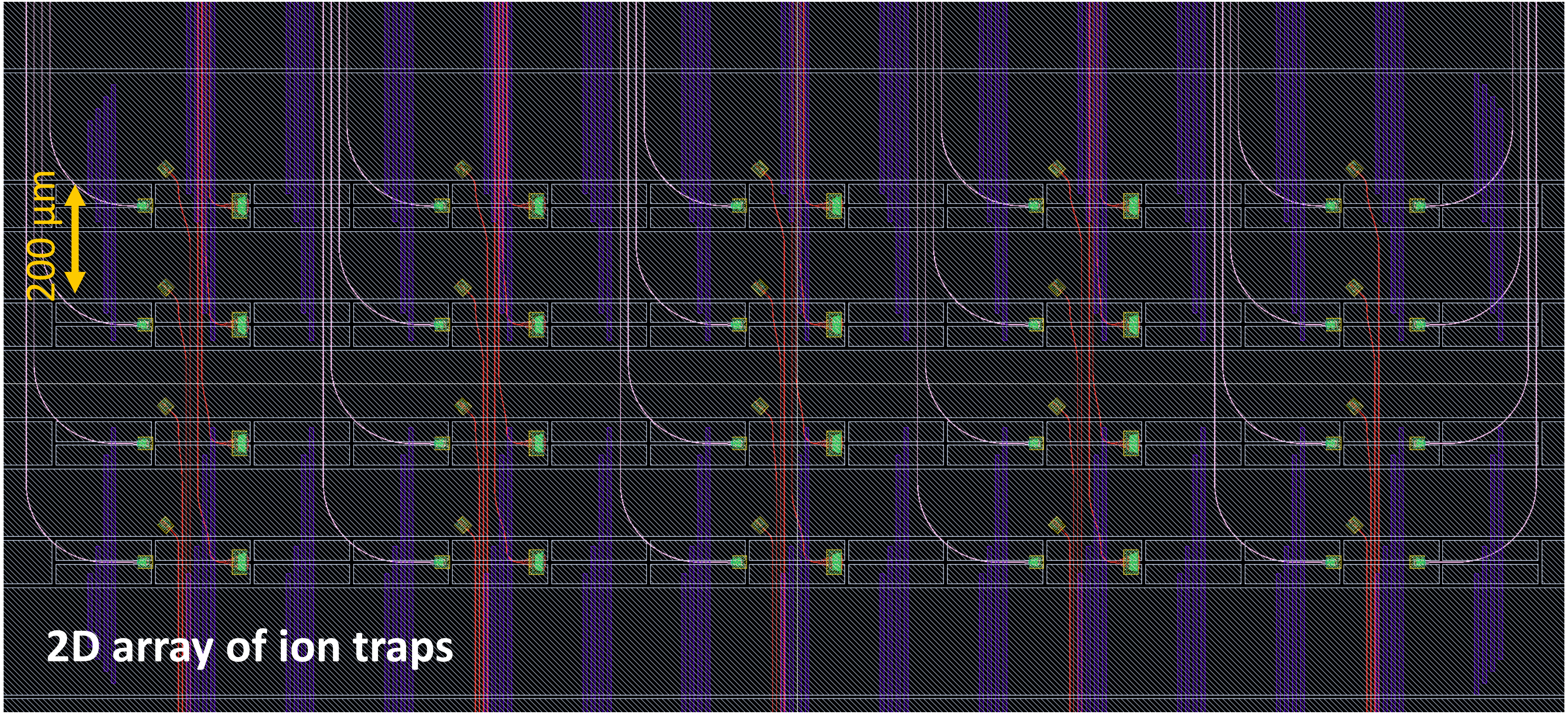
Niffenegger et al, Nature 586, 2020

Fully integrated (low loss) beam delivery

Multiwavelength gratings/Tunable gratings

Custom polarization and intensity profiles

What is next?



Multiplexing

Karan Mehta and Beck Gillenhaal, TIQI, ETH Zurich

Summary – integrated optics for trapped ions

- **An enginering challenge** – many interesting devices, but mostly proof-of-principle or not performant enough
  - Extinction ratios: -60 dB ideally
  - Powers: 10-100 µW, but sometimes 10s mW
- **Research breakthroughs** – both devices and materials
  - Going from 10s to 1000s of trapped ions?