A building block for a scalable quantum computing architecture

Trapped-Ion Quantum Information Group, ETH Zürich

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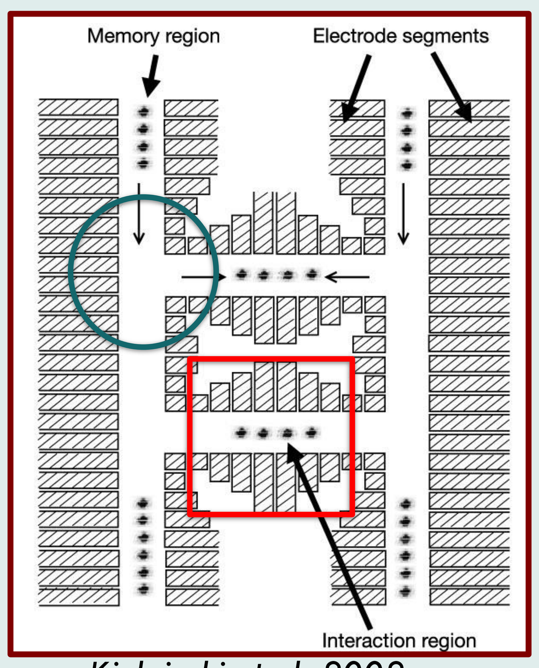
QSIT Quantum Science and Technology National Centre of Competence in Research

FNSNF

Towards a scalable quantum computer

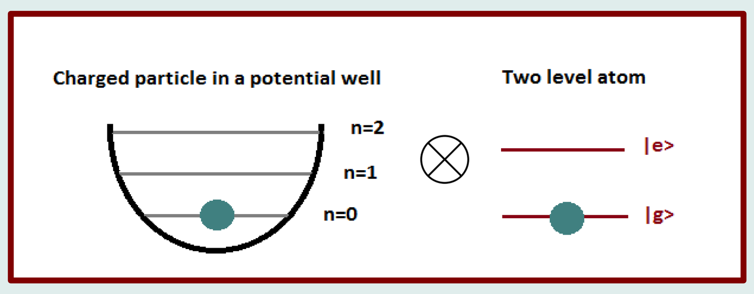
QCCD architecture: one approach to scalable devices

- Large number of independent **trapping units**.
- **Junctions** allow scalability by connecting trap units in two dimensions.
- Quantum information, encoded in the ions, is transferred by physically shuttling the ions to different trap units.
- Integrated optics are necessary for compact and scalable devices.

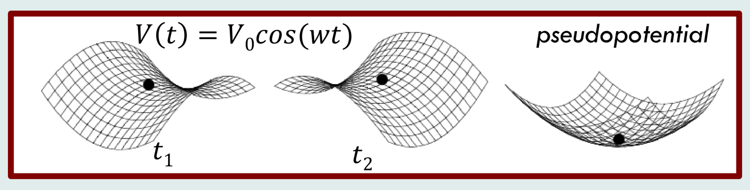


Kielpinski et al, 2002

Ion as a qubit: two internal energy levels are identified as the quantum states |0> and |1>, two qubits are coupled via their motion.

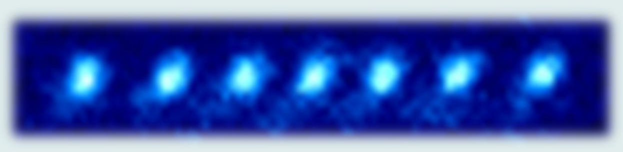


Trapping the ion: RF & DC electric fields confine the ion in all directions, DC fields are used to transport the ions, split and recombine potential wells.

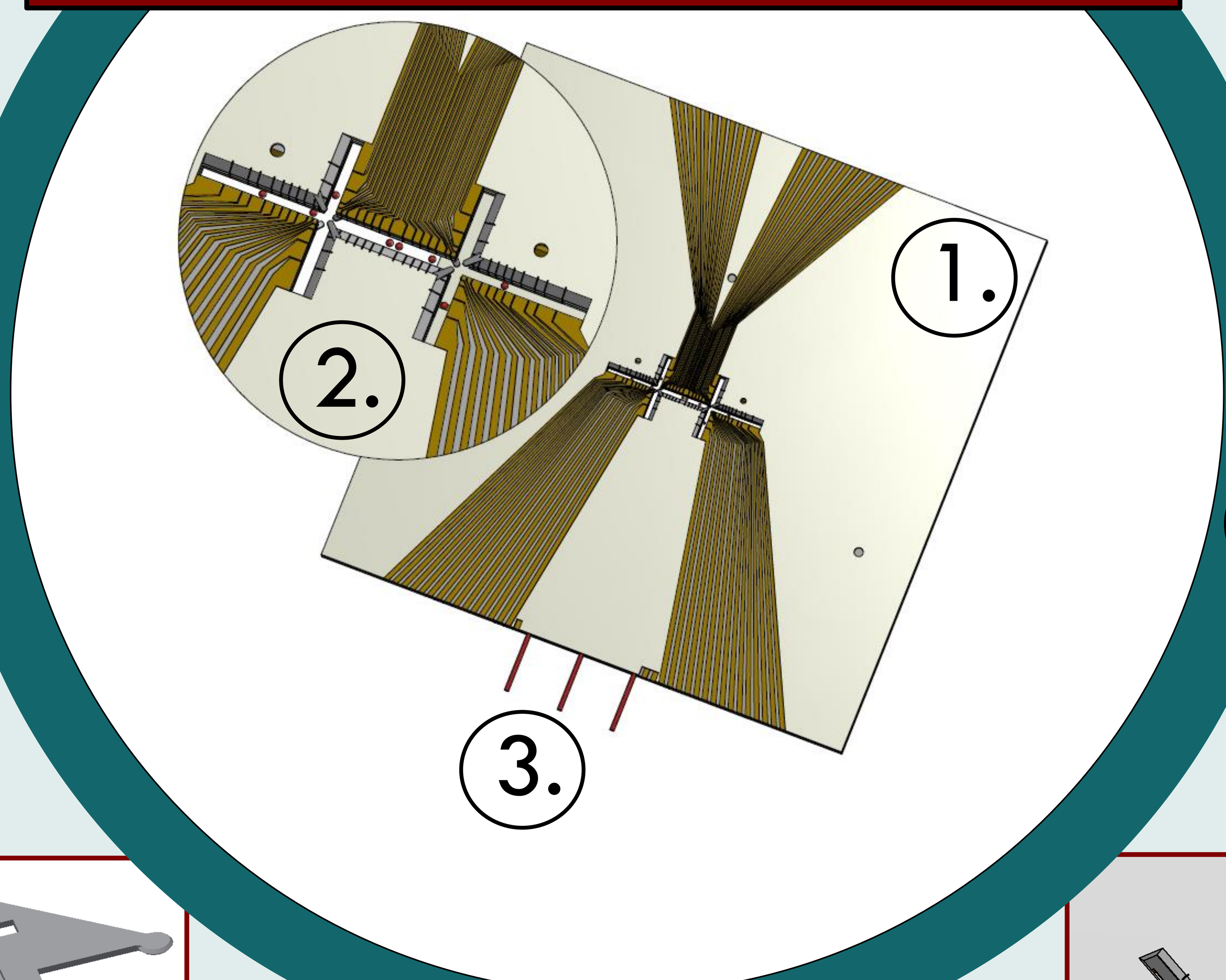


Manipulating the ion: laser light is used to cool the ion, initialize its state and realize a universal set of quantum gates, including two-qubit gates and qubit readout.

This work: a double-junction, multi- species ion trap with integrated laser delivery through optical lensed fibres, designed for:
-parallel operations
-Decoherence Free Subspace (DFS) ion transport across the junctions
-manipulation of long chains of ions


TIQI, ETH, string of ions

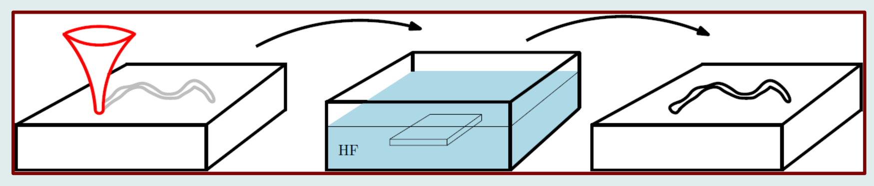
THIS WORK: a 3D double junction ion trap with integrated optical delivery for scalable quantum computation



1. Precise wafer alignment

Previous traps alignment: alumina trap wafers manually assembled, leading to misalignment of up to 10 µm. Misalignment affects the location of the minimum of the pseudopotential in which the ions are trapped.

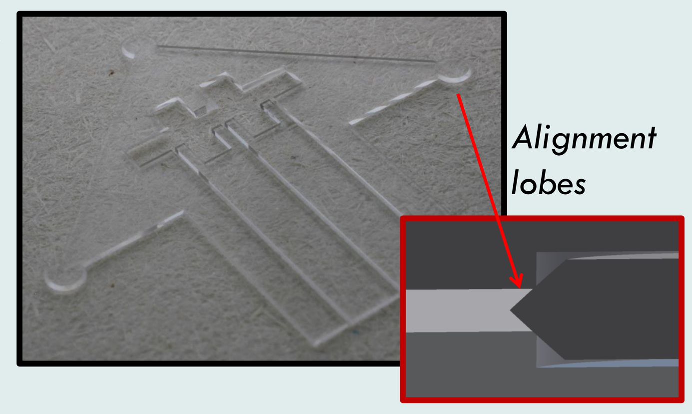
New wafer manufacturing technology: subtractive laser writing (FemtoPrint)



- Allows for the creation of small, precise structures on wafers.
- Alignment of wafers by mechanical guides less prone to misalignment errors.
- Easy, fast and precise assembly.

Our new traps using this technology: a cavity integrated 3D trap and a double junction 3D trap

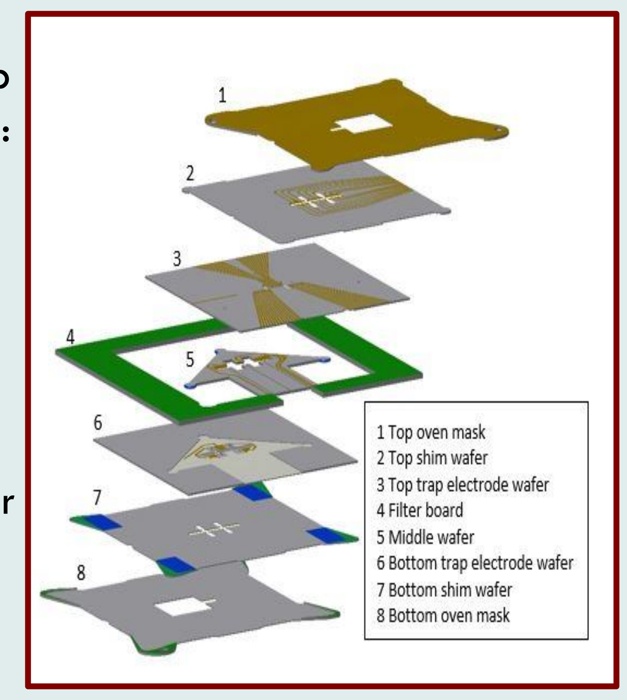

Cavity-integrated trap, S. Ragg



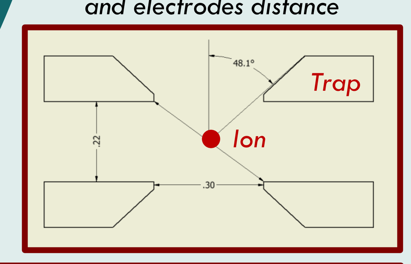
Surface roughness 3D surfaces < 200 nm
Surface roughness vertical < 80 nm
Horizontal precision ≈ 1 µm
vertical precision ≈ 5 µm

Double junction trap consists of 7 wafers:

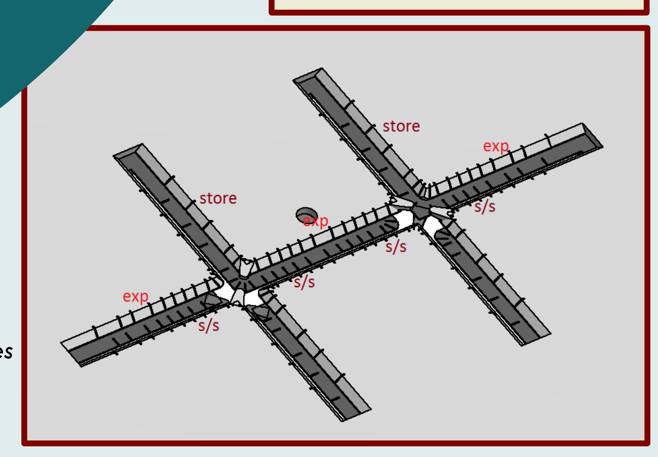
-two main trapping wafers
-middle wafer (spacer and optical integration)
-two shim wafers for compensation
-two oven masks



2. Double junction trap



Side view: optical access angle and electrodes distance

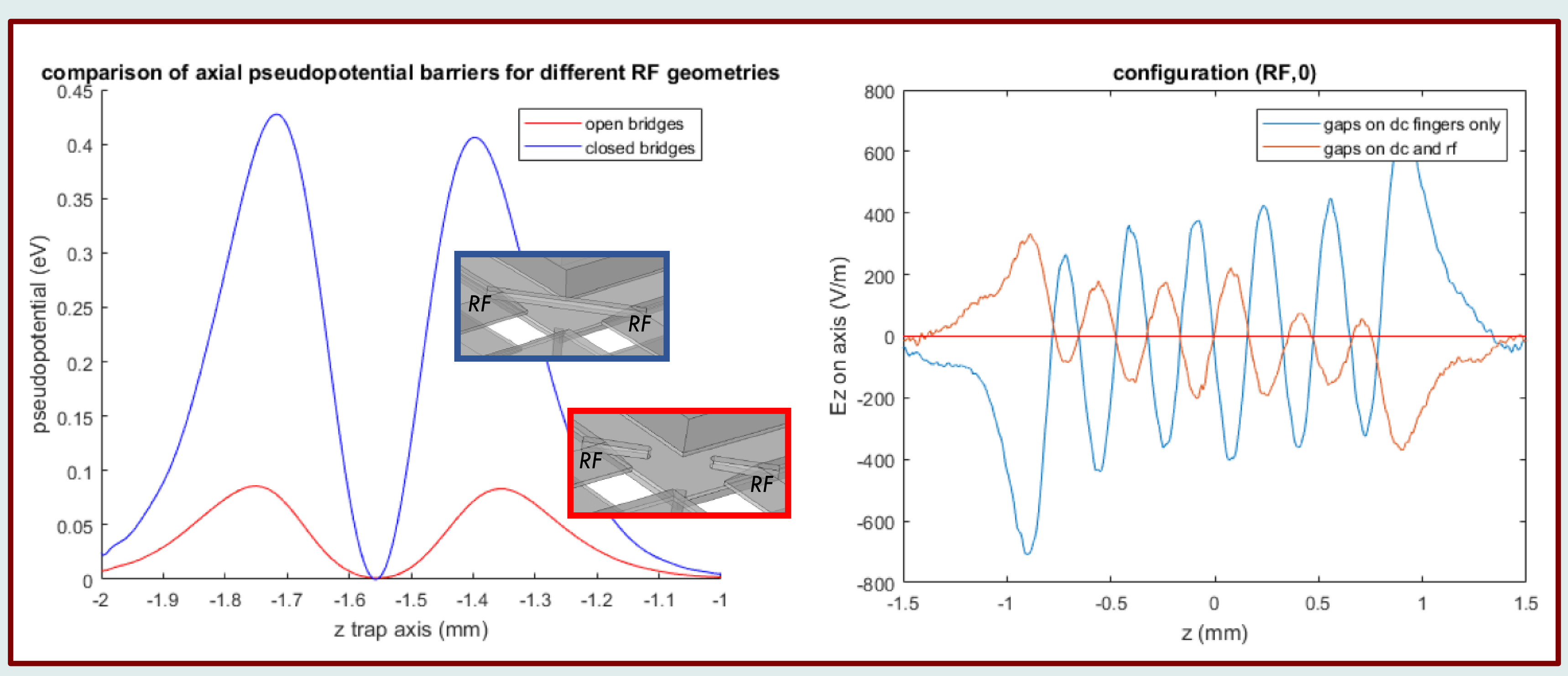


Top view: double junction with segmented electrodes

Design & trapping zones

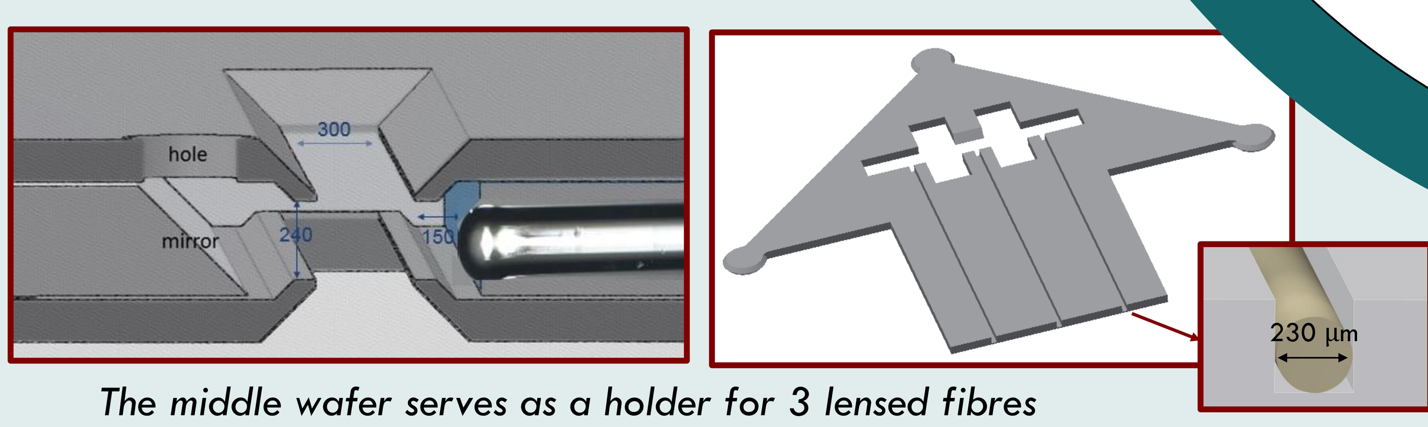
-two X junctions
-145 total electrodes (ca 100 control electrodes).
-two main trapping wafers (total stack of 7).
-electrode-ion distance: 185 µm
-three independent experimental zones.
-laser optical access angle to the ion: 48°.

- Symmetry of the electric fields needs to be broken to confine at the centre of the junction.
- Bridges connecting the RF electrodes break the symmetry but introduce **axial pseudopotential barriers** (*Fig. below: FEM simulation of pseudopotential on axis*).
- Shaping RF bridges allows for pseudopotential barrier's height minimization.
- **Open bridges** create lower pseudopotential barriers (0.1-0.2 eV) than full bridges.
- Segmenting the RF electrodes like the DC electrodes reduces micromotion.



3. Optical integration: lensed fibres

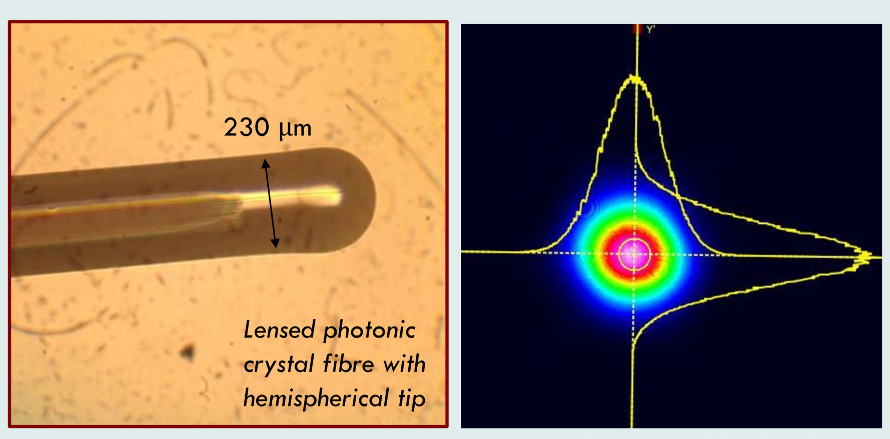
Previous technology: ions are addressed using free space laser beams: requires bulky optics and custom objectives, not easily scalable.



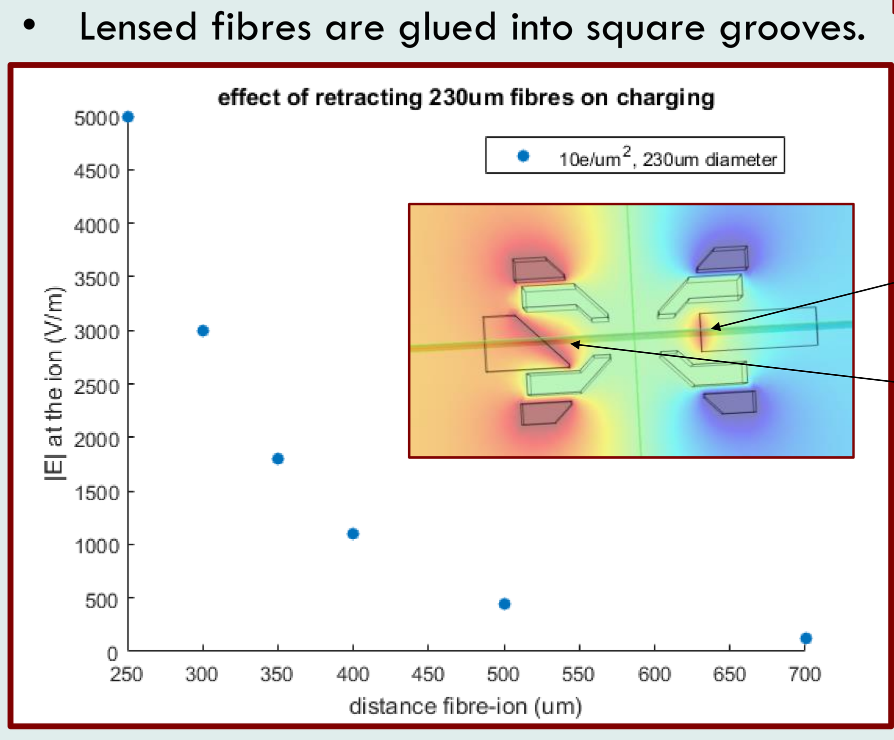
The middle wafer serves as a holder for 3 lensed fibres

Squared groove with PC lensed fibre

- Lensed fibres bring laser light to the ions at the experimental zones.
- Photonic Crystal Fibres (PCFs) have lenses at their tip to focus the light to 20 µm (FWHM), up to 500 µm away.
- Lenses produced via rounds of polishing.
- Hemispherical lens creates a Gaussian beam profile (*Fig. on the right*).
- Lensed fibres are glued into square grooves.



Measured beam profile after lens



Challenges and solutions of integrating optics

- Glass fibres tip accumulates **charges,** producing stray electric fields.
- Solution: **bias electrodes** serving also as mirrors for extracting light from setup.
- Alternative: coat fibres with Indium Tin Oxide (**ITO**), to make them electrically shielding, yet transparent at IR wavelengths (700-800 nm). Expected transparency 70-85 %.

Outlook

-Fabrication of the trap carried out in the ETH cleanroom using electron beam evaporation of gold.
-Experiments with the double junction trap: DFS ion transport across junctions, parallel control of ions, manipulation of long chains of ions towards the understanding of condensed matter problems.