

Munich Quantum Valley



Christoph Kutter
Fraunhofer EMFT, Speaker of K6

Foundation of Munich Quantum Valley e.V.



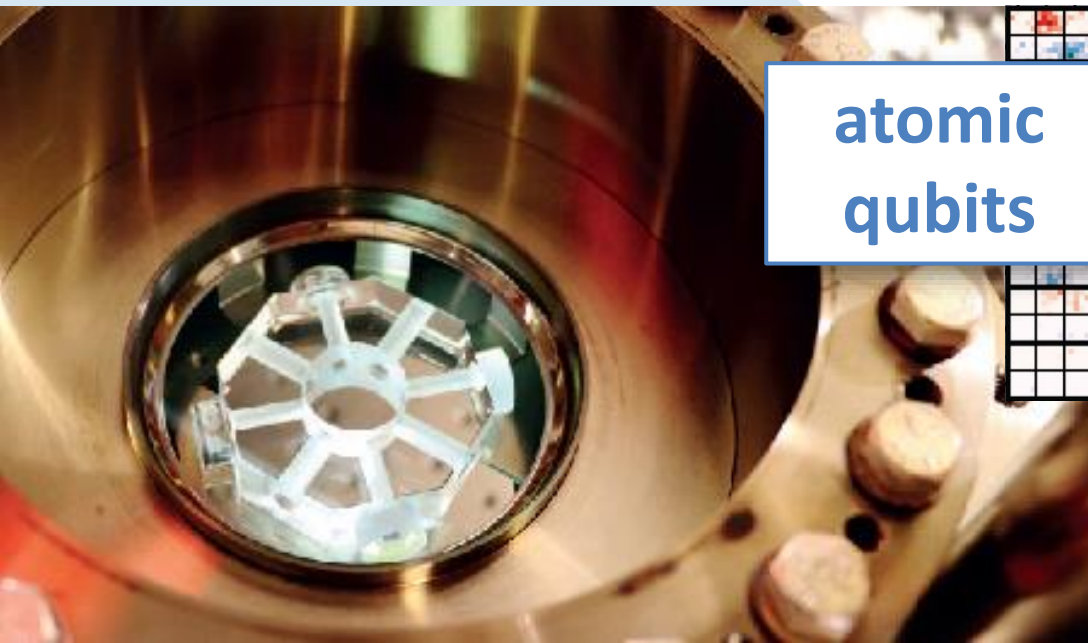
Munich Quantum Valley e.V successfully established

On January 27th 2022 the MQV e.V. was founded by the Bavarian Academy of Sciences and Humanities (BAdW), the German Aerospace Center (DLR), the Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), the Fraunhofer Society (FhG), the Ludwig-Maximilians-Universität München (LMU), the Max Planck Society (MPG), and the Technical University of Munich (TUM).

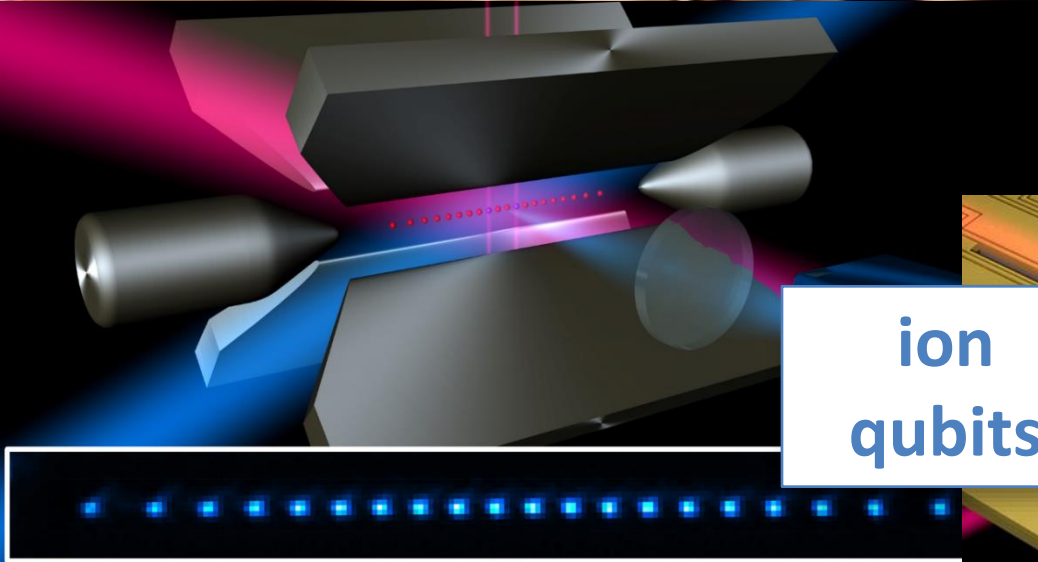
Chairman of the Board:

President of the MPG, Prof. Dr. M. Stratmann

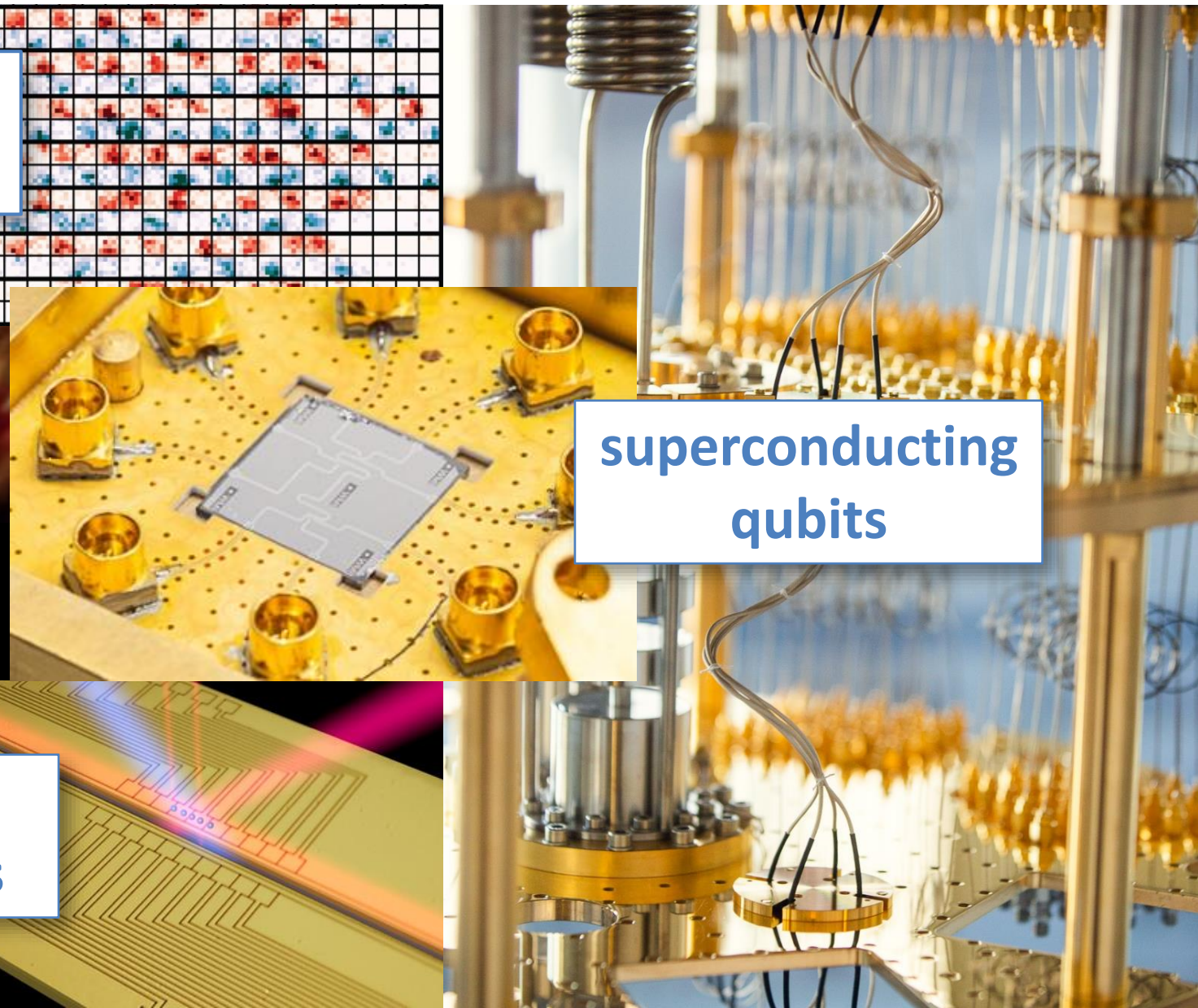
QC technologies



**atomic
qubits**



**ion
qubits**



**superconducting
qubits**

Superconducting Qubits

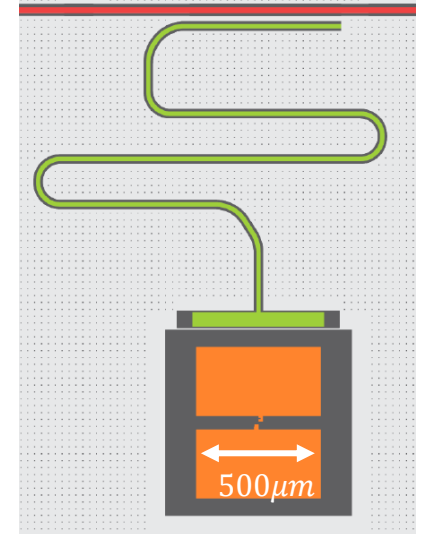
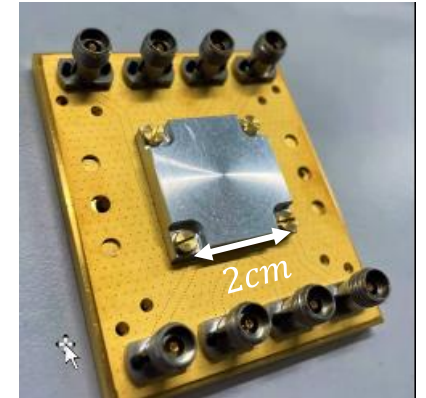
Goal: Quantum processor with 24 qubits, scalable to 100 qubits

Features:

- quantized non-linear superconducting circuits
- typical frequencies: 5 – 10 GHz (microwave range)
- fast gate operations within a few nanoseconds
- high fidelity gates ($\sim 99.5\%$ two-qubit gates)
- stable operation
- scalable fabrication
- demonstrated potential (e.g. IBM, Google, ETHZ,...)

Challenges:

- coherence (materials, interfaces,...)
- control (optimal pulses, fast & stable electronics)
- high-anharmonicity qubits
- reproducibility and uniformity
- crosstalk (classical and quantum)
- scaling: 3D-integration, I/O channel density



Superconducting Qubits

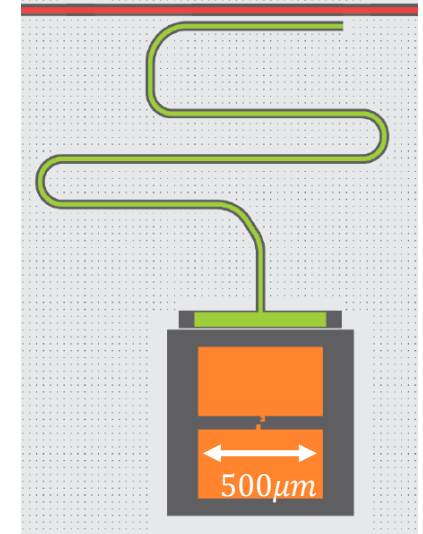
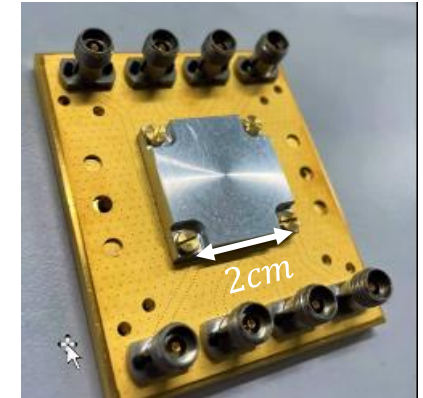
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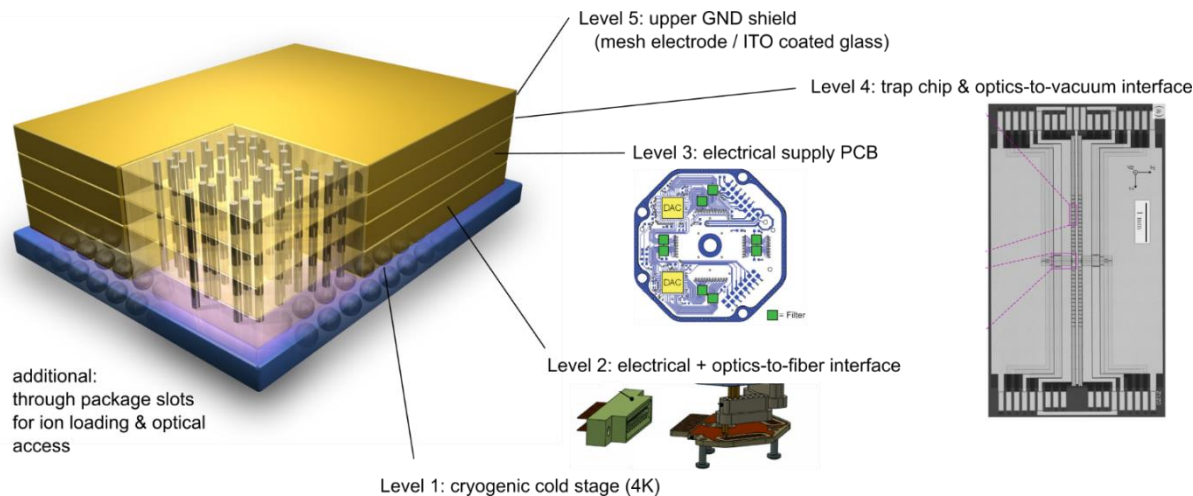
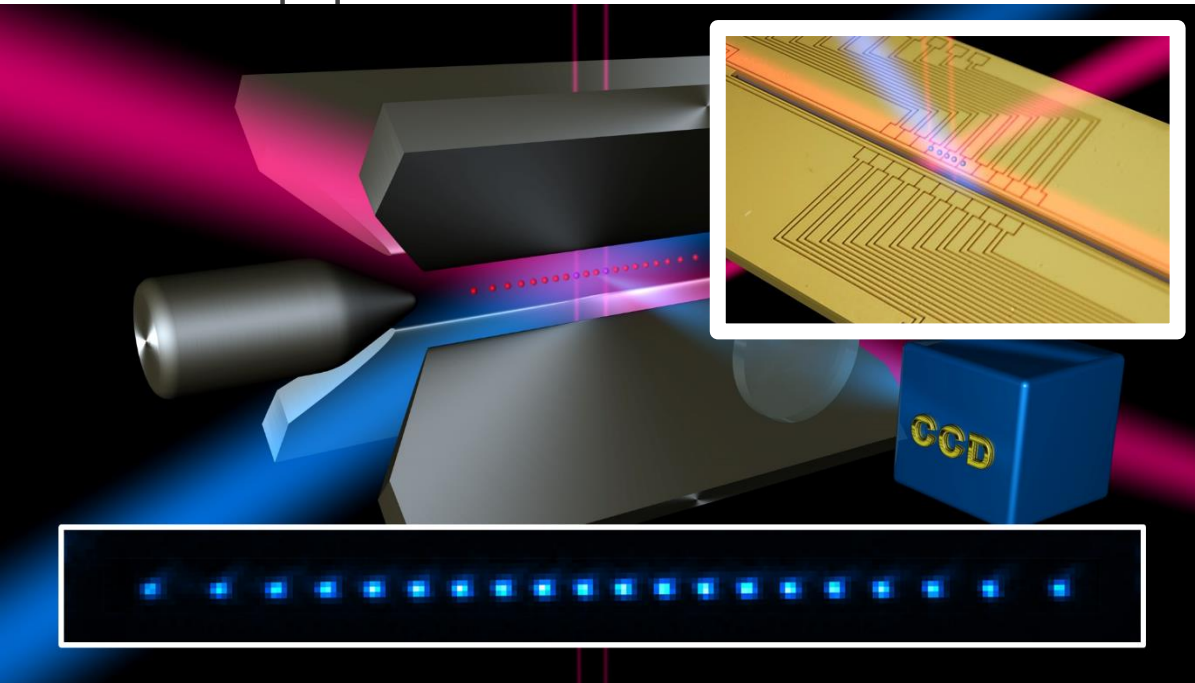


Trapped Ions

Goal: quantum processor with 24 qubits, scalable to 100+ qubits

Features:

- Qubits based on trapped Calcium ions
- Manipulated by addressed laser pulses
- Coherence times of more than 100 ms
- Gate operations only require 10s of microseconds
- Gate fidelities > 99.7% (single qubit) and > 99.5 % (two qubits)
- Uptime of hours/day
- All qubits identical by nature, facilitating the fabrication



Main challenges:

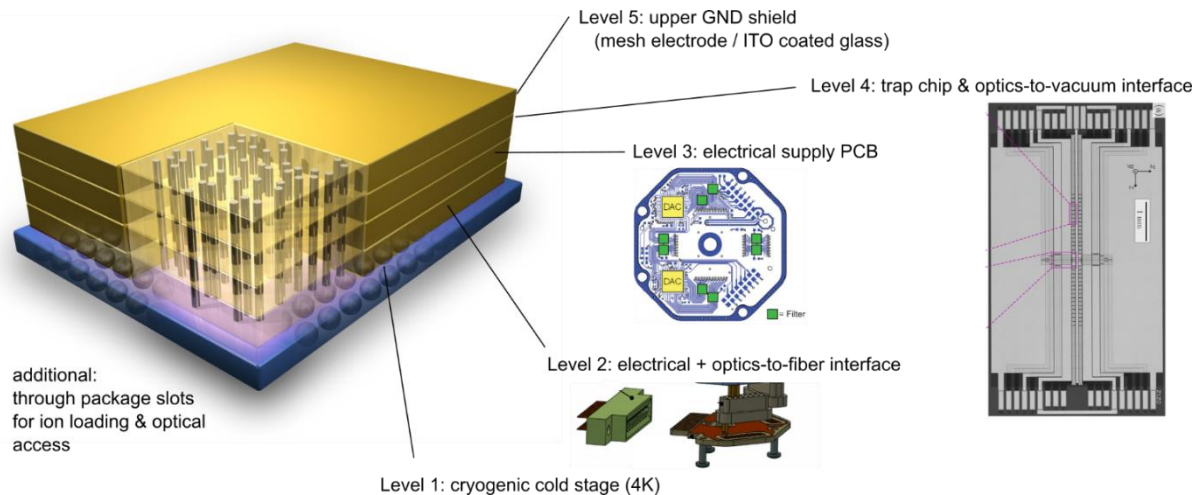
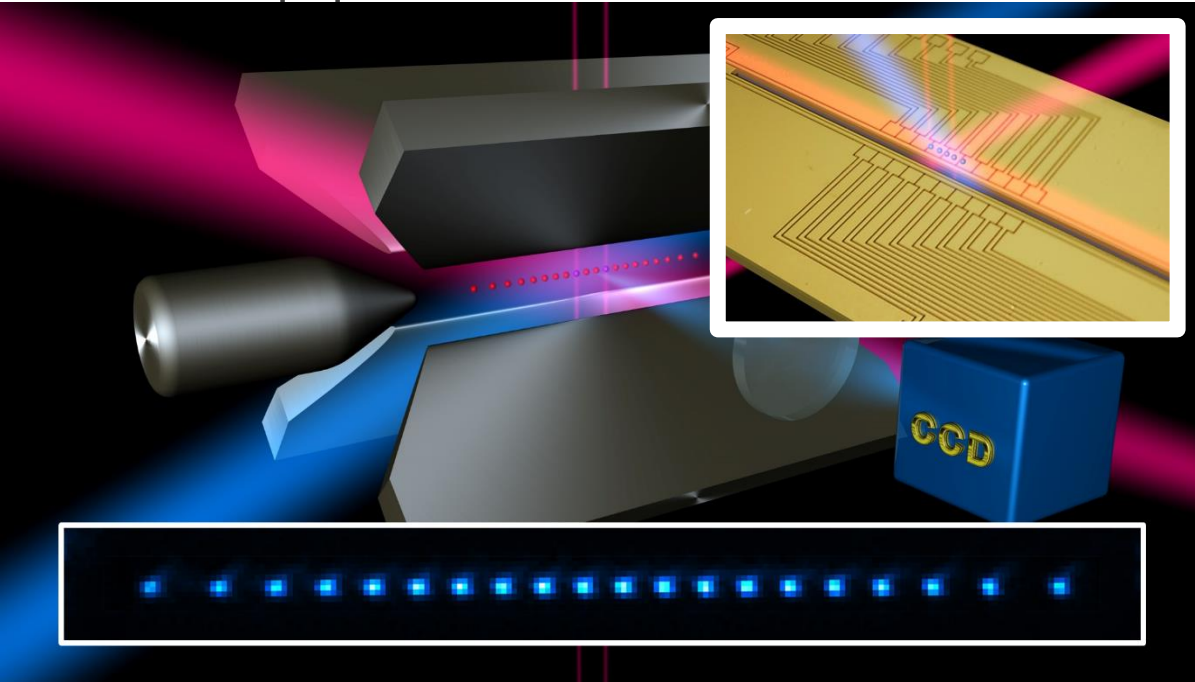
- Scalable realization of high-performance, segmented traps
- Integration of optics and electronics into trap

Trapped Ions

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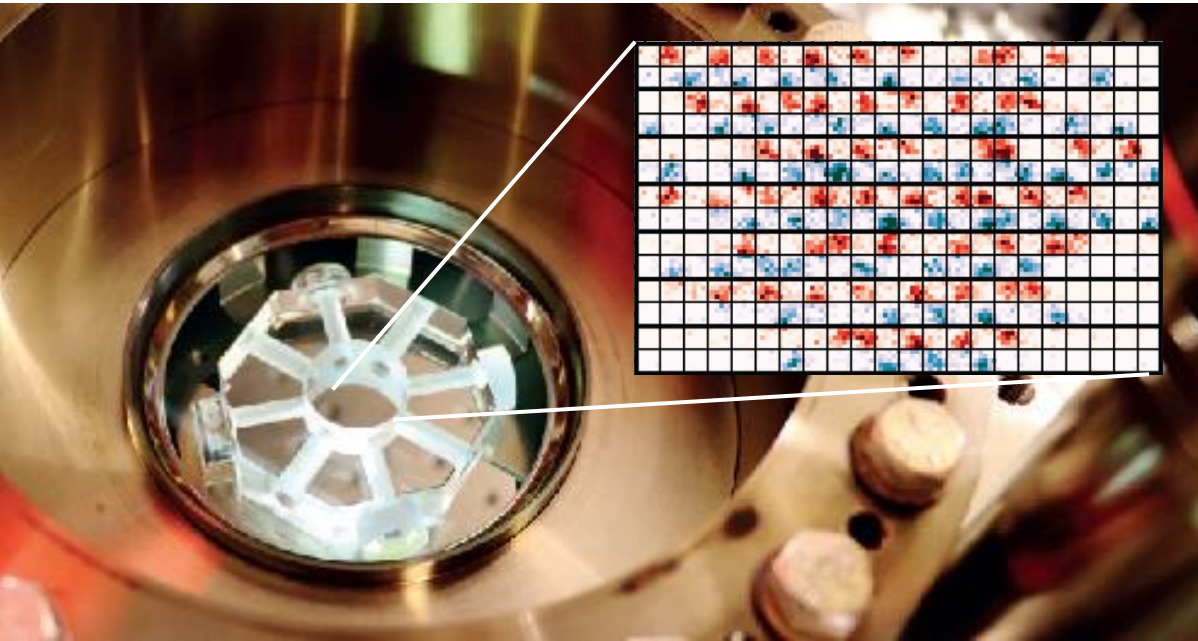
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Neutral Atoms

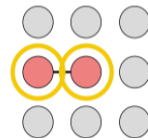


Goal: quantum processor with 24 qubits, scalable to 400+ qubits

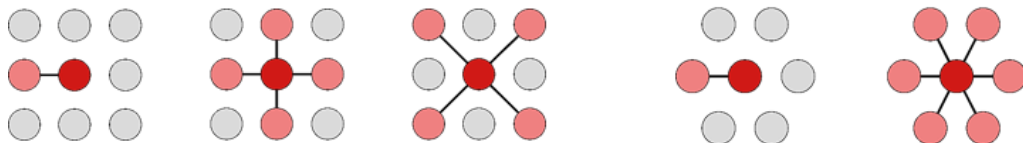
Features:

- Identical qubits based on transitions in optically trapped neutral strontium atoms (basis of currently best optical frequency standards)
- Flexible qubits from 429 THz (optical) to MHz (nuclear)
- Flexible 2D connectivity and scalability
- Qubit lifetimes of many seconds
- Sub-microsecond two- and many-body gates via strong Rydberg interactions

Rydberg-blockade gates



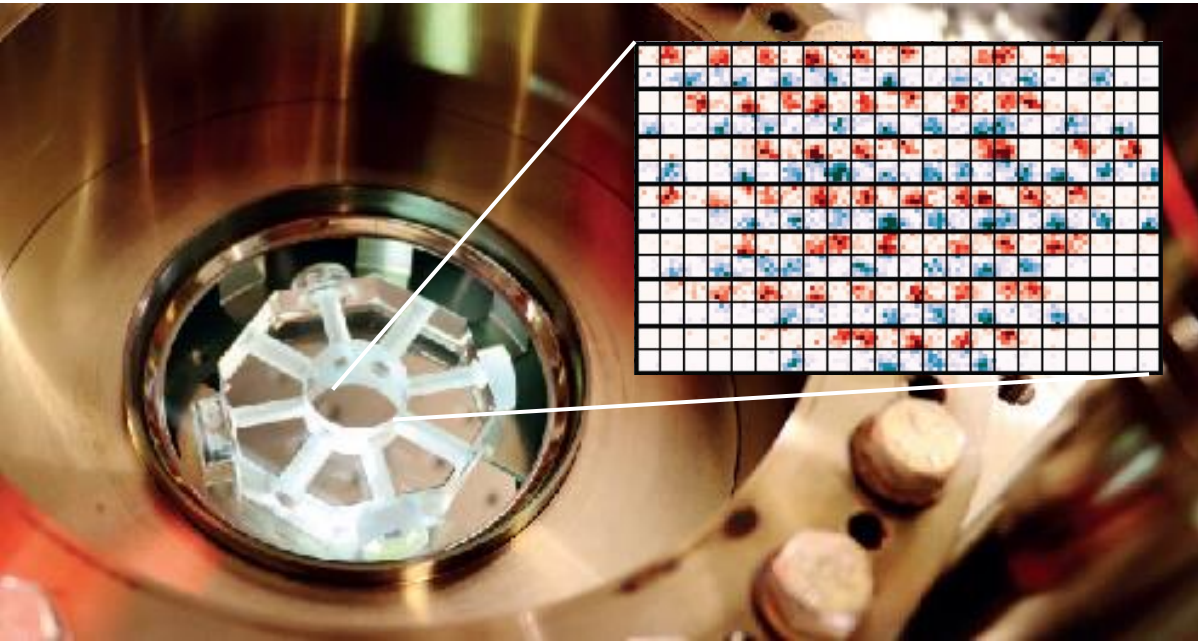
Versatile connectivity



Main challenges:

- Fast single-qubit gates
- Reduction of optical cross talk
- Increase technological readiness level (TRL)

Neutral Atoms

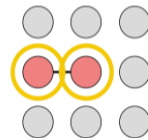


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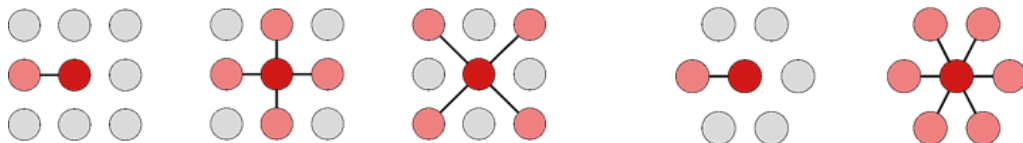
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Rydberg-blockade gates



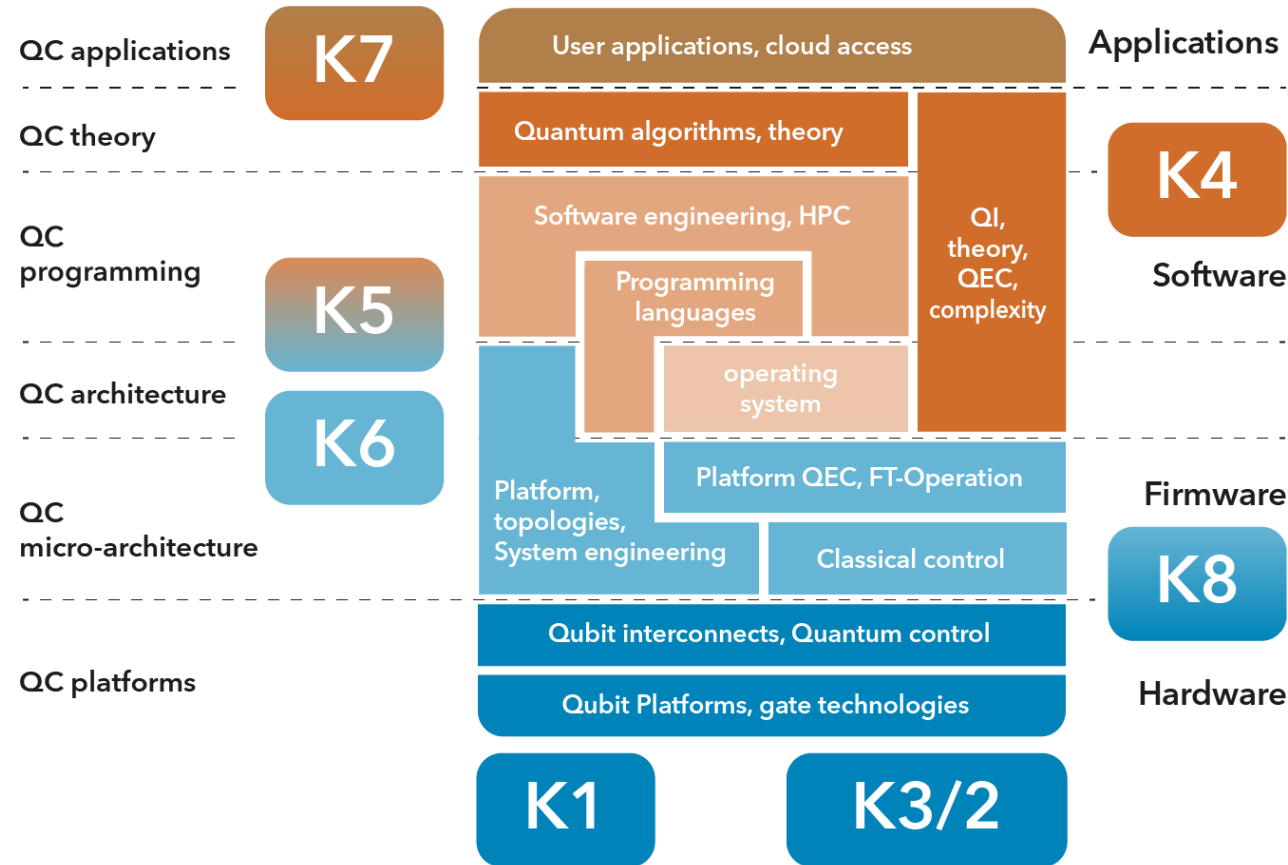
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QC stack-structure and consortia



QST-EB: Quantum Science and Technology Education in Bavaria

QTPE: Quantum Technology Park (QTP), Entrepreneurship

...plus Industrial Partners,
Startups and Lighthouse
Projects

Consortia and people

K1
SQQC



Stefan Filipp, TUM

K3/2 TAQC



Immanuel Bloch,
MPQ & LMU

K4 THEQUCO



Ignacio Cirac, MPQ



Michael Knap, TUM

QST-EB Quantum Science and
Technology Education in Bavaria



Alex Holleitner,
TUM



Jan van Delft, LMU



Florian Marquardt
FAU



Tatjana Wilk,
MCQST

K5
Q-DESSI



Martin Schulz, LRZ

K6
SHARE



Christoph Kutter,
FhG

K7
QACI



Claudia Eckert, FhG

K8
HAT



Steffen Glaser, TUM



Michael Hartmann,
FAU

QTPE
Quantum Technology Park
& Entrepreneurship



Rudolf Groß, TUM



Christopher Trummer,
TUM

Head



Rainer Blatt



Facts & Figures



13 institutes from
Fraunhofer and
Leibniz (4/2022)

SPONSORED BY THE



Federal Ministry
of Education
and Research

Investment of
EUR 350 million
for **infrastructure**
and **future**
developments
(1.4.2017-30.9.2021)



27,7 % female
quota (4/2022)

Approx. **4.500** employees
with **2.635** scientists (4/2022)



893 Publications
(4/2022)



563 Mio FMD Budget
204 Mio EUR industrial revenues
(12/2021)



Our foreign partners come from
38 countries in the world, **21** of
which are in the **EU** (12/2021)



In 2021, we worked together with
almost **1000 companies**, **531** of
which were from **abroad** (12/2021)



19.500 m² cleanroom space
with **ISO9001 certification**; **1**
MES over 10 institutes (4/2022)

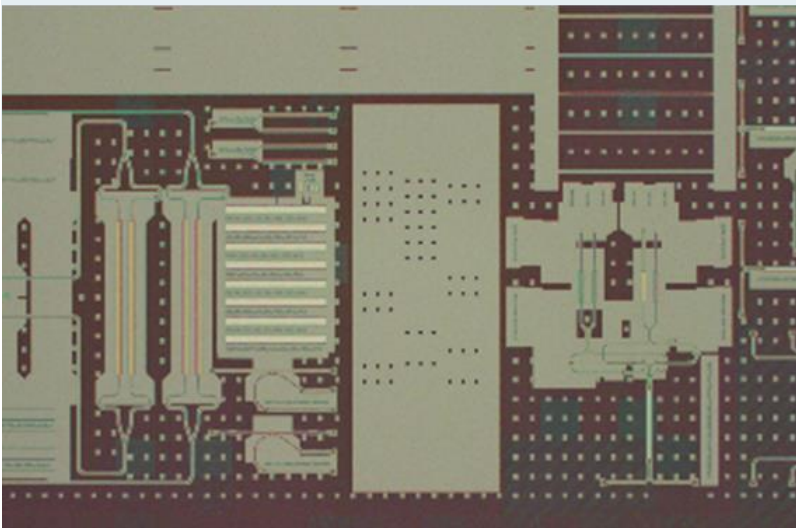


Over **2.200 equipment** in
13 cleanrooms all over Germany
(4/2022)



Mass Manufacturing of Data Center Interconnects

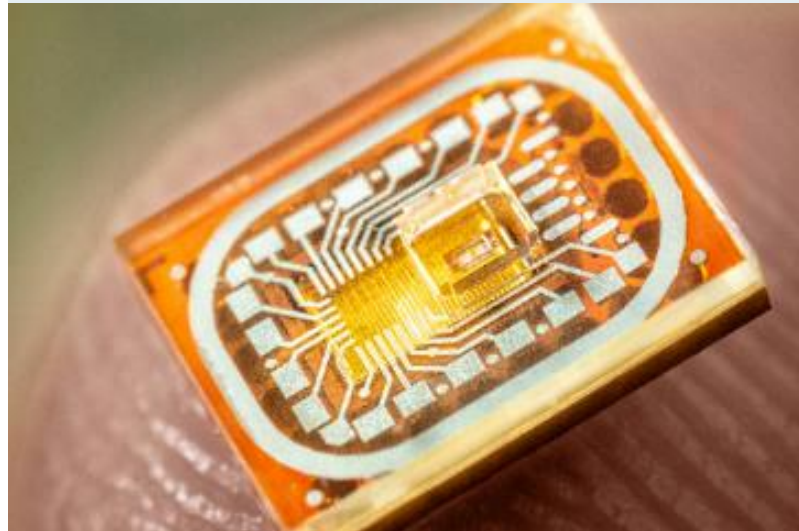
High speed photonic transceiver towards bringing the cost down



TSV process development for inter data center Tb/s coherent transceiver

Glass interposer platform for high-frequency applications

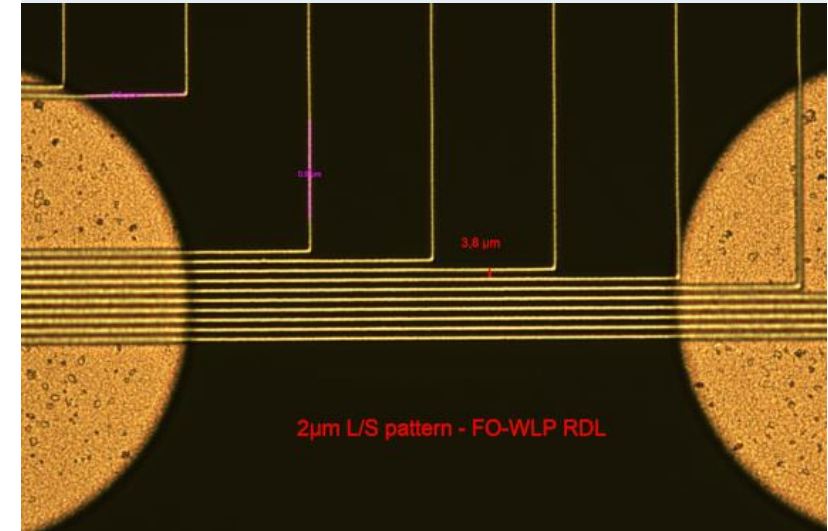
Demonstration of a hermetic glass package for sensors based on Wafer-Level-Technology



Radar front-end for future radar fill level sensors with operating frequency of 160 GHz; extremely compact dimensions 5.9 x 4.4 x 0.8 mm³

High density RDL routing (Polymer based)

Maskless exposure lithography technology for ~1μm L/S Cu RDL formation



Process development for high density RDL 1st FO-WLP (12" Wafer)

Technology Examples

MEMS Micropump – TUDOS

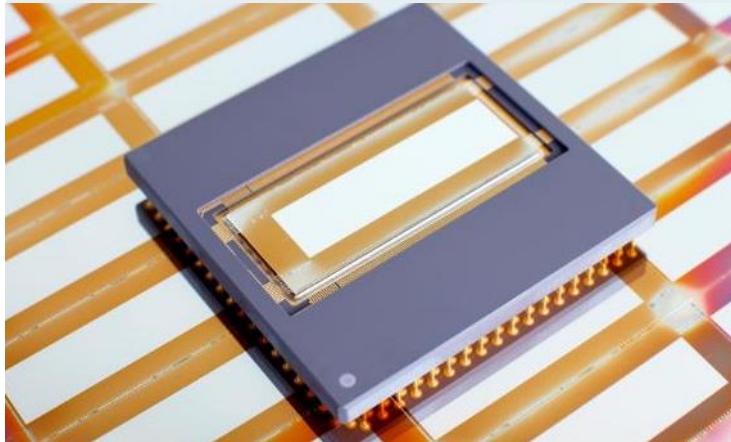
Once a cancer tumor begins to metastasize, the chances of recovery diminish significantly. Fraunhofer EMFT tackled the challenge in the project μ P Brain Test.



*Device for tumor dosing: TUDOS.
© Fraunhofer EMFT*

MEMS/CMOS Integration

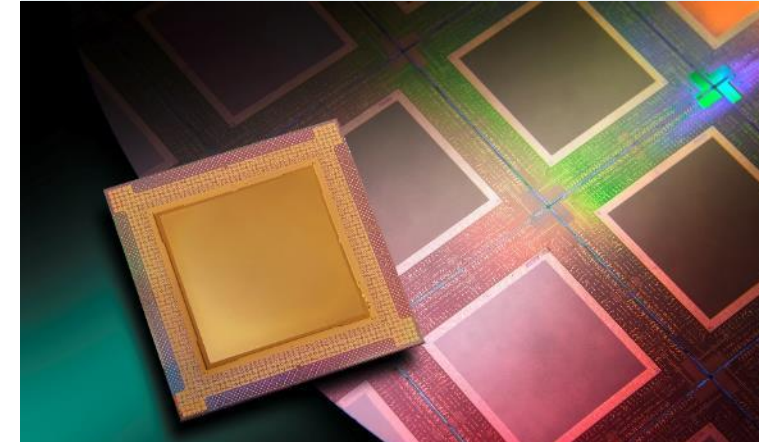
In a well-established, highly productive cooperation, the Fraunhofer institutes IMS and IPMS are developing a process for integrating actuators on CMOS backplanes.



Tilt mirror array with 1 mln. individual mirrors. © Fraunhofer IPMS

Multi e-beam Deflection Chip

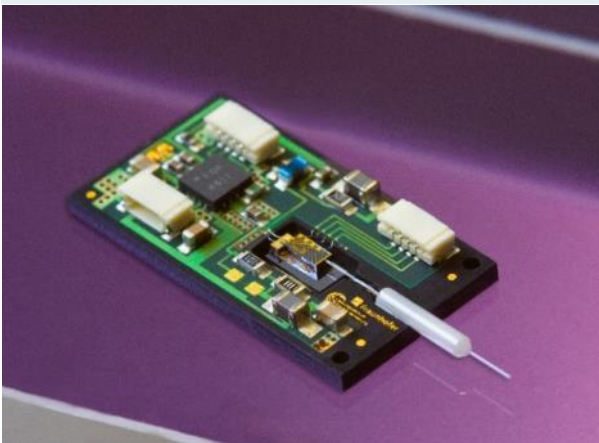
centerpiece of Multi Beam Mask Writing (MBMW) tools for high integration EUV semiconductor production



CMOS/MEMS Chip with 256k individual e-beam deflection units. © Fraunhofer ISIT

Tunable Laser Module

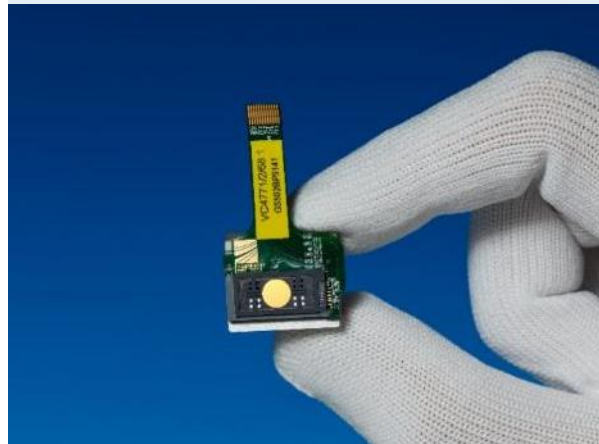
for a broad range of application fields.



*Integrated tunable laser chip.
© Fraunhofer IZM*

External Cavity Quantum Cascade Lasers

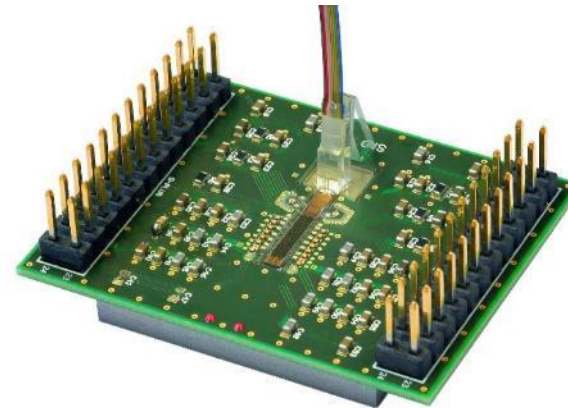
for completely new ways of infrared spectroscopy.



*Scanning MOEMS grating module.
© Fraunhofer IPMS/Jürgen Loesel*

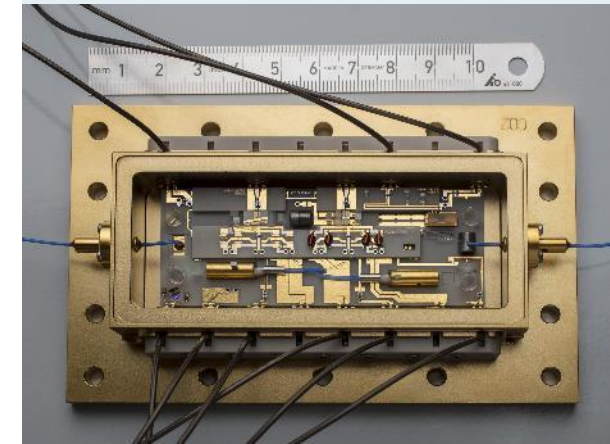
Implementation / Coupling of a Photonic Integrated Circuit

from the cooperation in the BMBF project SPeeD.



Wire bond / grating-coupler variant of the opto-electronic SPeeD-400G modulator chip. © IHP GmbH

Laser Modules for Space Applications

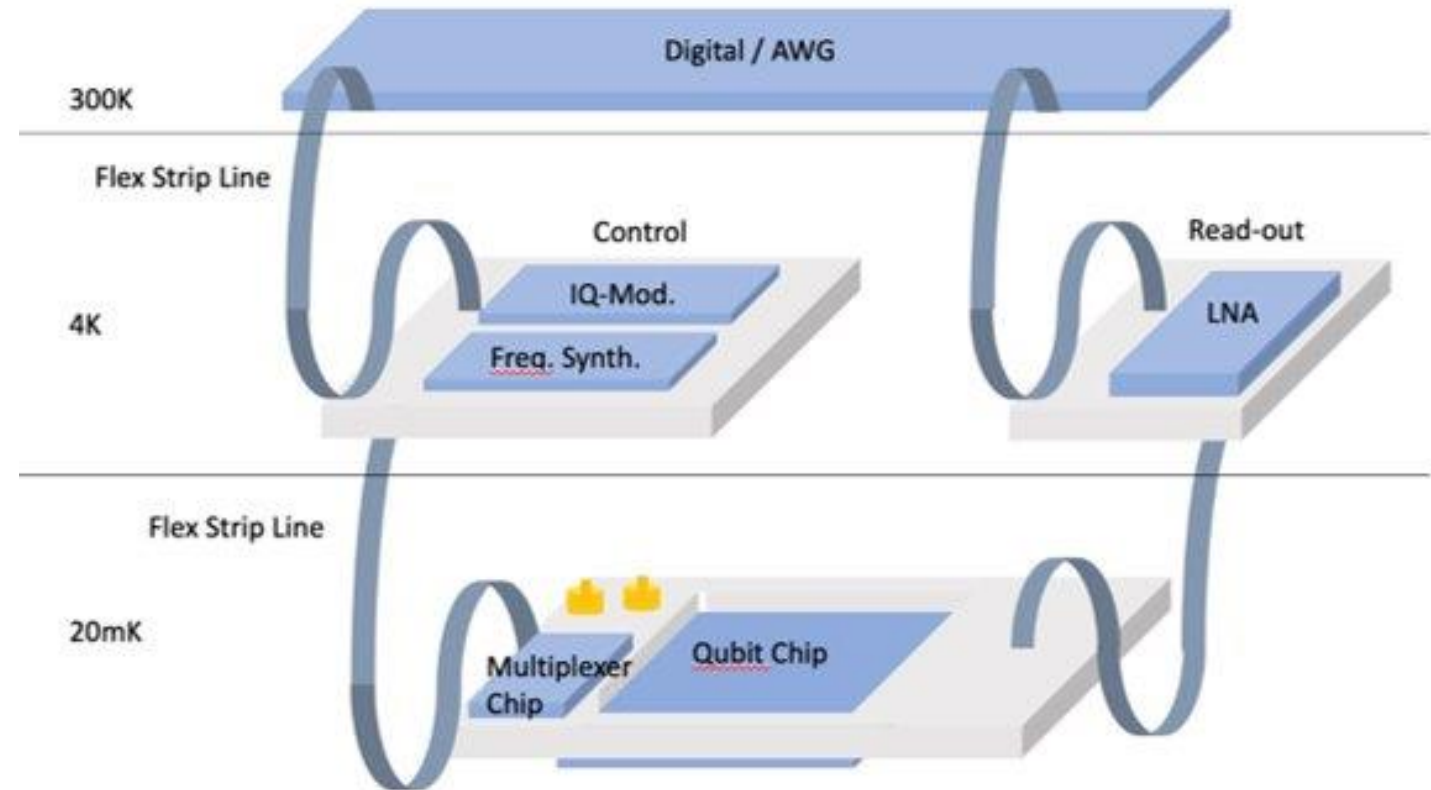


*Successfully used in space: a micro-integrated diode laser module.
© FBH / schurian.com*

K6 SHARE: Scaling and Industrializing of Quantum Computer Hardware

SC Compute Components

- Control electronics for multi channel @ RT and 4K
- 20mK multiplexer
- Qubit system with interposer and 3D integration
- Multichannel LNA
- SC Cables

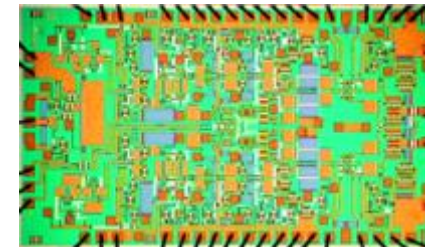
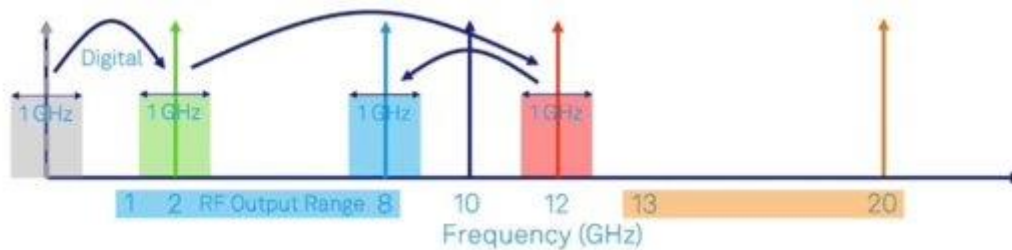
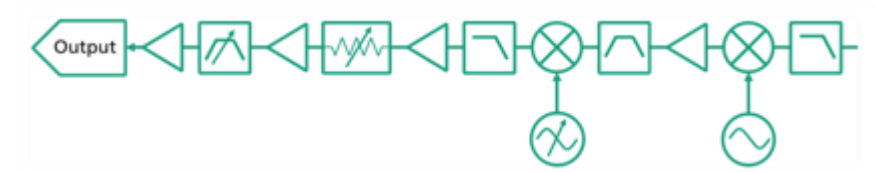


K6 SHARE: Scaling and Industrializing of Quantum Computer Hardware

Multichannel RF Control Signal Generation:

- Intel16 Technology
- Operation at room temperature
- High frequency mixers up to 20 GHz

Integrated Double Super-Heterodyne Transmitter



K6 SHARE: Scaling and Industrializing of Quantum Computer Hardware

Wafer production:

- Fabrication of highly uniform SC Qubit structures
- Use of semiconductor production technology and methodology
- Development of production processes that allow fabrication of 100++ Qubit systems

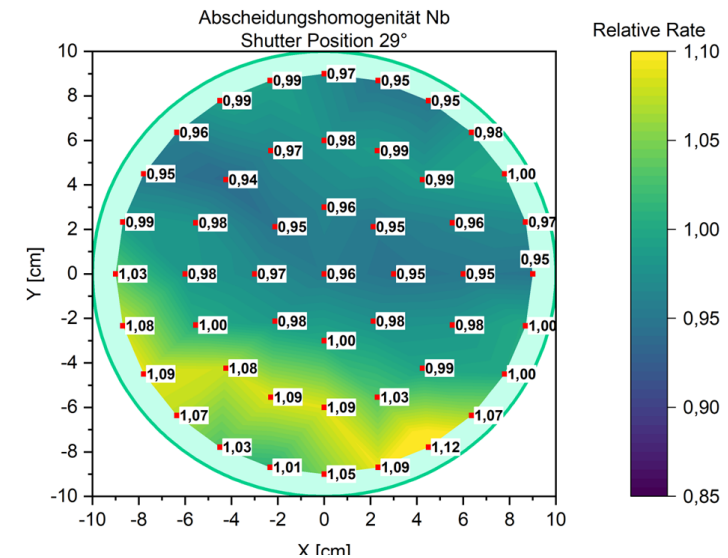
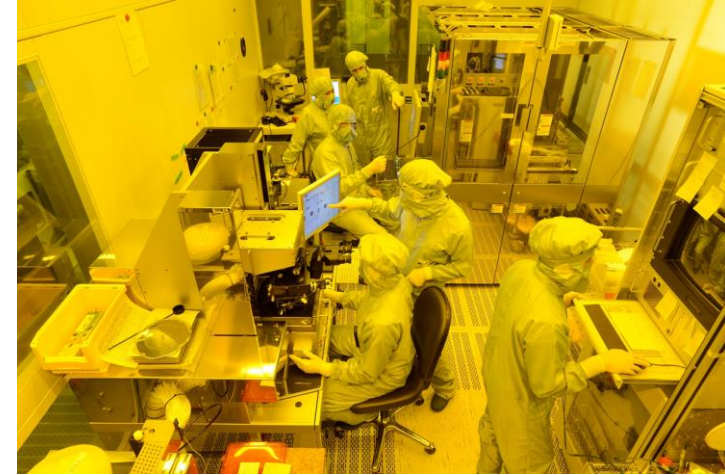


Fig: Homogeneity of sputtered Nb on Si carrier wafer

K6 SHARE: Scaling and Industrializing of Quantum Computer Hardware

3D integration challenges:

- 3D integration architectures for higher density and better Qubit performance
- SC Through Silicon Vias required as key technology (Filling w/ TiN and W)
- Possibility to establish ground planes and separation of technologies to different chiplets

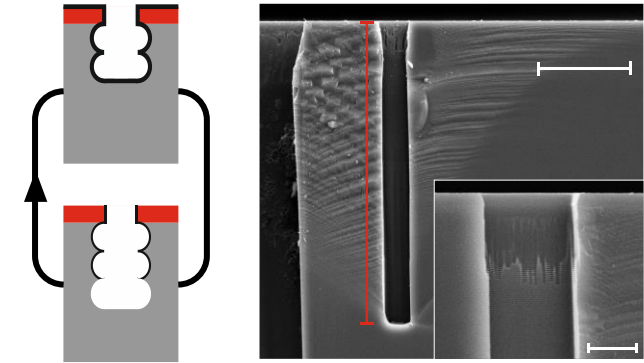


Fig: Through Silicon Via etch – Bosch process

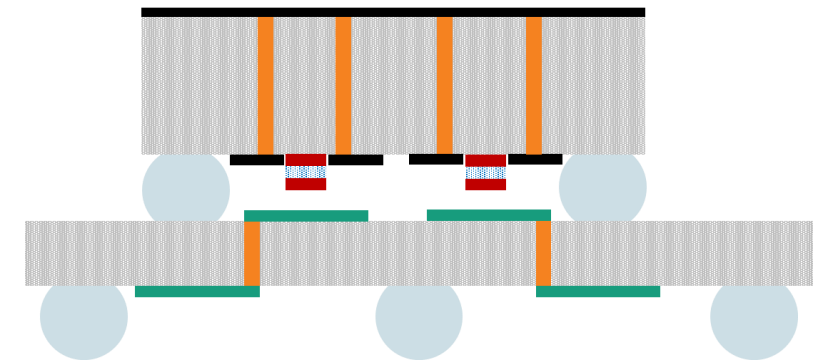


Fig: Concept for 3D integration

K6 SHARE: Scaling and Industrializing of Quantum Computer Hardware

Flexible electronics in roll-2-roll technology:

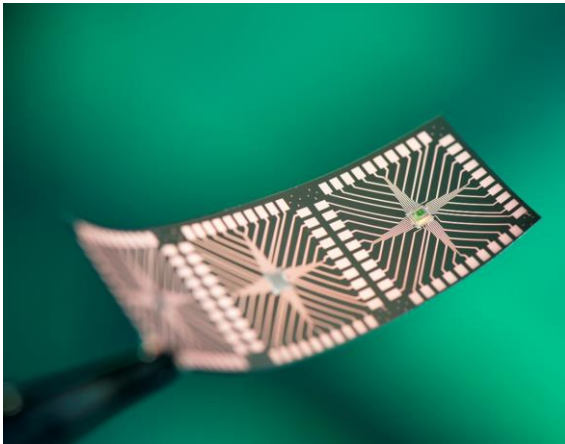


Fig: Chip-foil package



Fig: printed circuit on endless substrate

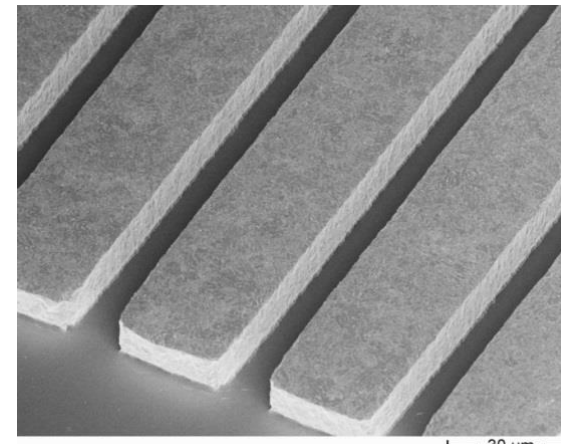


Fig: fine pitch metal lines



Fig: Coax Cable for 40 GHz

K6 SHARE: Scaling and Industrializing of Quantum Computer Hardware

Superconducting cables:

- (>) 100 cables per inch
- Standard 50Ω line impedance (<30db reflection)
- Shielded signal lines to mitigate cross talk (<70db)
- Excellent RF performance
- Good mechanical properties

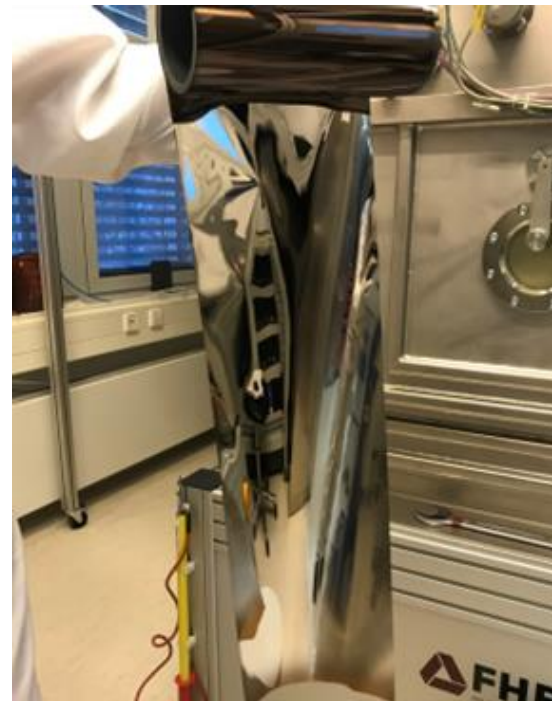


Fig: Roll-2-roll processing for production of SC cable

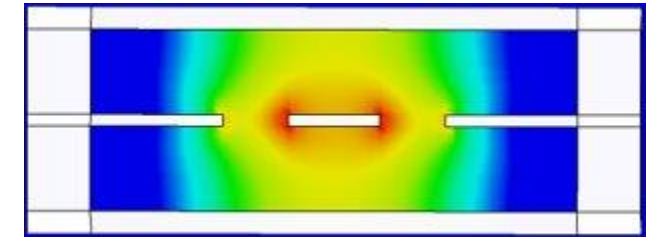


*Fig: em Simulation of cable
Polyimid – Nb center – Cu
shielding*

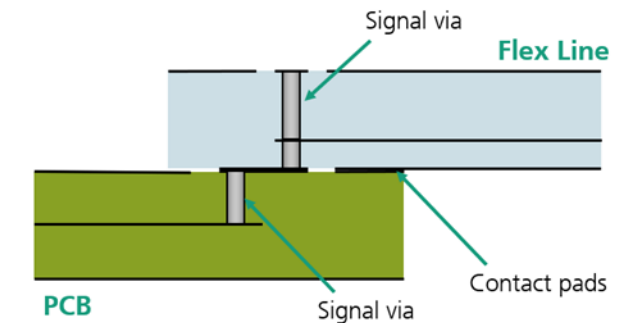
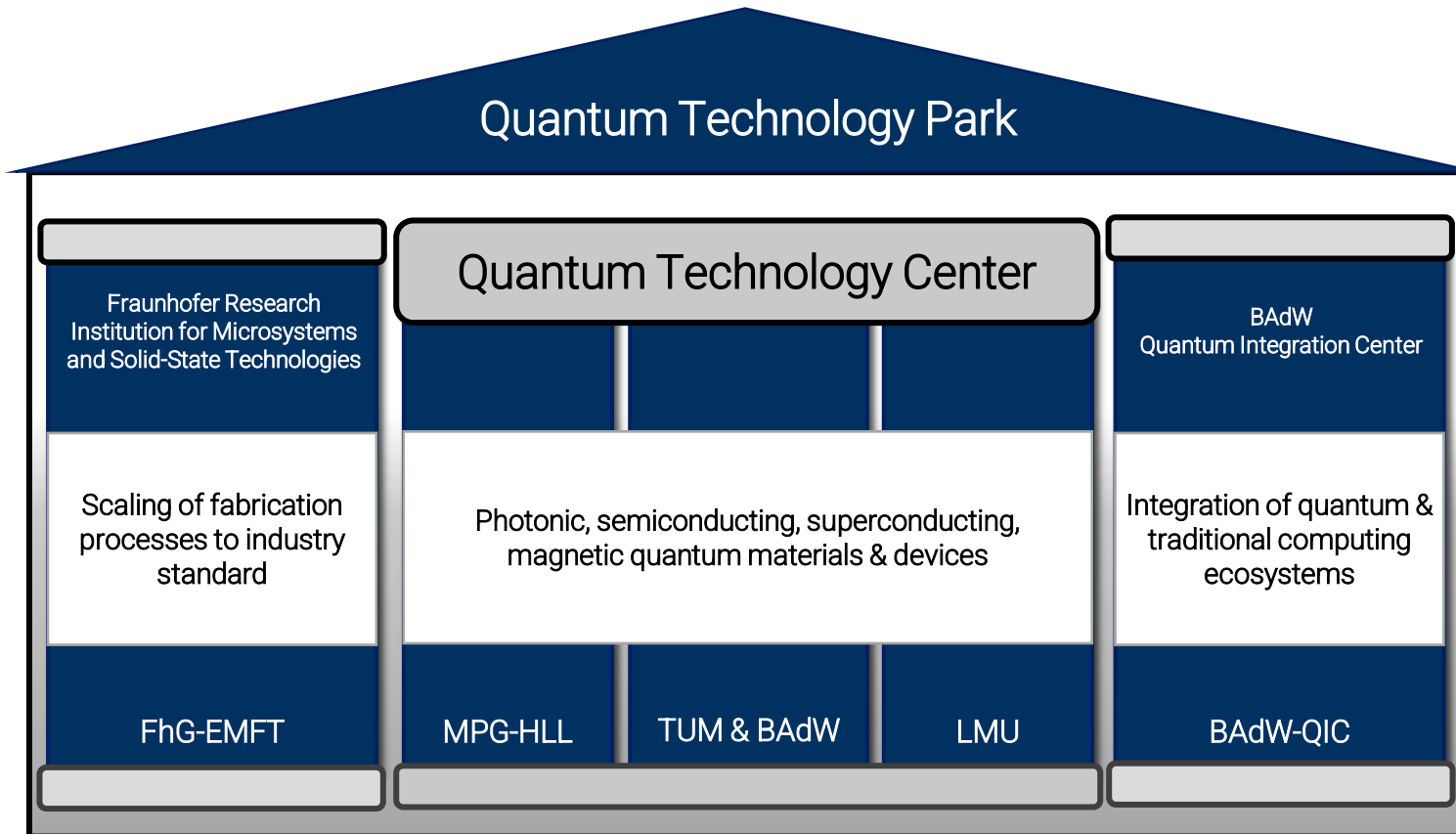


*Fig: Connector concept for
SC cable*

QTP: Building the infrastructural framework for a leading quantum ecosystem in Munich & Bavaria



Setup & goals of the QTP:

- Connected state-of-the-art infrastructure elements as basis for a leading quantum ecosystem
- Decentral **five pillar structure** covering all major fields of quantum tech leveraging existing plans & locations
- Key goals of the QTP:
 - Improved technological **knowledge transfer** between institutions
 - Accelerated transfer from research stage to **commercial grade solution**

MQEC: Driving entrepreneurship in quantum tech & support the translation into innovative businesses

Munich Quantum Entrepreneurship Center



Drive **entrepreneurial mindset** & **support teams** on their founding journey

Build **tailored support structures** for quantum tech founders



Support **external start-ups** with their relocation or partial move to Munich

Strengthen the **local ecosystem** & key connection to international start-ups

Goals of the MQEC:



Attract and retain quantum research talent through appealing professional perspective

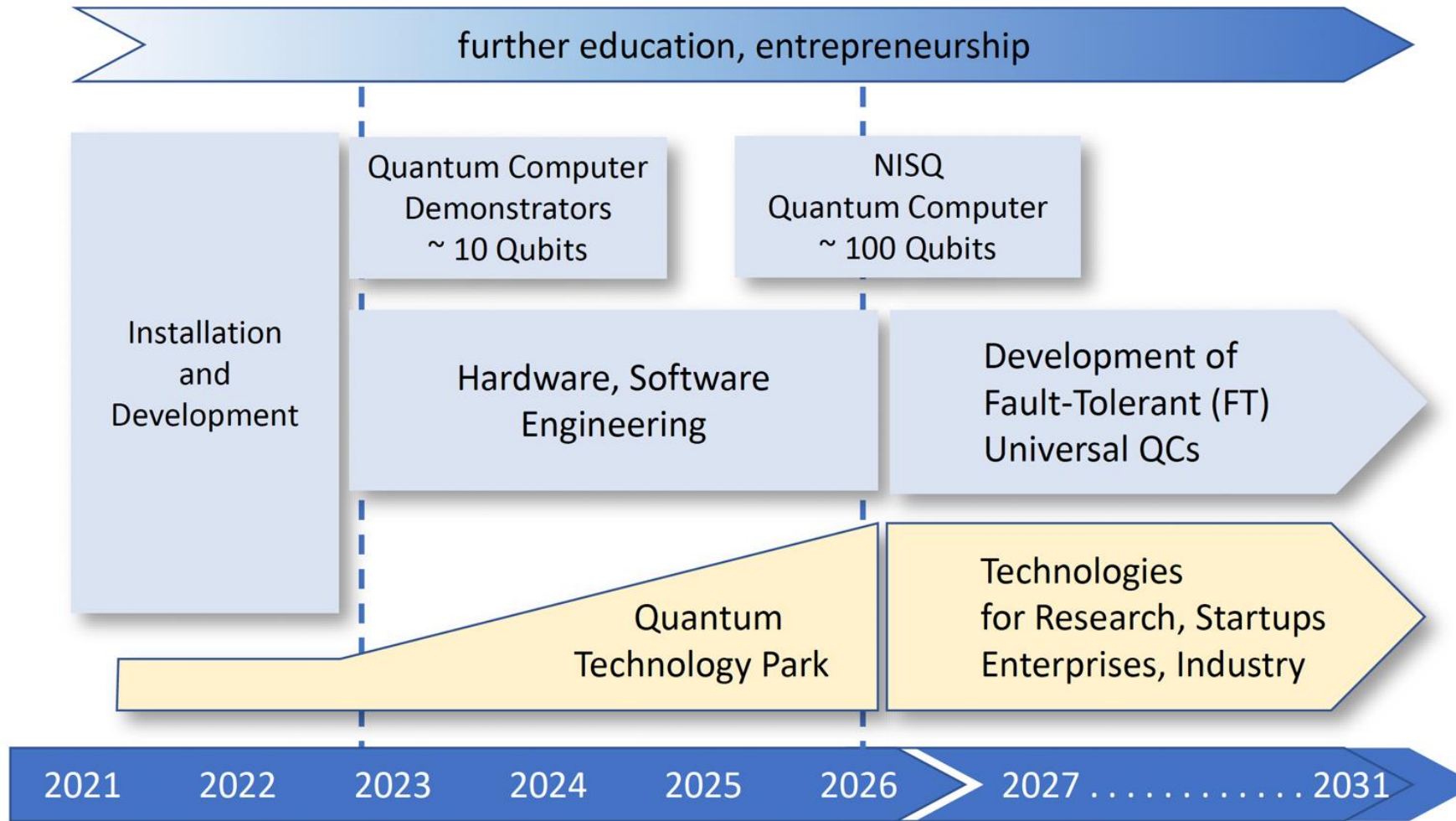


Attract global **capital** via promising investment opportunities



Create economic value and jobs through scalable quantum start-ups

Roadmap





THANK YOU FOR YOUR ATTENTION.

www.munich-quantum-valley.de