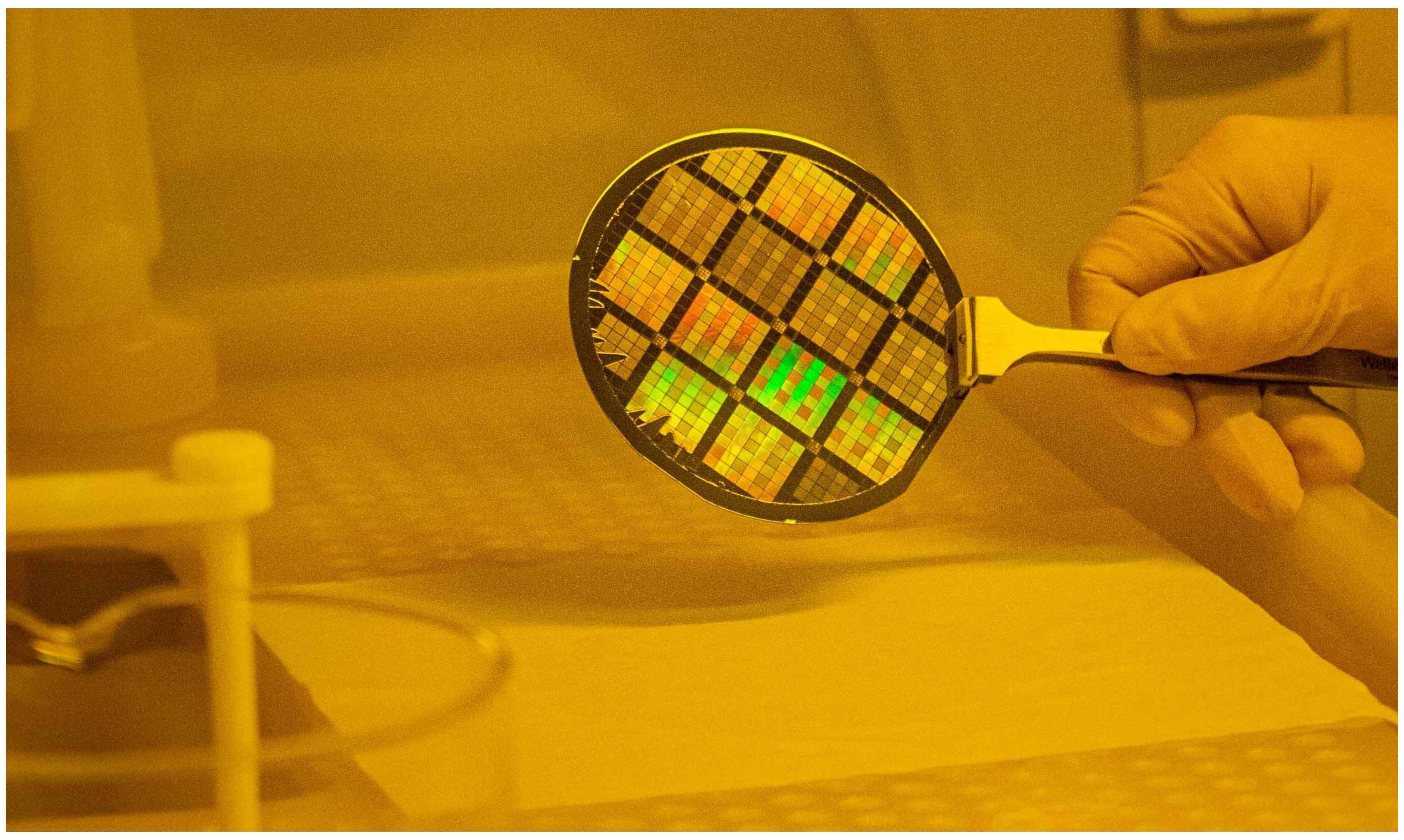
# Enabling technologies for ion trap based quantum computers

This hardware project focuses on the development of enabling technologies and microtechnological manufacturing processes for ion trap based quantum computers, including:

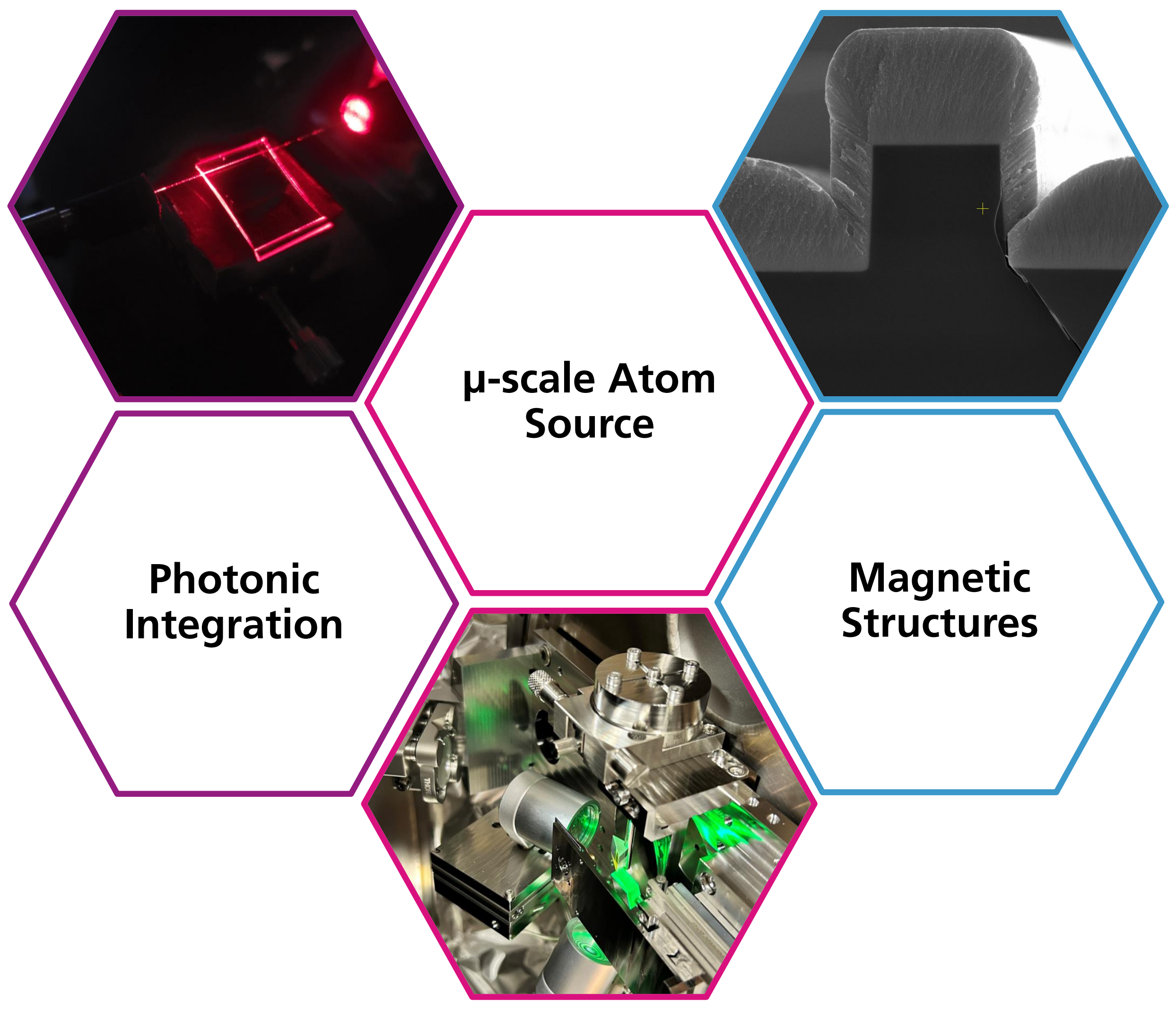
1. Photonic integrated circuits, within trapping chips or used as interposer technologies
2. A miniaturized atom source, featuring light-induced backside loading of atoms
3. Micro-scaled, permanently magnetic layers and their magnetization

- Enabling Technologies
- Ion-Traps



## Motivation

Scalability is a major challenge for the development of large scale quantum computers, hindering their ability to address meaningful tasks. One obstacle is the scaling behavior of peripheral systems when ramping up the qubit number. We are tackling essential issues through the development of enabling technologies, which facilitate the integration of peripheral components into modern ion traps. Our aim is to accelerate the developments of our industry partners and enable an increase in the overall scalability within their quantum processors.



μ-scale Atom Source

Photonic Integration

Magnetic Structures

## Goals

**Photonic Integration**

- Development of optical interfaces, particularly directly written waveguides in glass and SiN based waveguides, that can be integrated in ion traps
- Characterization of the optical waveguides in terms of their losses and damage threshold behavior

**μ-scale Atom Source**

- Development of a miniaturized atom source that allows to load ions into the trap via backside loading
- Characterization of ablation thresholds for different source materials with a 1064 nm nanosecond pulsed laser

**Magnetic Structures**

- Development of on-chip, μm-scaled, hard magnetic structures
- Controlled, directional and individual magnetization of single magnetic structures on sub-millimeter scale

## Outlook

After the development of a demonstrator for each technology component, the focus will shift to integrating those into state of the art ion trap systems. The goal is to merge the two topics of "photonic integration" and "μ-scale atom source" into an atom source architecture that accommodates multiple loading zones and can be operated without the use of a free beam laser setup.

For hard magnetic SmCo-layers, the process development to reliably fabricate a crystalline phase is challenging. In combination with the development of a magnetization tool, for precise control over local magnetizations, this technology will enable a new way of engineering complex magnetic fields on the micro- and mesoscale.

Though current efforts revolve around ion traps for quantum computing, possible use cases also include many applications within the fast-growing quantum communication and sensorics sector. We aim to expand further into these fields by developing and supporting relevant enabling technologies for quantum systems, with the focus on miniaturization and scalability, and also through the improvement of available test- and characterization-setups and microsystems fabrication processes.

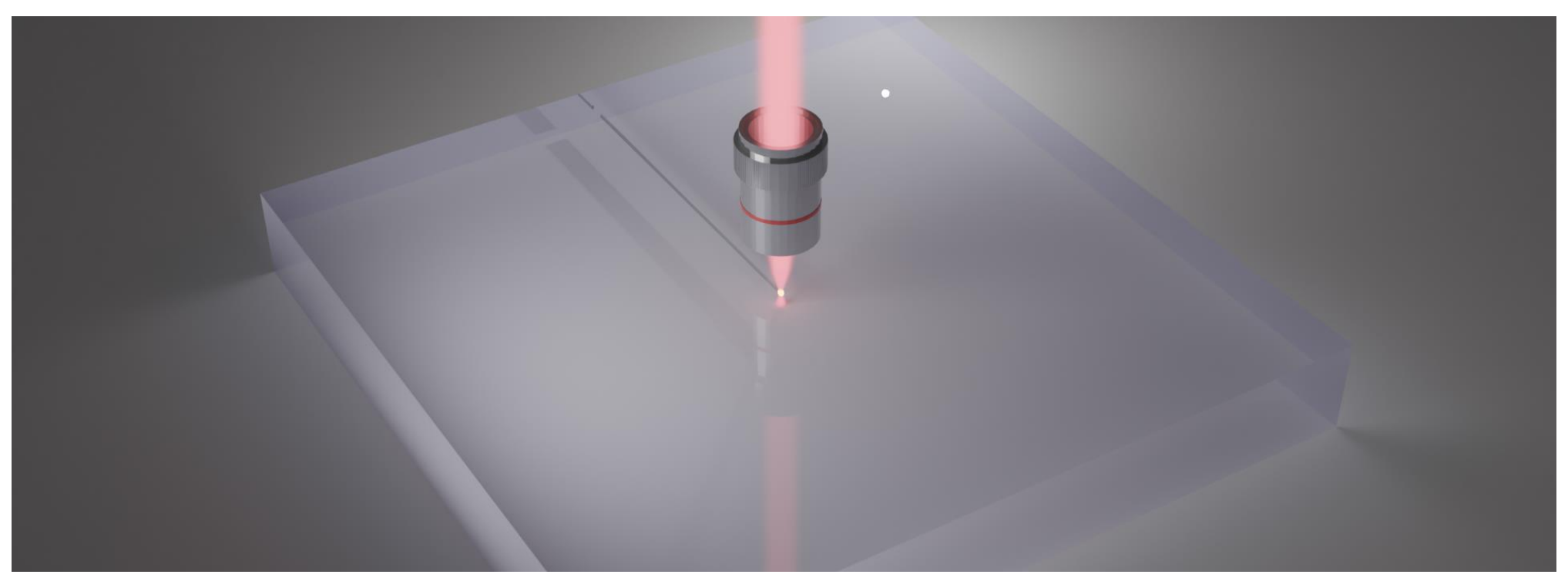
**Mehr Infos zu dem Projekt finden Sie auf unserer Website.**

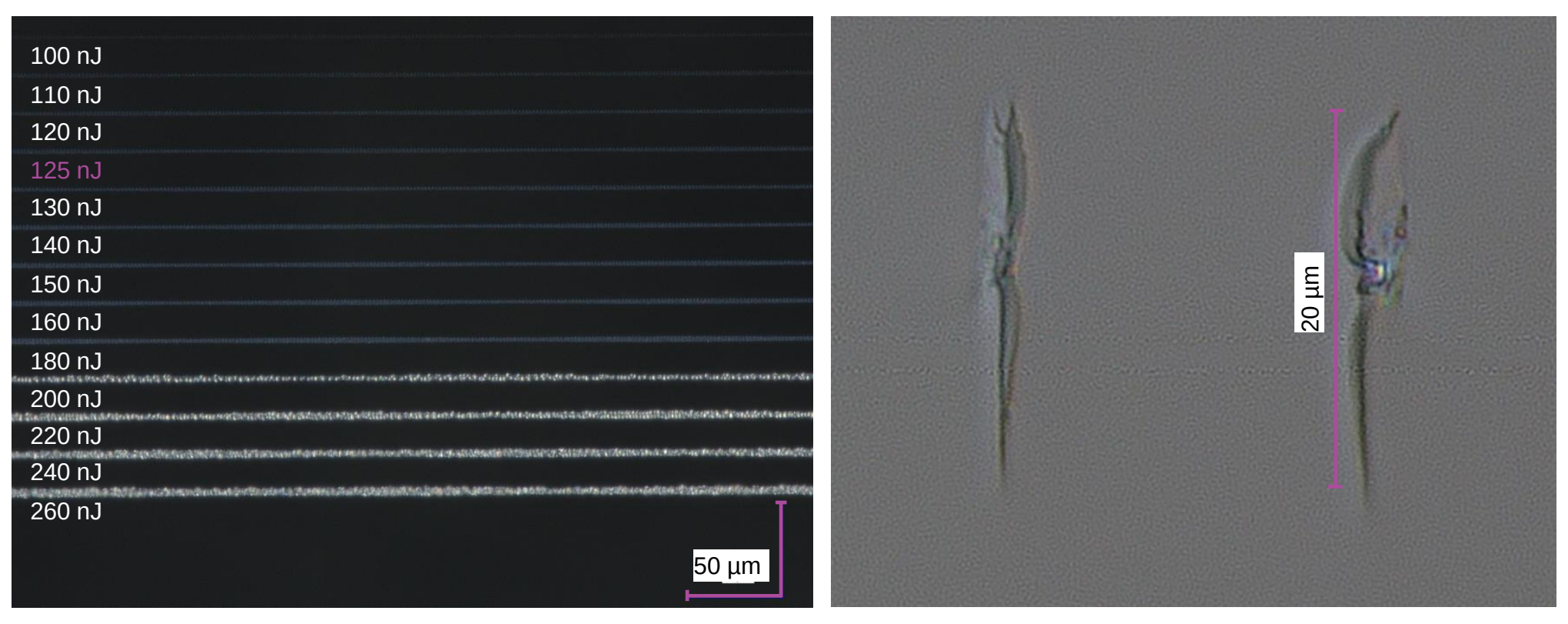
## Photonic Integration

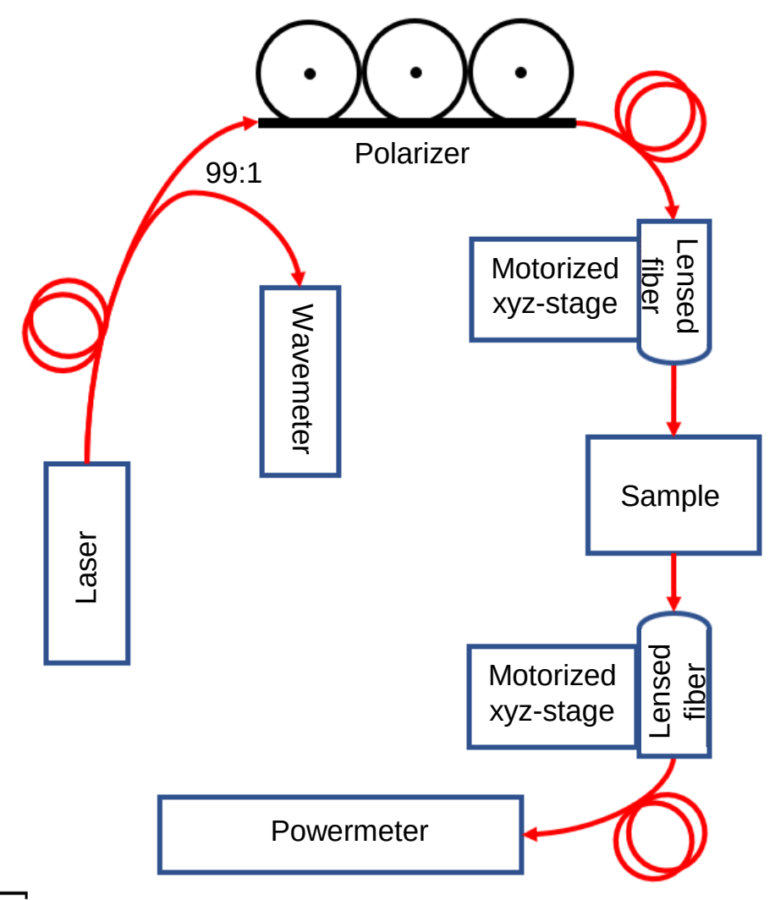
### Fabrication

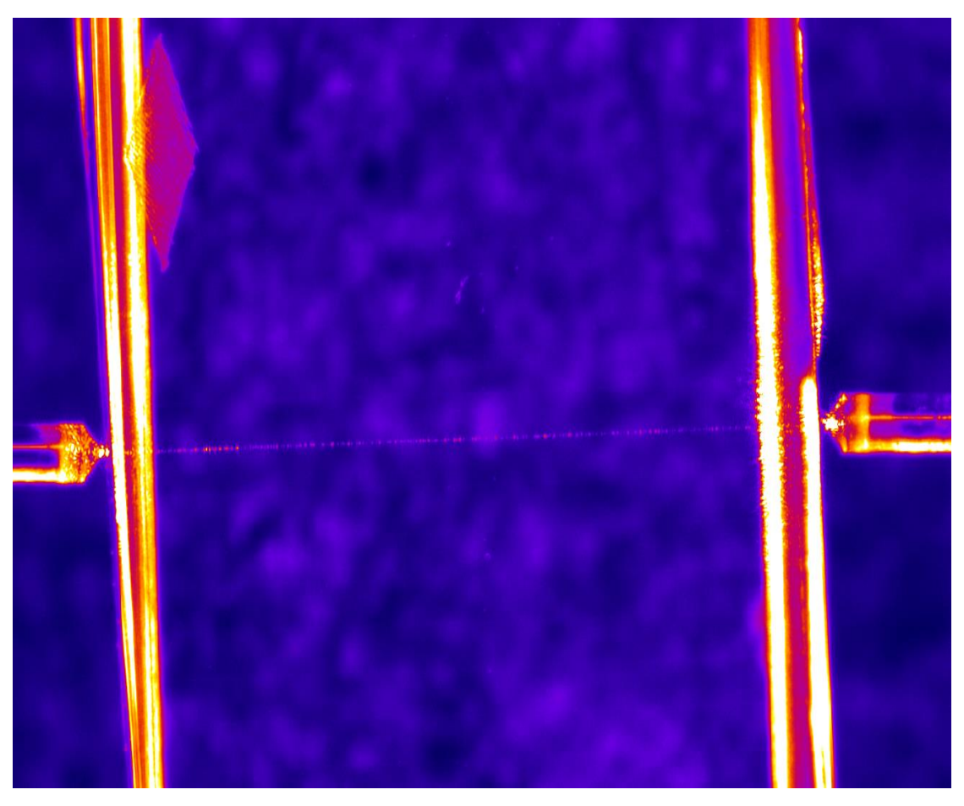
For the photonic integration, optical waveguides are being fabricated through two different process flows:

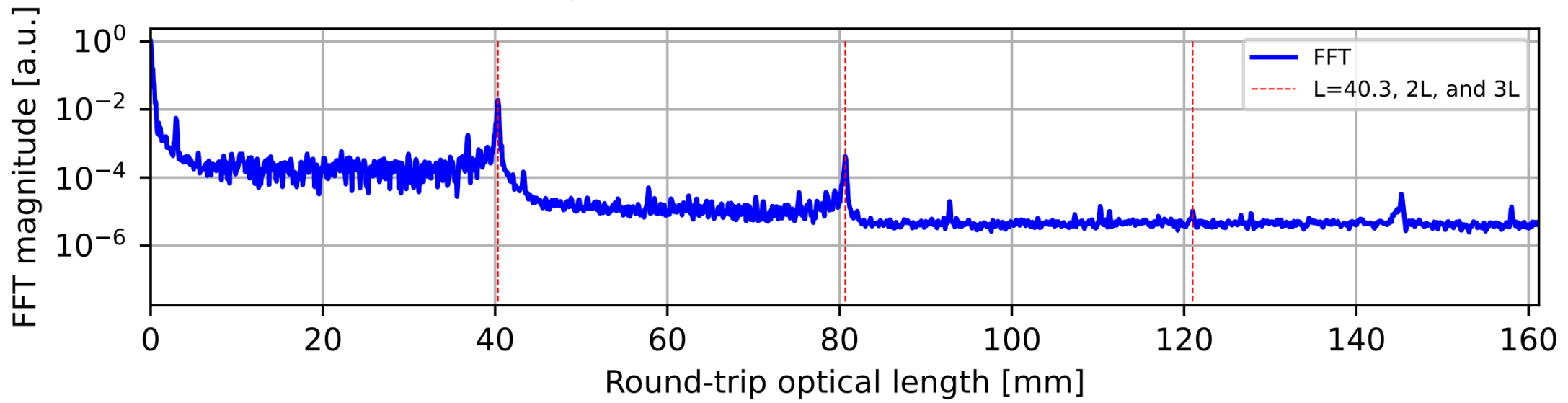
1. PECVD grown SiN waveguides that have been structured through UV-Lithography and a subsequent ICP-RIE etching step
2. Directly written waveguides that are fabricated in glass through the exposure by a fs-laser











### Testing

To characterize optical waveguides, we built a testing setup, within which light is coupled into the waveguide, via endfire-coupling. The light is partly reflected on the interfaces, leading to the creation of interference effects. Those interference effects are dependent on the wave-length of the incident light. If the wavelength is varied systematically and the outcoupled signal analyzed via a Fourier analysis, one can determine the intrinsic losses within the optical waveguide.

## μ-scale Atom Source

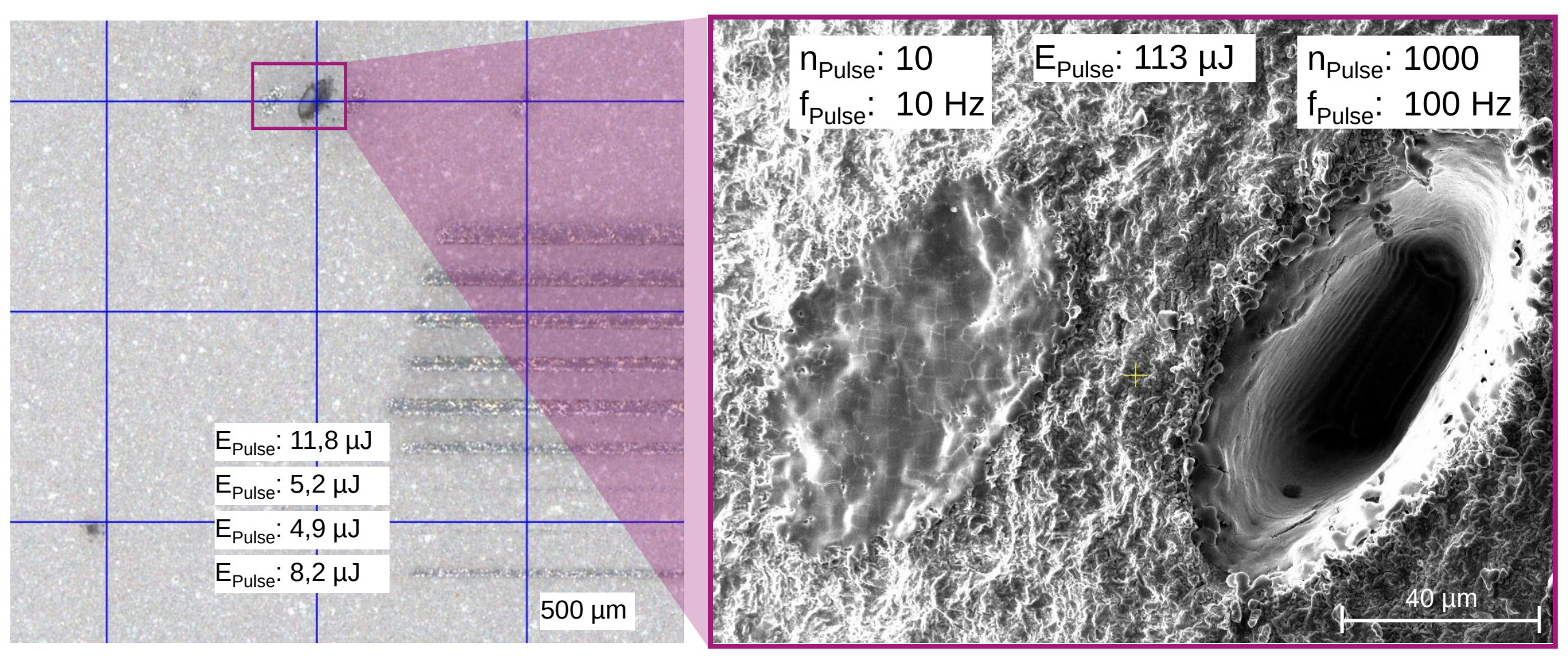
### Development

The development of a miniaturized atom source aims for a set of advanced characteristics to enable fast, reliable and efficient loading of atoms into chip-based ion traps. It supports an adaptable design to accommodate various layouts of loading and trapping zones, as well as other ion trap interfaces. Key characteristics are the atom generation via laser ablation and a backside loading configuration, all based on microfabricated components and compatible substrates.

Controllable atom generation

Backside loading

Integrated Ablation



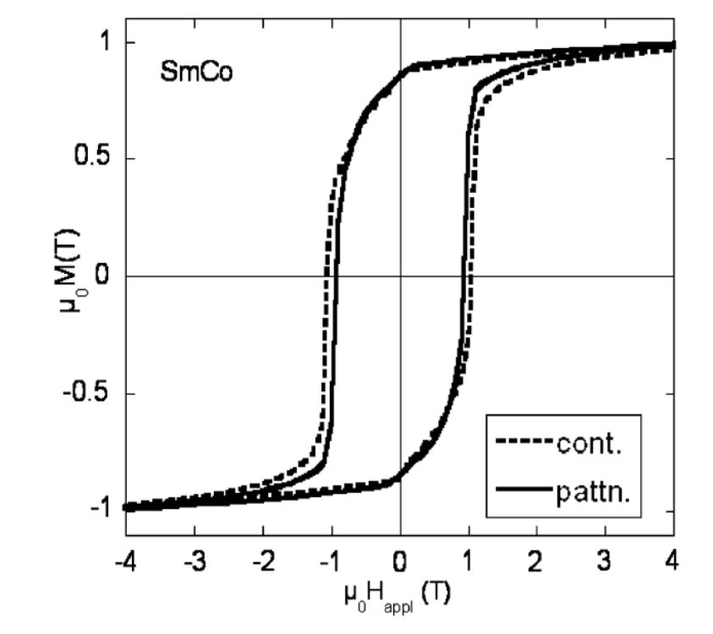
### Laser Ablation Setup

To explore feasible target materials, for different atom species to be trapped, we built a UHV (10E-8 mbar) ablation setup, including a hollow core fiber based beam launching system which can deliver short and ultra-short pulsed lasers with peak powers of up to 50 MW. With spot sizes of ≥20 μm, the ablated atoms are detected and analyzed by a quadrupole mass spectrometer. We thereby aim to characterize a set of potentially compatible materials for a given atom species, which could be enriched with a specific isotope and ideally combine low ablation thresholds with good handling characteristics. First experiments with a 1064 nm ns-pulsed laser led to estimated ablation thresholds of Yb (0.4 J/cm²), $Yb_2O_3$ (0.5 J/cm²), YB:YAG (9.8 J/cm²) and SrTiO3 (1.2 J/cm²).

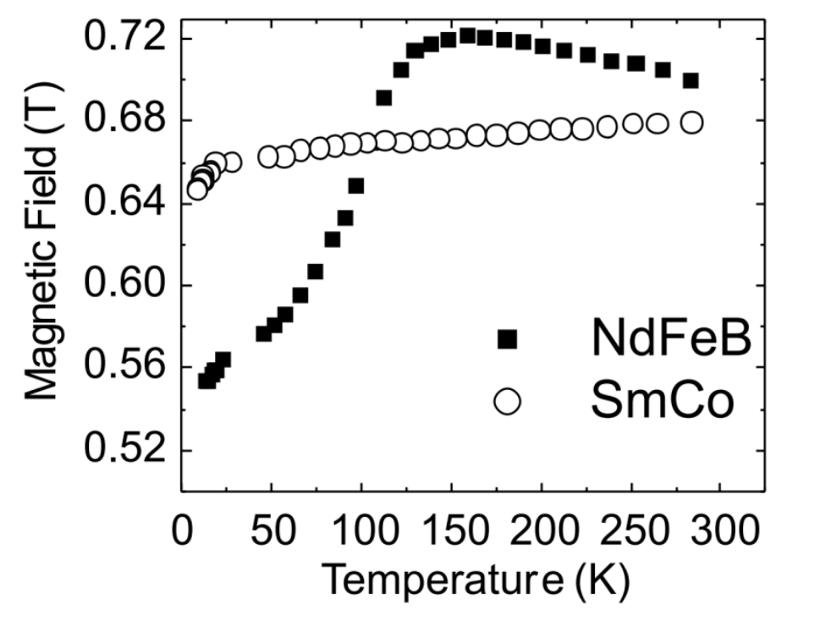
## Hard Magnetic Microstructures

### Manufacturing process

We focus on the development of physical vapor deposited (PVD) layers of hard magnetic SmCo-phases with low Sm contents of below 20 at%. They exhibit excellent magnetic properties including a high remanence of ~0.6 T which is thermally stable over a wide temperature range. Since ion trap based QCs are operated at very low temperatures, SmCo phases are superior to $Nd_2Fe_{14}B$.



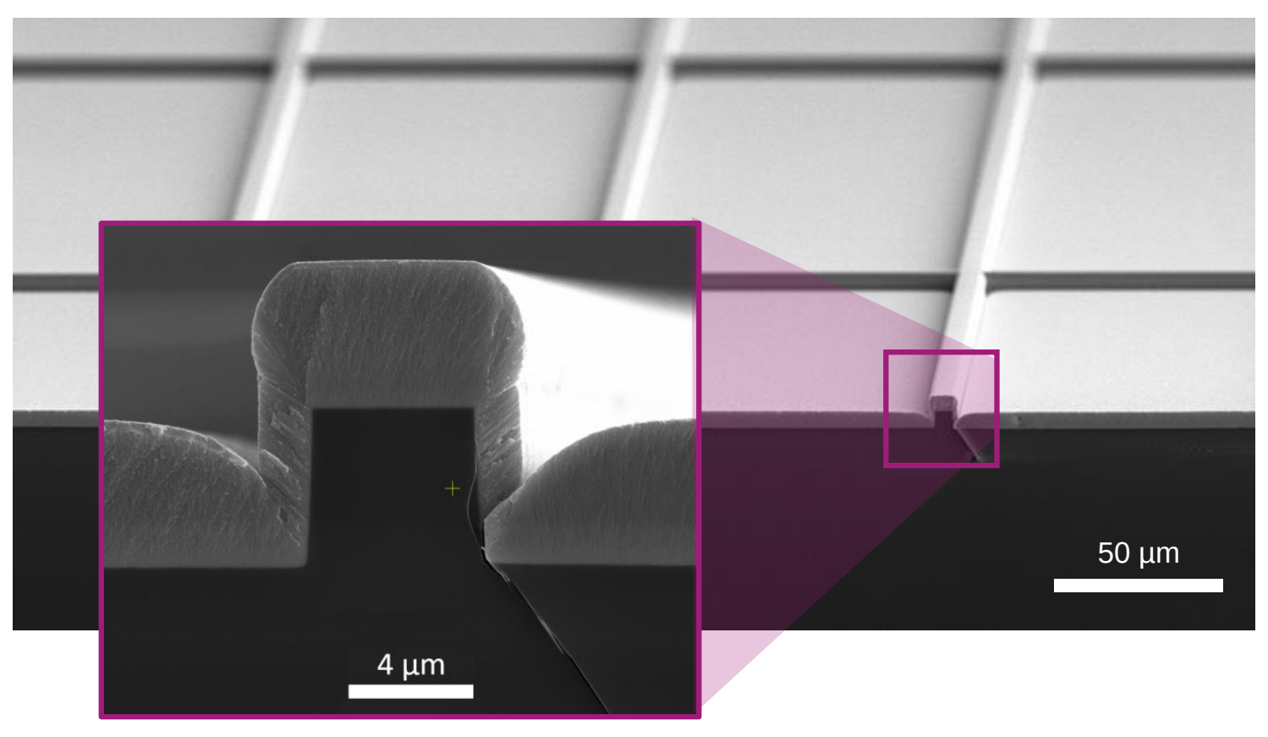
*Hysteresis curve of SmCo (Walther et al. 2009)*

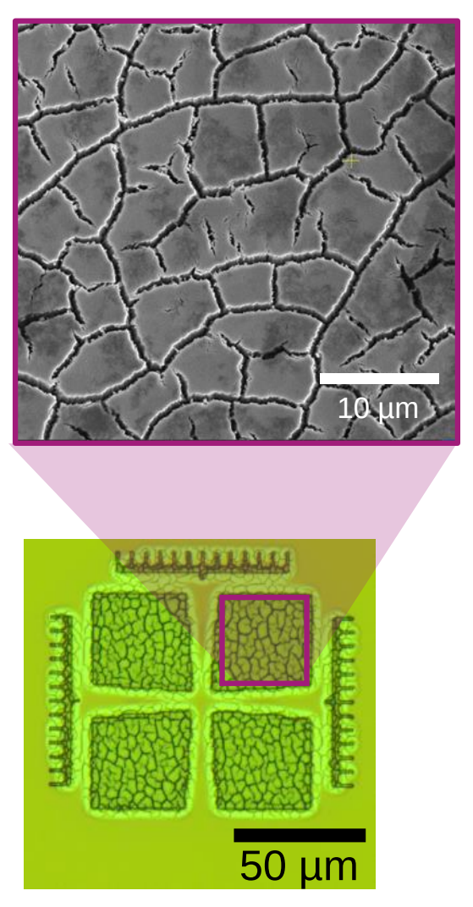


*Thermal stability of SmCo (Fredricksen et al. 2003)*

The integration of hard magnetic materials consists of several steps:

1. Layer deposition on plain or structured substrates, e. g. Si(100)
2. Annealing of amorphous layers obtaining suitable SmCo-phases
3. Subsequent planarization (on structured substrates) or etching step (on plain substrates)





*Pre-structured substrate deposited with SmCo (top) and wet-etched SmCo layer (right)*

### Experiments

Despite the non-optimal filling degree at the edges, our first experiments on pre-structured Si(100)-wafers show encouraging results. The following planarization process is under development and requires a suitable slurry to gently oxidize the surface layer.

Following a different approach, amorphous Sm-Co layers might exhibit inhomogeneous wet etching behavior which requires a careful adaption of the solvents' composition. In addition, some experiments using $Cl_2$-based ion beam etching resulted in low etching rates as well as low selectivity towards the photoresist soft masks, indicating purely physical plasma dry etching.

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**We enable quantum!**