HELMHOLTZ ZENTRUM
DRESDEN ROSSENDORF

Creation and characterization of quantum defects

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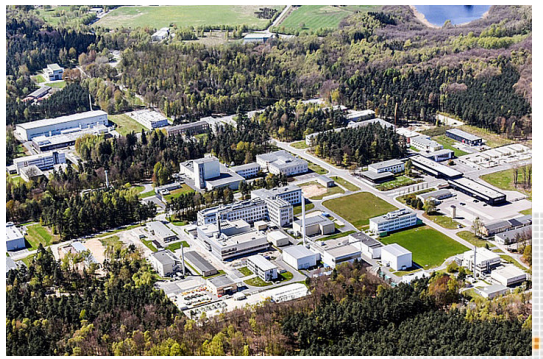
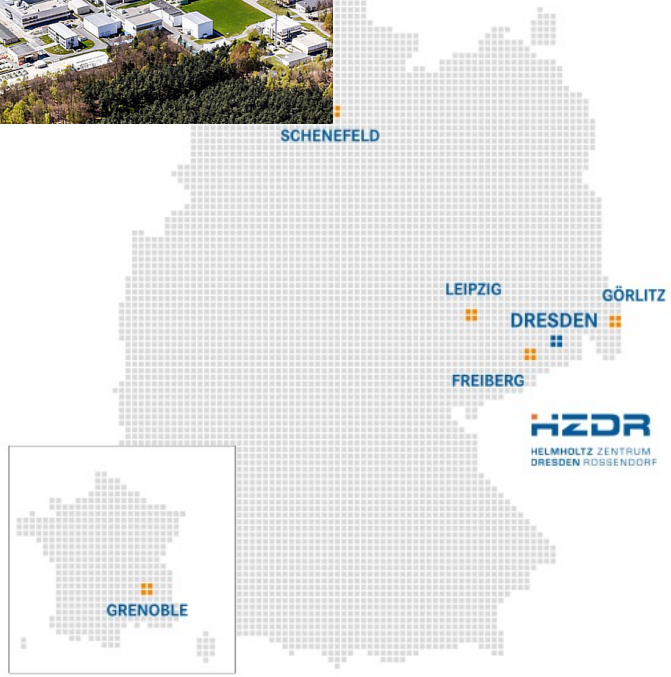
Andrei Anisimov, Ayisha Suhana, Tatiana Uaman

HZDR, Institute of Ion Beam Physics and Materials Research,
Quantum Technologies (FWIQ)

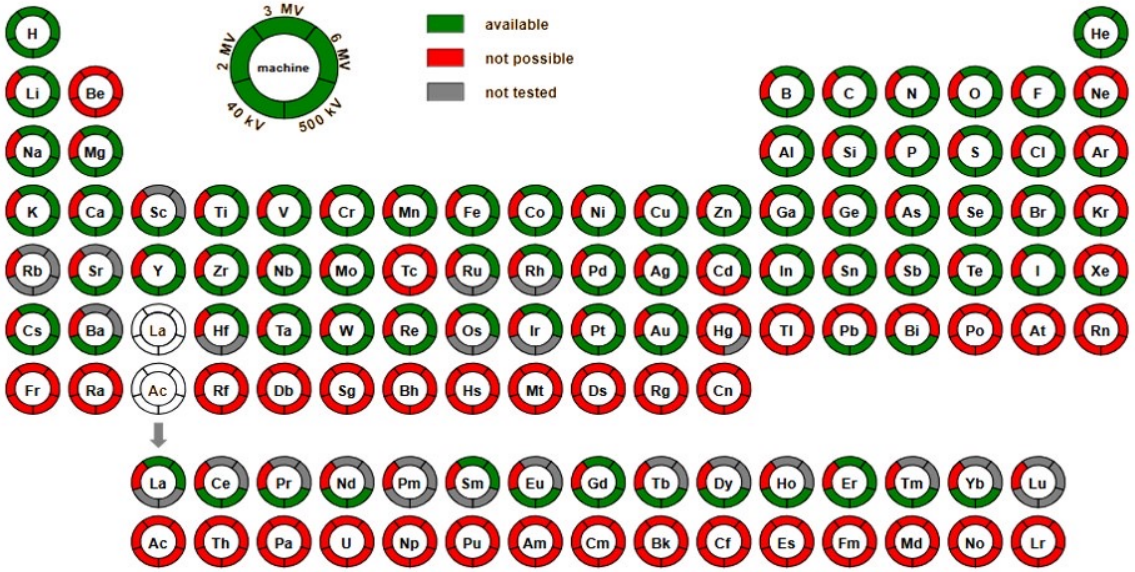
DRESDEN concept

Helmholtz-Zentrum Dresden-Rossendorf





Ion Beam Center at HZDR



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Outline

1. Motivation
2. Scanning Quantum Magnetometer
3. Imaging DC Current in Quantum Microscope
4. Advanced Protocol for Imaging Electrical Signal

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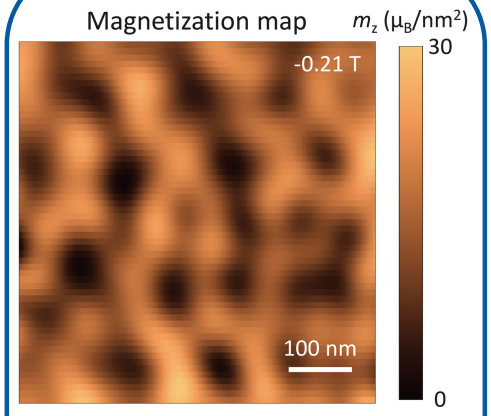
Application Domains: Materials, Health, Energy and Environment

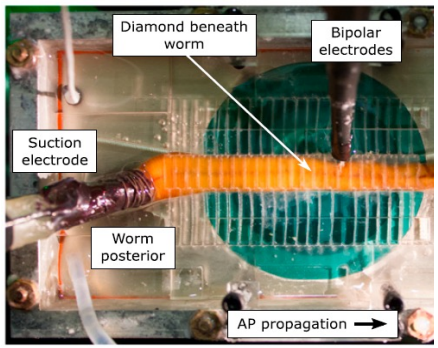
Materials



Visualization of magnetic domains and moire magnetism in twisted 2D magnets

T. Song et al., Science **374**, 1140 (2021)

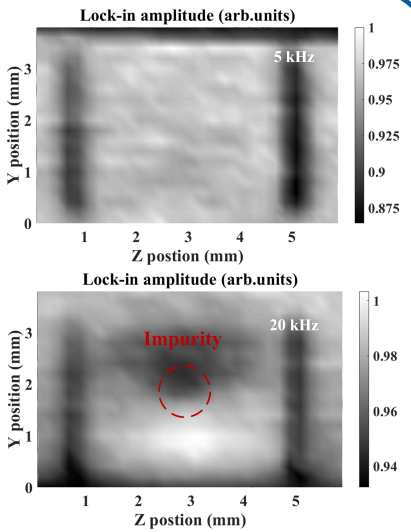
Health



Overhead photo of *M. infundibulum* positioned on an NV diamond sensor for single-neuron action

J. F. Barry et al., PNAS **113**, 14133 (2016)

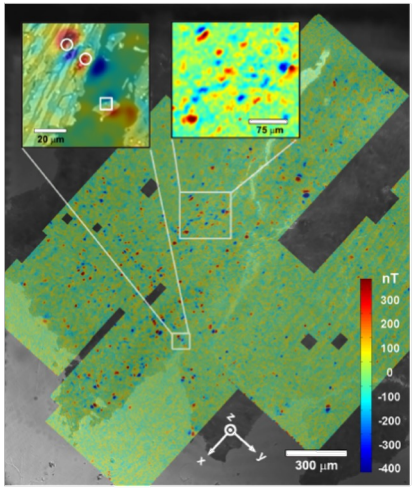
Energy



Battery characterization via eddy-current imaging

X. Zhang et al., Appl. Sci. **11**, 3069 (2021)

Environment



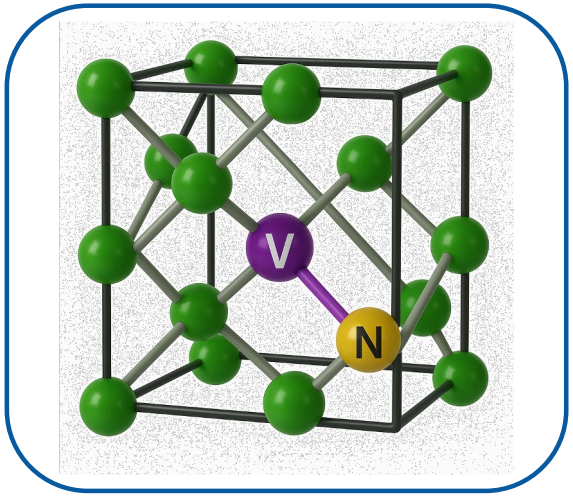
Quantum diamond microscope image of a geological sample

D. R. Glenn et al., Geochem. Geophys. Geosyst. **18**, 3254 (2017)

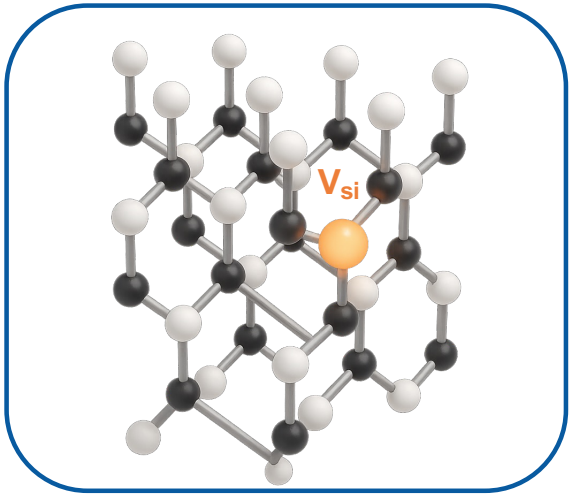
Comparison of Material Platforms for Quantum Sensing

- **Diamond NV center -** Sensitivity: 1 pT/Hz$^{1/2}$, The most developed system
- **SiC -** Sensitivity: better than 100 nT/Hz$^{1/2}$, Wafer-scale, industrially relevant
- **hBN -** New, Sensistivity: 100 µT/Hz$^{1/2}$, Promising for 2D quantum sensing, proximity

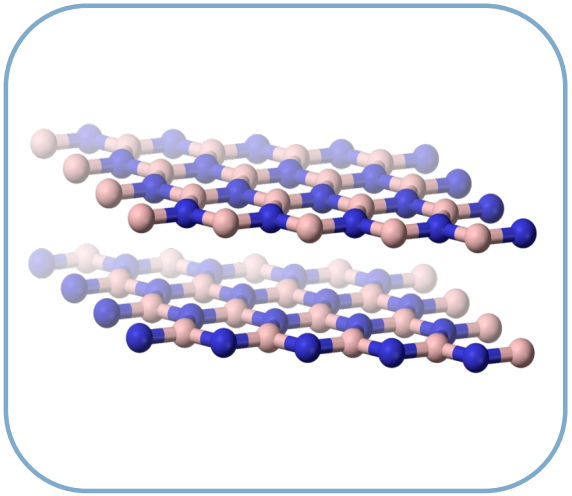
Nitrogen-vacancy in diamond



Silicon vacancy in SiC



Boron vacancy in hBN



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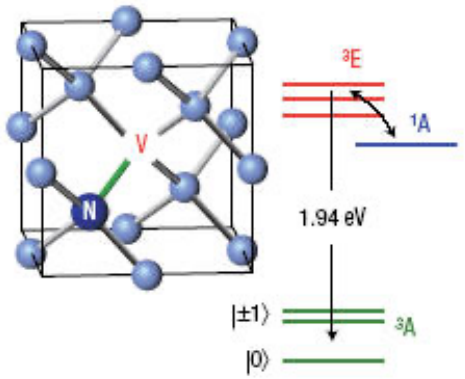
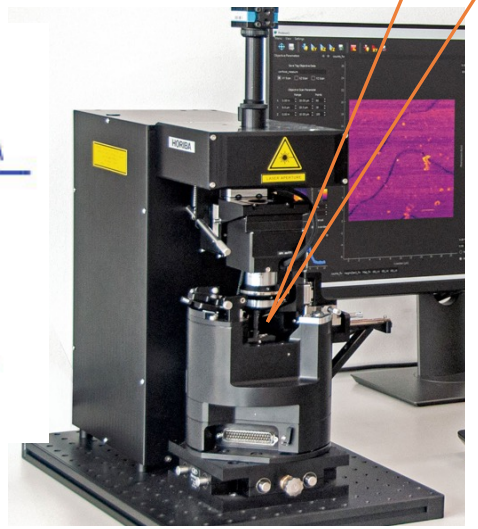
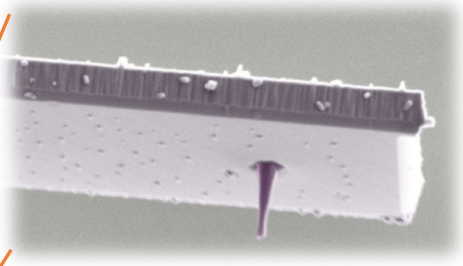
Scanning Quantum Magnetometry with NV Defects in Diamond

- Scan range 80 µm x 80 µm x 10 µm
- Magnetic spatial resolution <100 nm
- Single NV center with sensitivity 3 µT/Hz$^{1/2}$
- Magnetic field range up to 5 mT
- Time-domain measurements including Rabi, Hahn-Echo



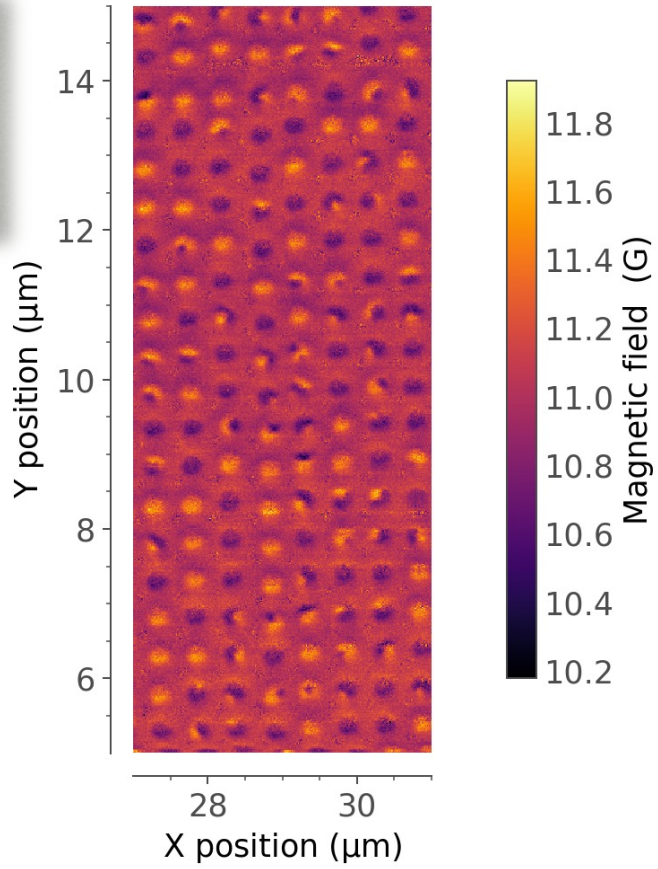




Imaging of antiferromagnetic domains

Cooperation:
P. Makushko,
D. Makarov (FWID)

P. Rickhaus et al., Nano Lett. 24, 13172 (2024)



Quantum Sensing in Hybrid Structures hBN-3C-SiC

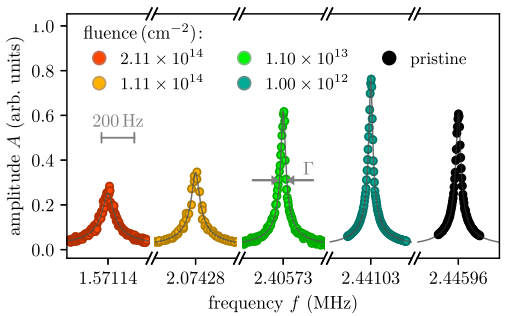
Cooperation:

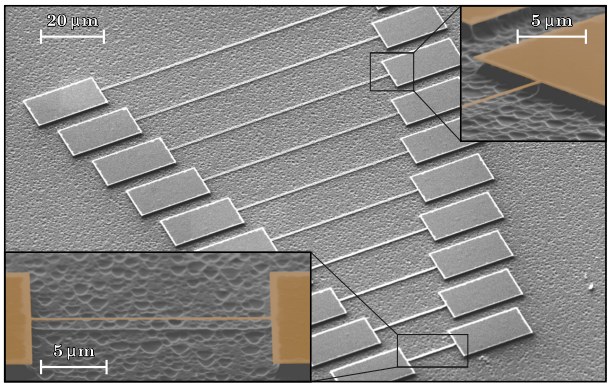
E. Weig (TU Münich) and A. Erbe (FWIO)

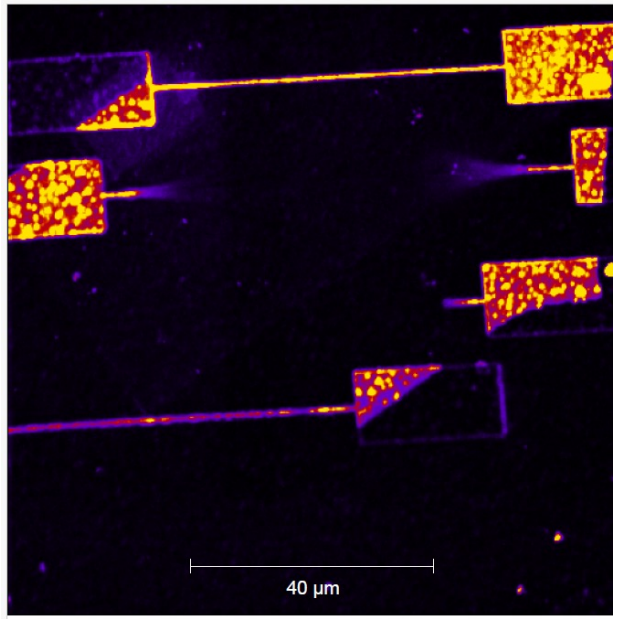
3C-SiC nanostrings: High mechanical Q-factor (>10,000)

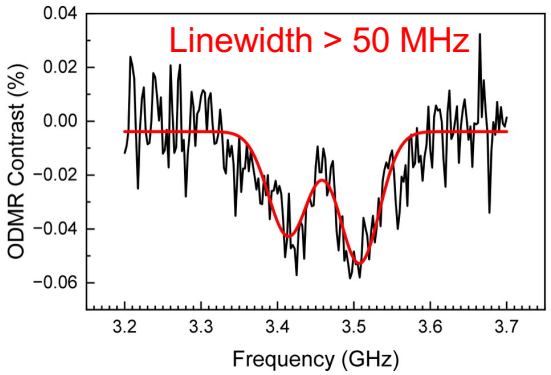
hBN: Quantum sensing with boron vacancies (V_B) near the surface

3C-SiC
on Silicon









Theoretical questions

- Strain-spin interaction of atomic defects in 2D materials

P. Bredol, et al, GA, A. Erbe, E. Weig, Phys. Rev. Applied **22**, 034036 (2024)

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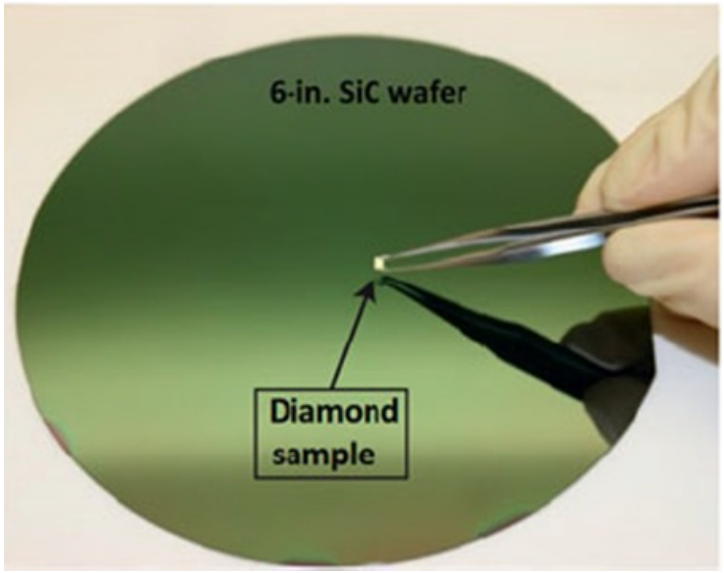
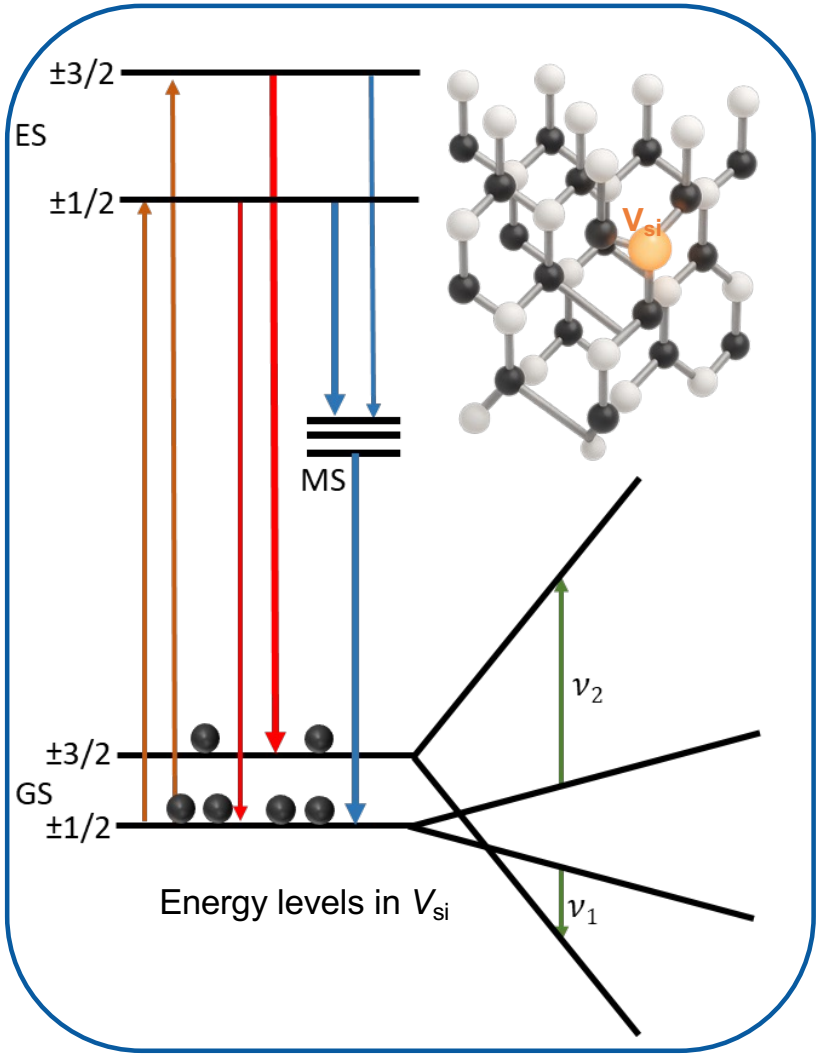
Quantum Sensing with Defects in SiC

Silicon Vacancy in SiC:

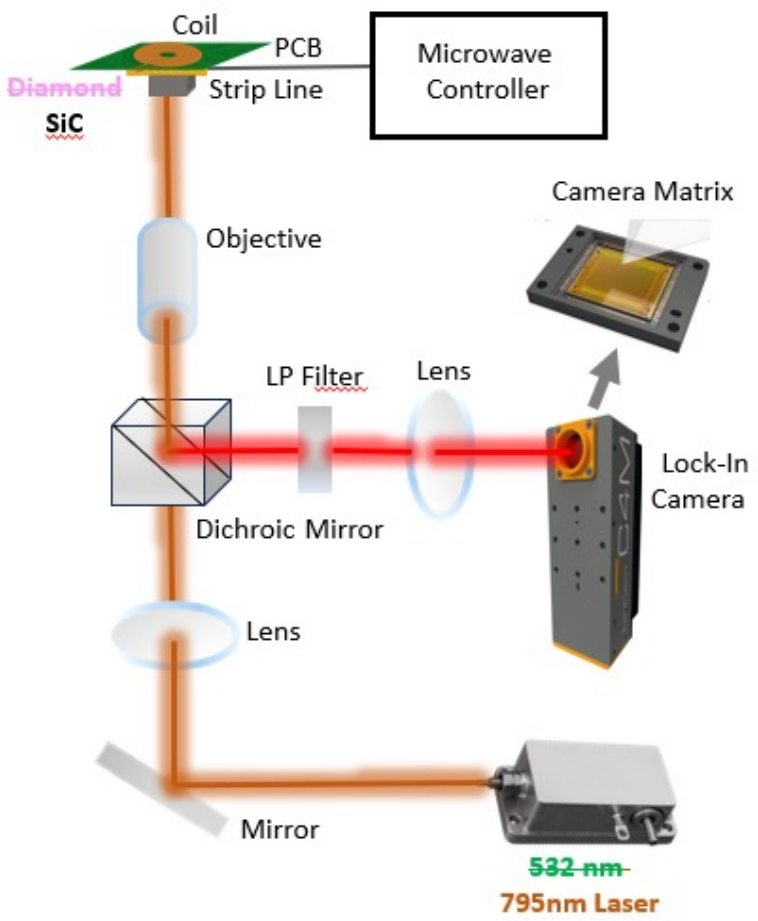
- SiC, with its wafer compatibility, allows quantum sensing under ambient conditions, making it a promising material for advanced applications



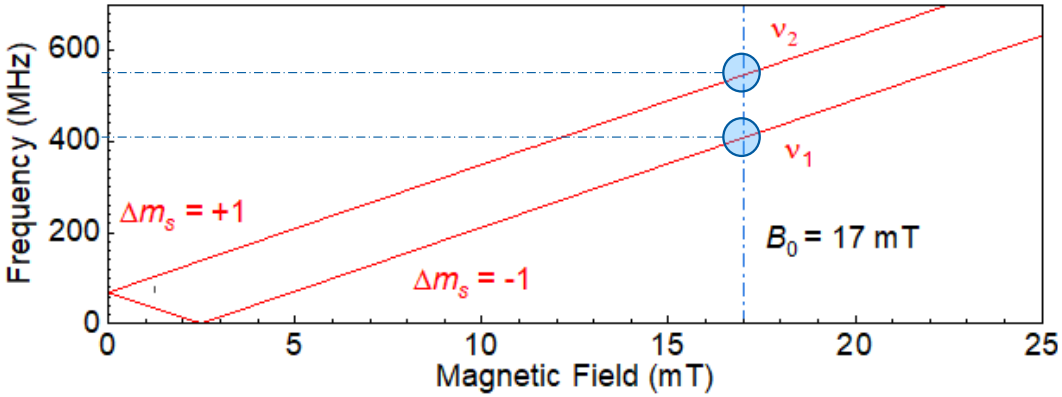
W. F. Koehl et al., MRS Bulletin **40**, 146 (2015)



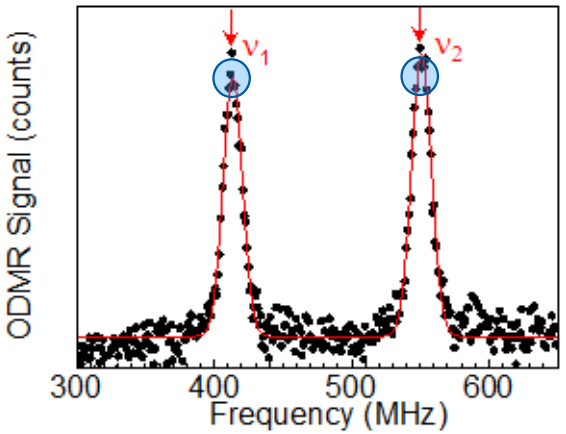
Optical detection scheme



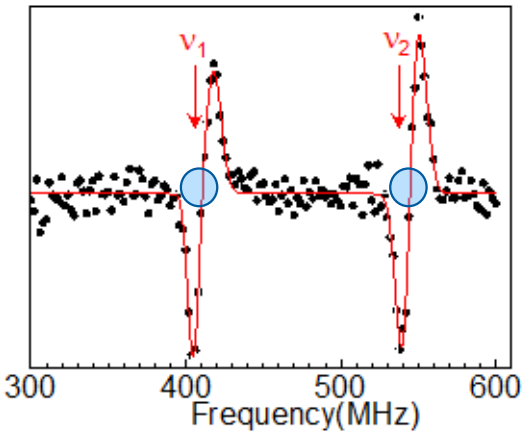
Spin resonances in SiC



ODMR with AM

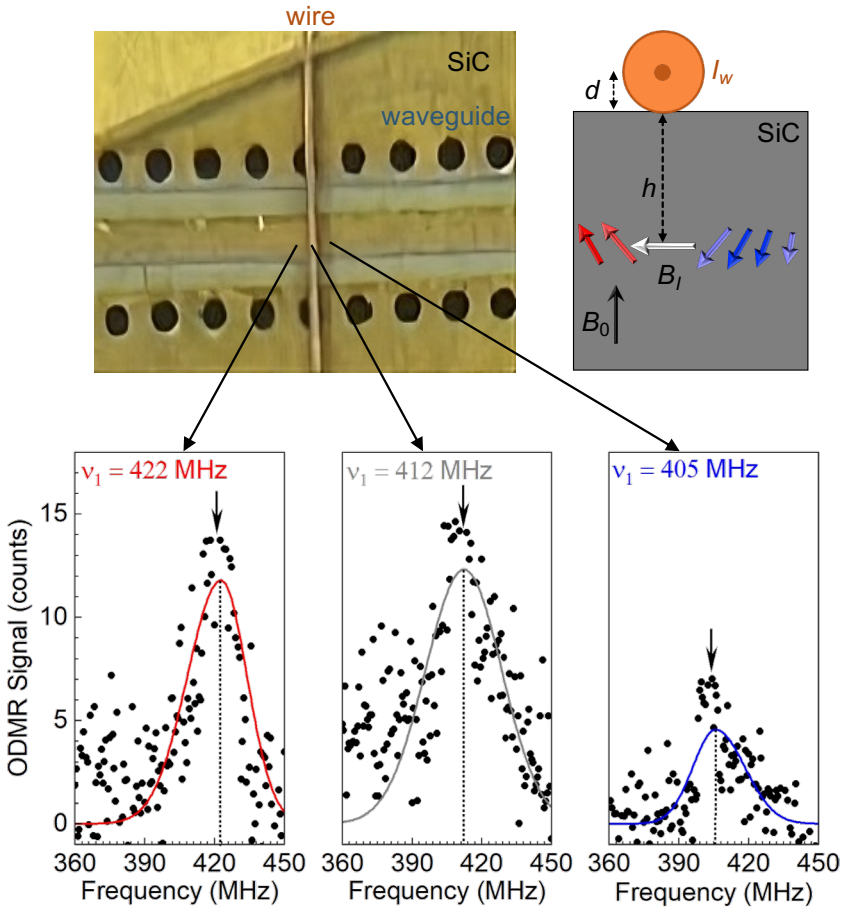


ODMR with FM



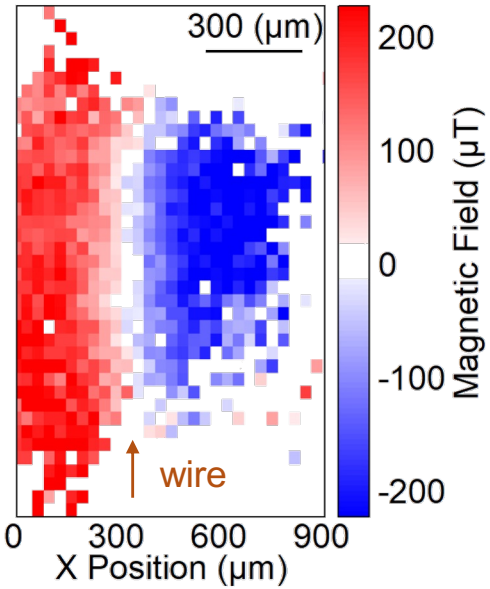
A. Suhana et a., arXiv:2509.14888 (2025)

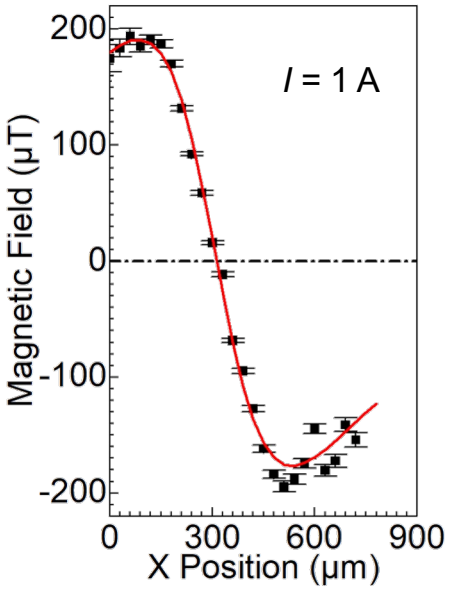
Imaging magnetic fields generated by electrical signals



$$B_I = \frac{\mu_0}{2\pi}\frac{I}{d+h}$$

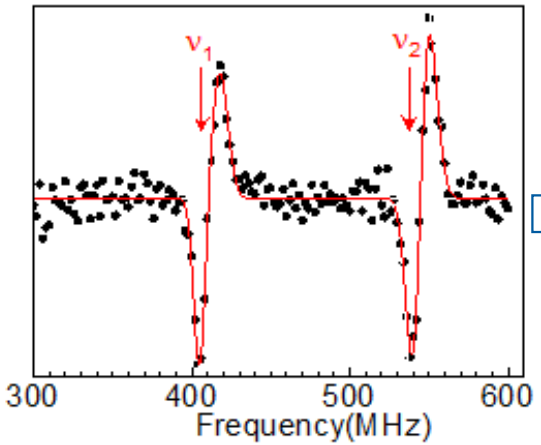
$$B_{detect} = \frac{\mu_0}{2\pi}\frac{x}{\sqrt{(d+h)^2+x^2}}I - B_0$$

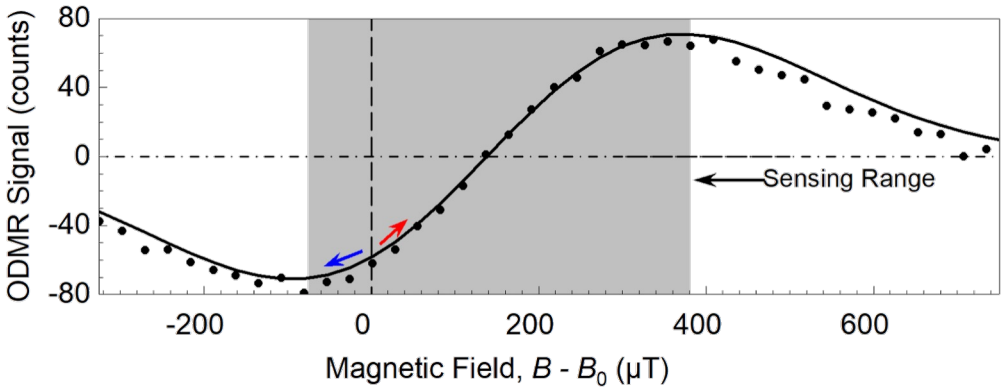


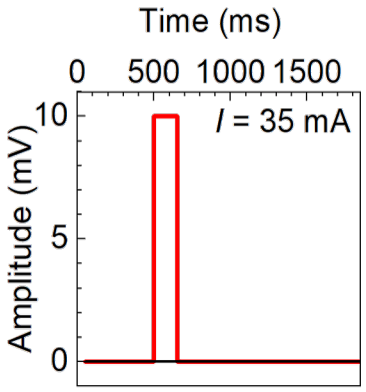


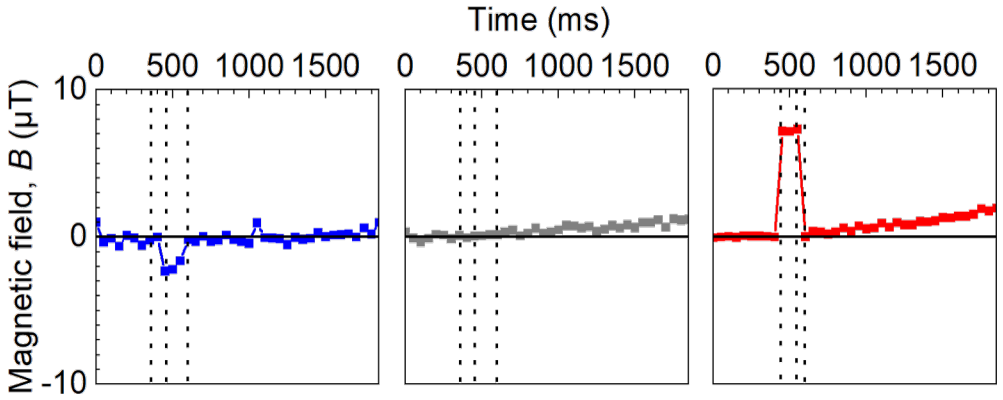
A. Suhana et a., arXiv:2509.14888 (2025)

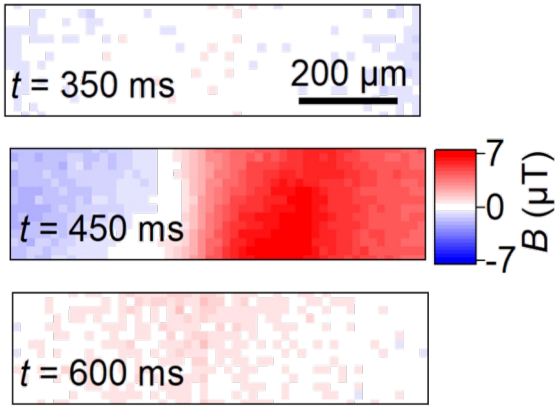
Imaging magnetic pulses using two-frequency modulation











A. Suhana et a., arXiv:2509.14888 (2025)

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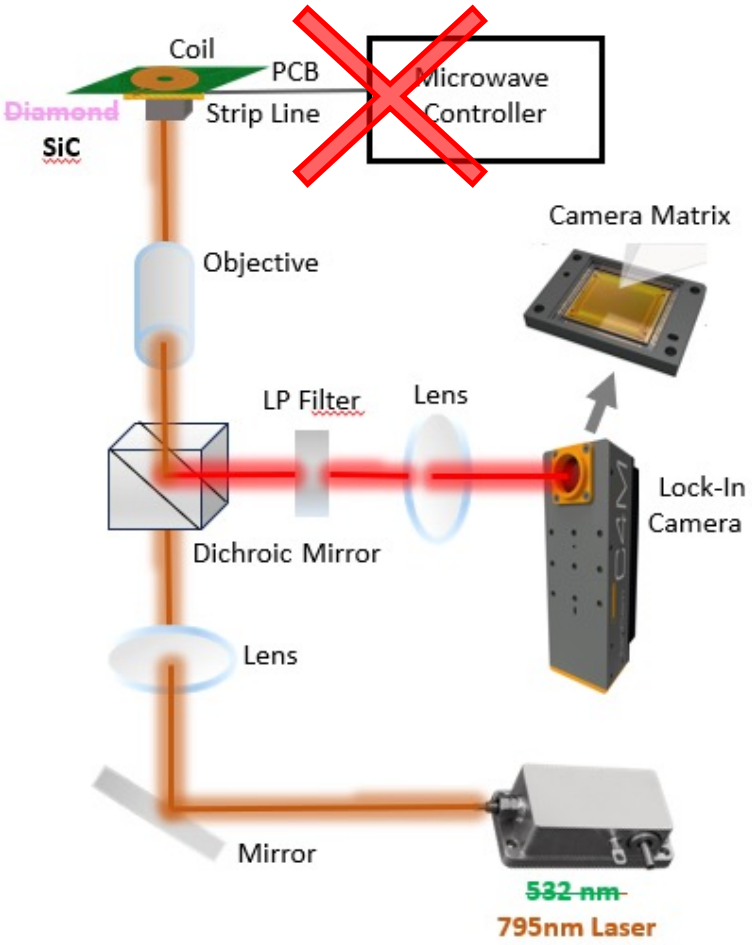
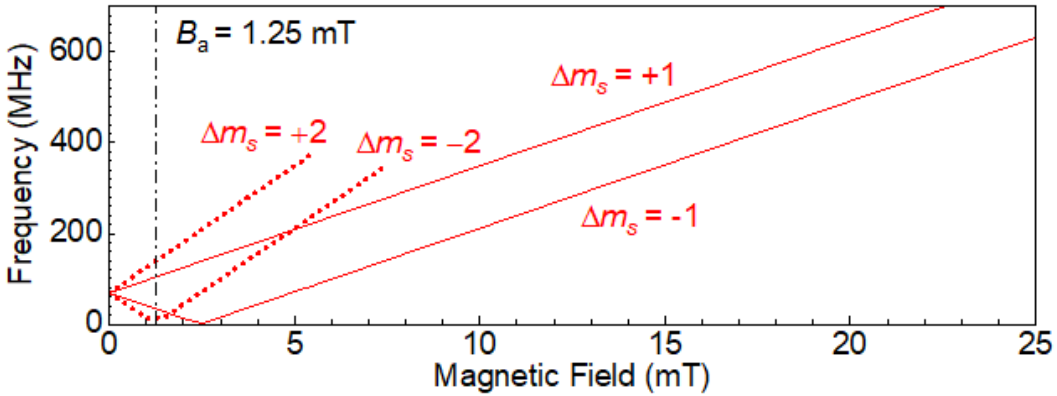
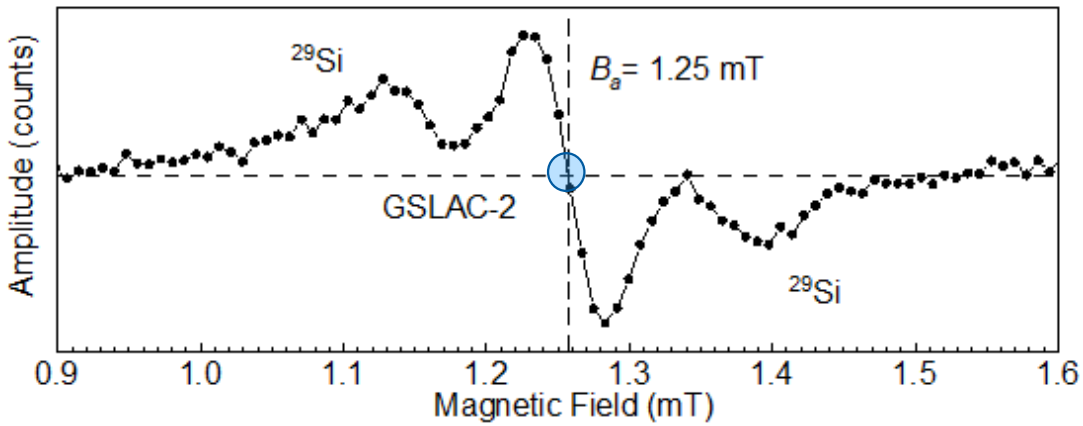
Microwave-free detection scheme



Spin resonances in SiC

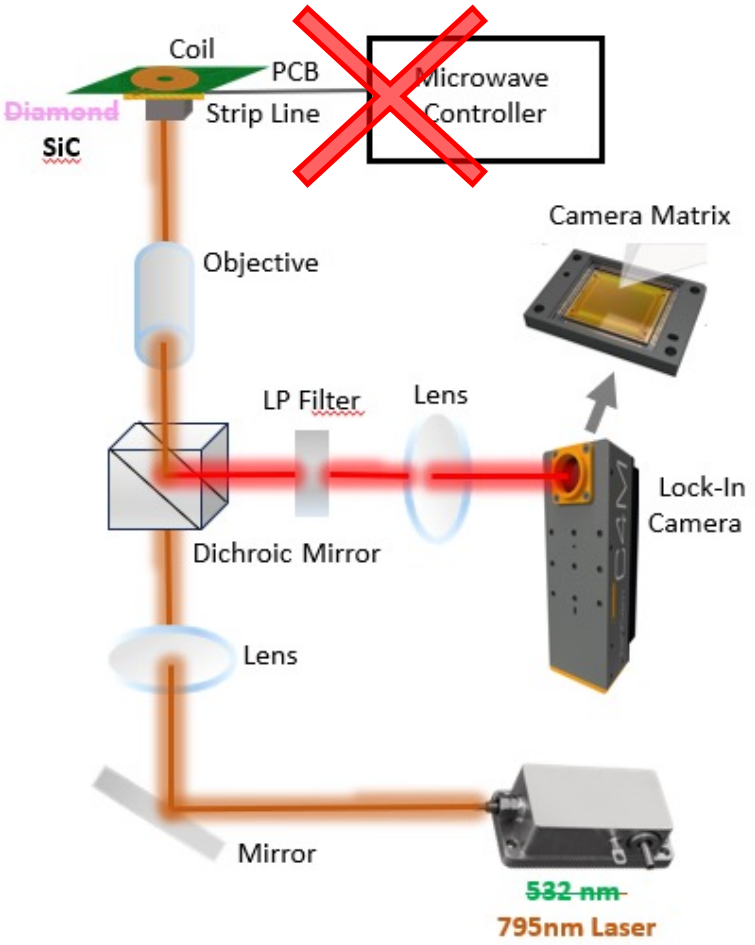


Level-anticrossing signal (GSLAC – 2)

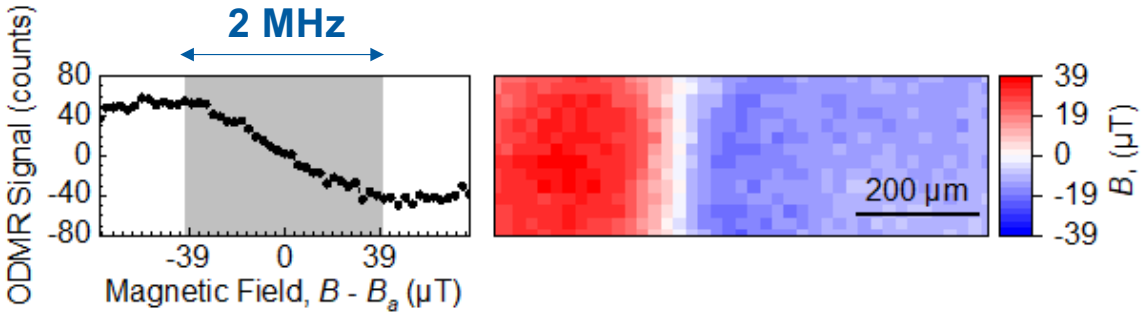


A. Suhana et a., arXiv:2509.14888 (2025)

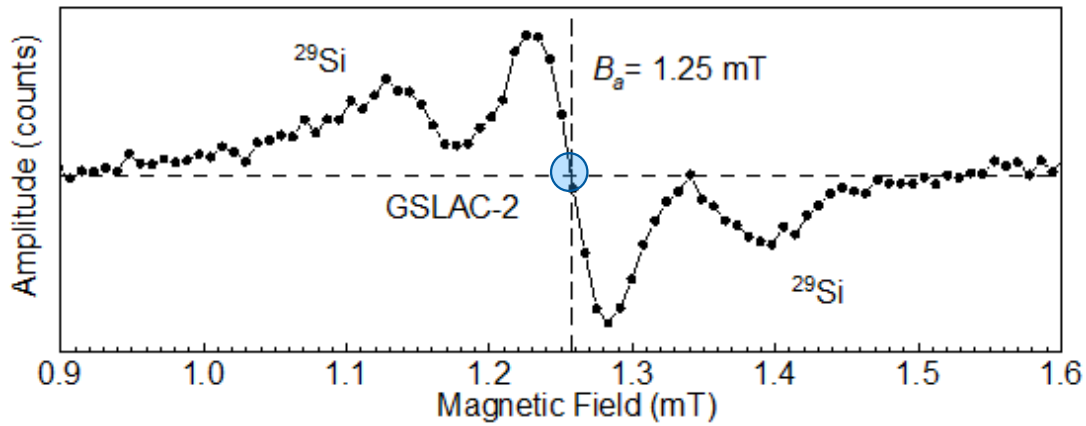
Microwave-free quantum imaging



Level-anticrossing signal imaging (GSLAC – 2)



Level-anticrossing signal (GSLAC – 2)



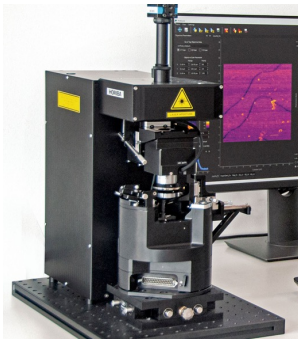
A. Suhana et a., arXiv:2509.14888 (2025)

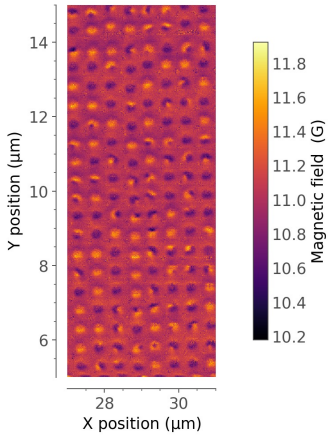
Summary: Quantum Sensing Modalities

➢ Scanning Quantum Magnetometer

High spatial resolution (< 100 nm) but slow

Moderate sensitivity (3 μT/Hz$^{1/2}$)

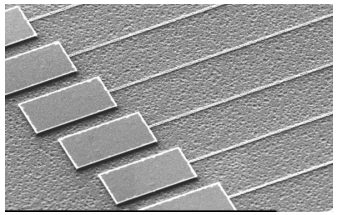


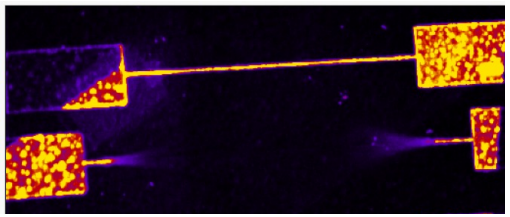


➢ Hybrid Quantum Sensors

Close proximity (< 100 nm)

Low sensitivity (100 μT /Hz$^{1/2}$)



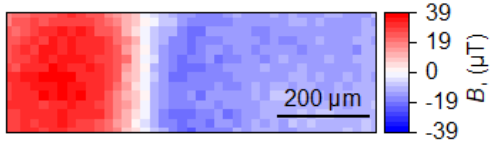


➢ Quantum Microscope

Optical spatial resolution (>1 μm) and fast

High sensitivity (< 50 nT/Hz$^{1/2}$/pixel)

Time resolved signals (> 1 ms)



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