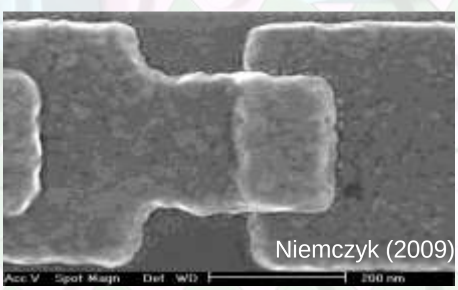
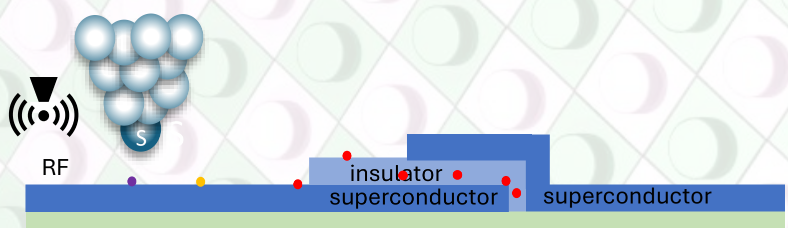
STM based Josephson Junctions
BSc/MSc Project

One key application of superconductivity is the development of superconducting qubits, which are set to serve as the foundation of quantum computers. However, the problem with these qubits is their limited coherence time, which is affected by microscopic effects within superconductors. Decoherence happens when qubits interact with their surroundings, causing loss of quantum information and errors in quantum computations.

Join our cutting-edge project where we grow niobium on beryllium substrate to use as one component of Josephson junction. Collaborate on experiments using scanning tunneling microscopy (STM) to test and understand the factors that influence quantum decoherence times—a key challenge in advancing quantum technologies.





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Correcting Creepy Moves

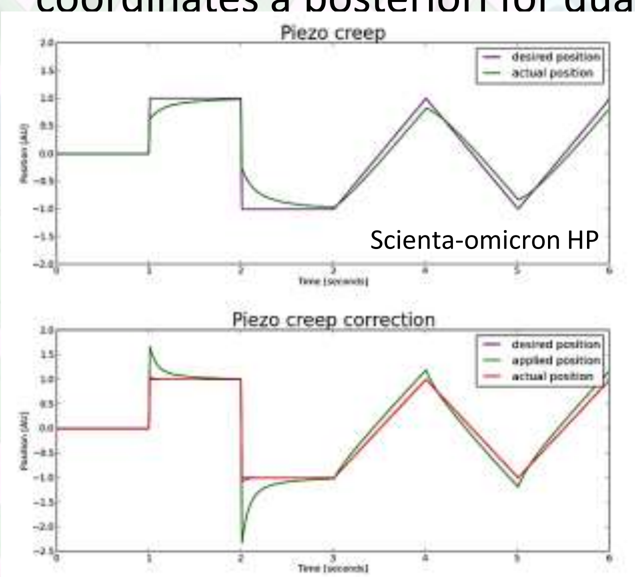
(characterizing and compensating for nonlinearities in a piezo scanner)

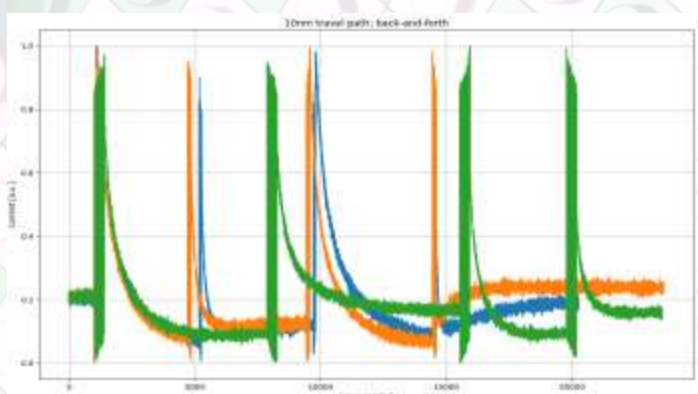
BSc/MSc Project

A piezo-tube is a ceramic component that allows arbitrarily fine adjustment of its length by the application of a voltage. This is very useful for positioning devices, which is why it is at the heart of a scanning probe microscopes, enabling atomic resolution and manipulation capabilities at microscopic length scales.

Unfortunately, piezo scanners exhibit nonlinearities when the voltage is changed, which makes it difficult to accurately position or know the location of the tip.

This project aims at characterizing the creep and hysteretic behavior of a low-temperature scanning tunneling microscope to either remove the nonlinear effect during measurement or to correct the coordinates a posteriori for quasiparticle interference imaging.





Courtesy Kevin Hauser

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In tune with spin qubits – Spin Resonance

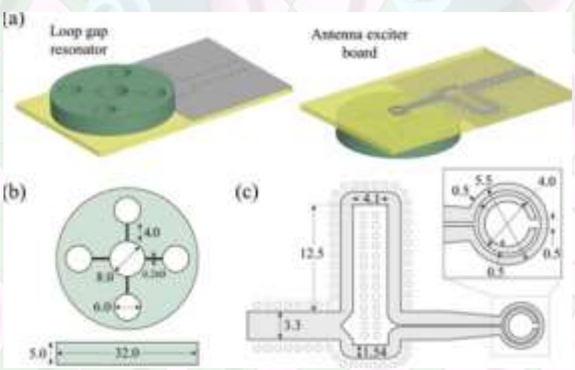
(convert high-frequency electrical into magnetic field)

BSc/MSc Project

Electron Spin resonance with the scanning tunneling microscope operates at the single atom limit. This unique tool combines atomic resolution of scanning probe microscopy with the excellent energy resolution of electron spin resonance that enable the study of single atom magnets, magnetic molecules, molecular qubits, and artificially built quantum matter.

However, the working principle of ESR-STM presently depends on a rather indirect piezo-effect between the STM tip and the adatom, only compatible with few sample systems.

The goal of this project is to design microscopic resonators that make ESR-STM independent of specific substrates. The microresonator directly produce RF fields in proximity of the qubots and should be compatible with the geometry of a scanning tunneling microscope.



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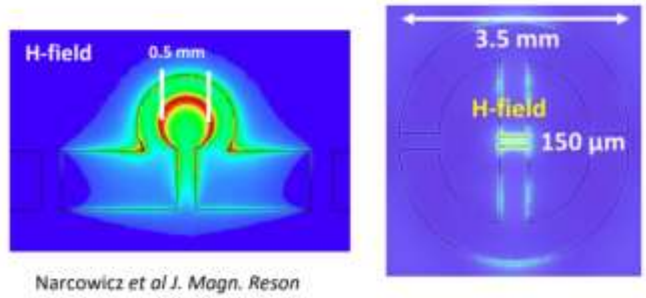

Narcowicz *et al J. Magn. Reson* **2005** *175* 275

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“What’s your time, wavelength?”

(building a time-of-flight spectrometer)

BSc/MSc Project

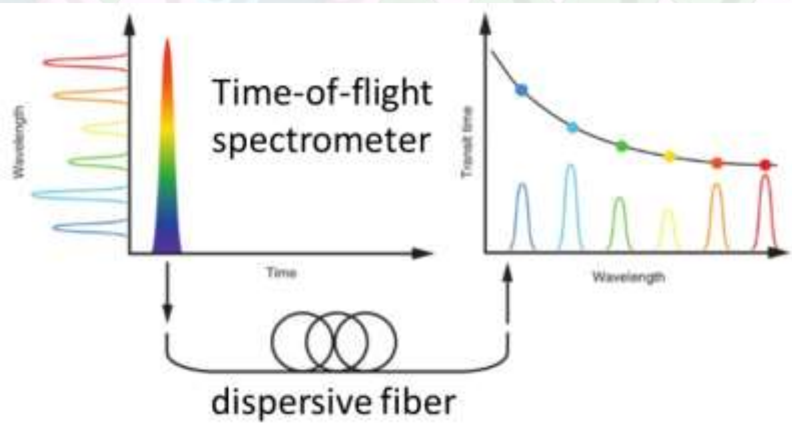
The wavelength and intensity at which photons are received carries a wealth of information about the physical processes that lead to their emission.

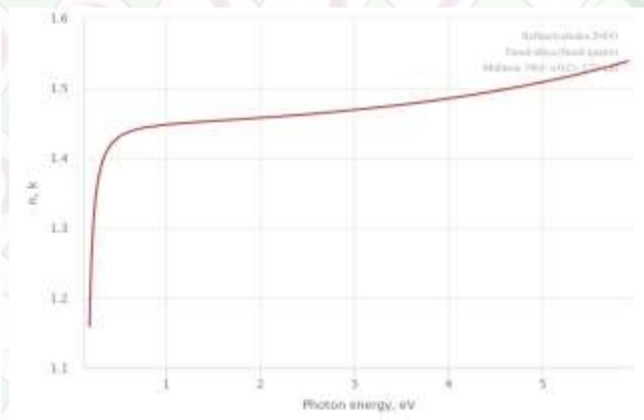
In condensed matter systems, photons excited via electro luminescence in a scanning tunneling microscope reveal unique insight into a molecule or convey insight into the atomic details of 2D material’s properties.

The separation of the photon’s wavelength is conventionally achieved with the dispersion from a grating and a cooled CCD sensor array.

Albeit providing high spectral resolution, each pixel in the grating spectrometer has an individual dark count rate making the measurement of faint signals challenging, in addition to being very expensive.

This project aims at building a spectrometer using the wavelength dependent refractive index of an optical fiber that transforms the photons arrival time into wavelength information using a single photon detector.





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From Icky to Pretty

(pulse shaping for ultrafast qubit control)

Master Project

The dynamics of qubits happens on very short timescales (picoseconds to nanoseconds), which can be measured by pump-probe spectroscopy using ultra-fast voltage pulses. One pulse excites, the other probes the system.

However, when sending pulses through cables, they get deformed, which limits our time-resolution. The cables change amplitudes and phases of every frequency component in the pulse.

The goal of this project is to measure the pulse-deformation (amplitude and phase transfer function) and to use this information to pre-shape the ultrafast voltage pulses such that they arrive with sharp edges at the experiment, taking the deformation of the transmission into consideration.

$$V(t) = \sum_{n=1}^{\infty} a_n \exp(i\omega_n t + \phi_n) \Rightarrow \sum_{n=1}^{\infty} a'_n \exp(i\omega'_n t + \phi'_n)$$

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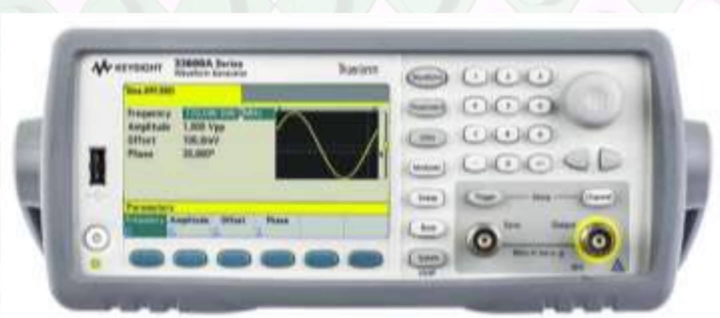


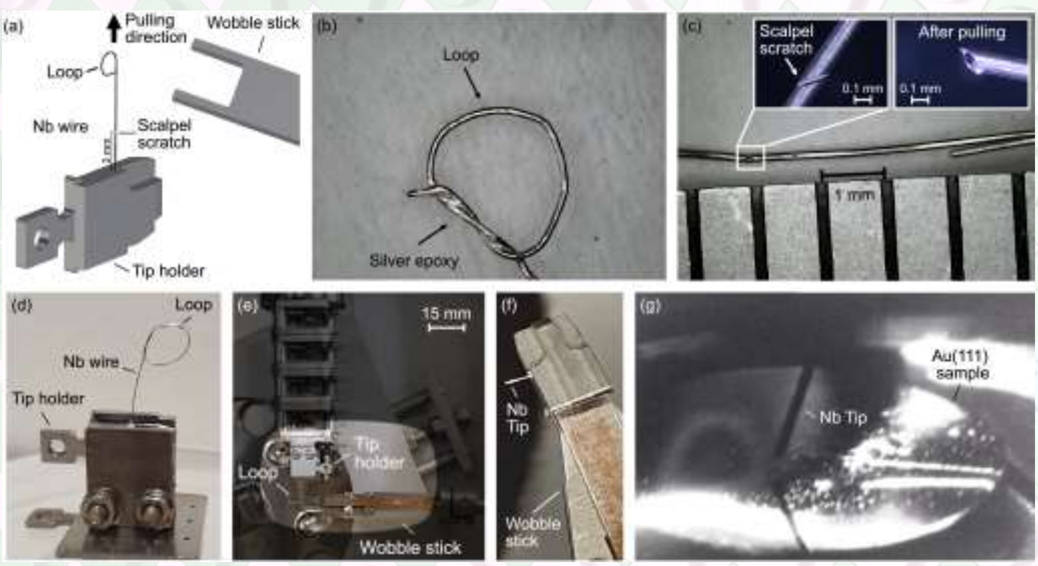
Break it, to make it!

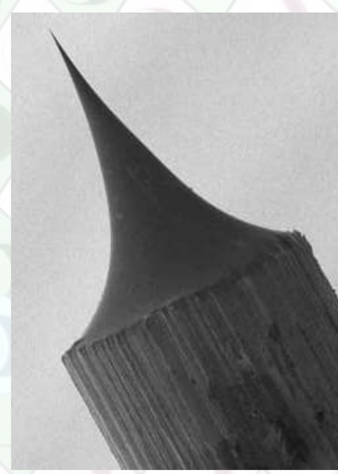
(vacuum breaking of scanning probe microscopy tips)

BSc Project

The scanning tunneling microscope is a unique tool that offers atomic resolution and atom manipulation capabilities. The tip of an STM is typically made from etched tungsten wires that terminate in a single atom. These tips, albeit sharp, provide no information about the magnetic state, are not luminescent, and are non-superconducting. Unfortunately, materials with these desired properties tend to oxidize rapidly, which motivates the preparation of tips in vacuum conditions.

The aim of the project is to investigate how to best break wires of antiferromagnetic, superconducting, or plasmonic materials. Observation of the breaking process in a microscope, targeted weakening of the wires, and breaking in vacuum will help achieve atomically sharp tips without oxide or pollution layers for measurements that require spin-polarization, high luminosity, or in Josephson junction STM.





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Shaping magnetic fields to go vertical

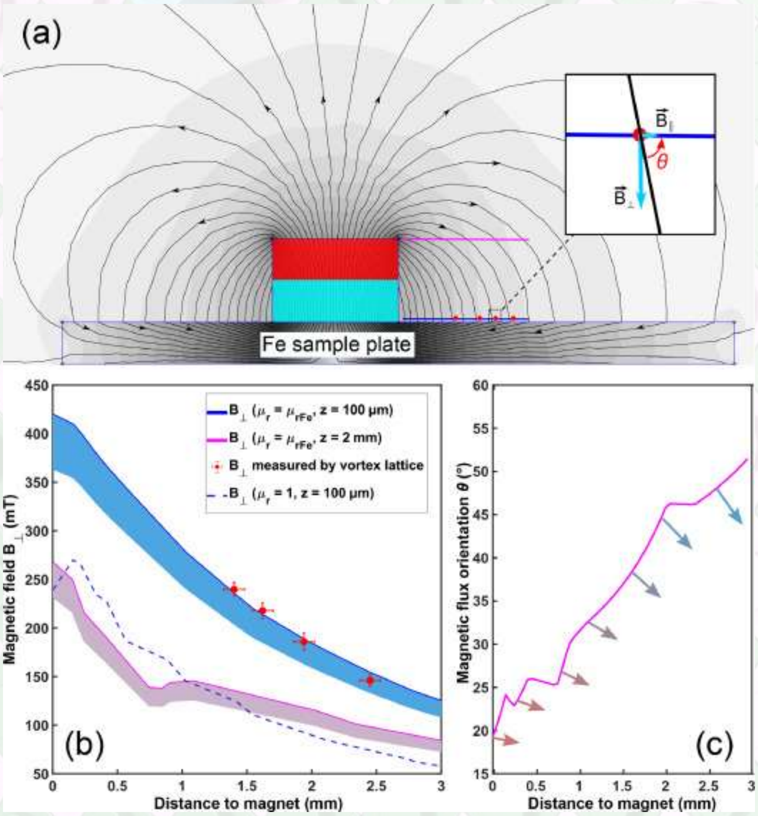
(turn magnetic field lines perpendicular)

BSc Project

Electron spin resonance with the scanning tunneling microscope combines excellent energy resolution with the atomic manipulation capabilities.

In an ESR experiment, the magnetic field provides a Zeeman splitting to which a microwave field is tuned. We generate magnetic fields using a permanent magnet. Unfortunately, the field lines are tilted, which leads to state mixing for systems in which the quantization axis is not aligned with the external field.

The aim of this project is to find a way how to shape/turn/position the magnet and sample plate to achieve perpendicular magnetic field at the sample surface. This will greatly increase the relaxation times of our molecular qubits.



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Simulate a high dynamic range STM

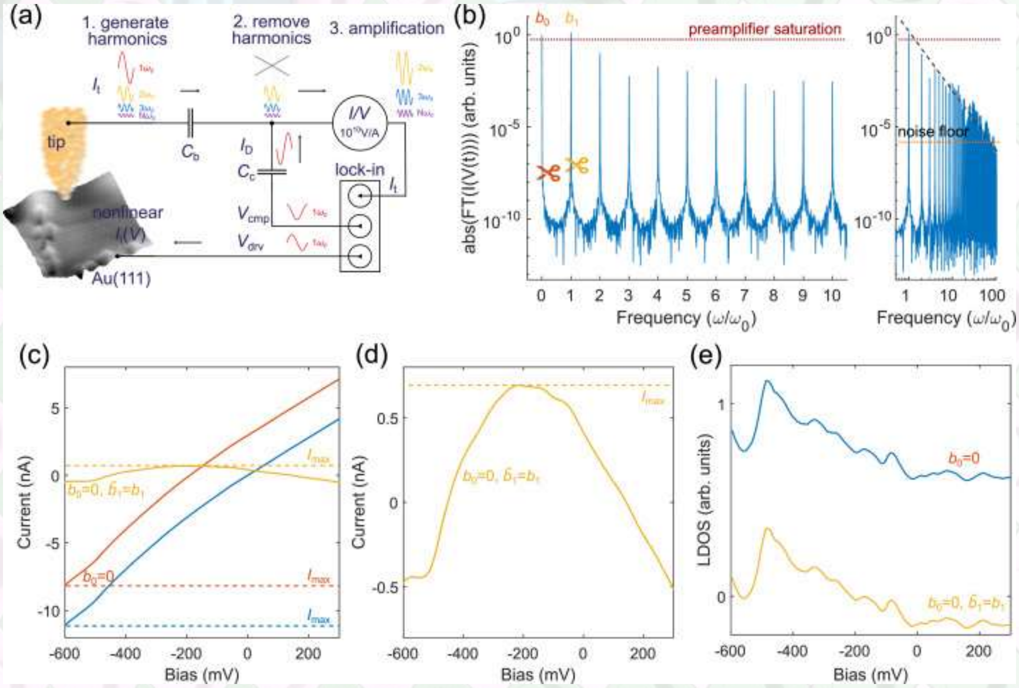
BSc Project

The small currents in a scanning tunneling microscope require large amplification stages that have a limited dynamical range.

Using the exact cancellation of large valued current-contributions, we can dramatically increase the dynamical range of the STM.

While we have tested the working principle in experiment, we now need to optimize the circuit for optimal noise and dynamic range performance.

Using LT Spice or other circuit simulation software, this project aims at finding the best choice for compensating and blocking capacitors and understanding the frequency dependence of the STM.



Karić et al., *MethodsX* **13**, 102857 (2024)

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