QUANTERA
DECADE OF IMPACT 2016-2026

QuantERA Call 2021 Final Evaluation

SENSEXTREME

Quantum sensing with diamond defects at extreme conditions

J.-F. Roch, ENS Paris-Saclay
April 2022 – March 2026 (one-year extension received in January 2025)

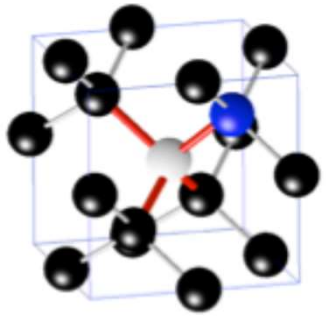
Final seminar · Metrology session · September 29, 2026

Why diamond defects for extreme conditions?

An atomic-scale optical probe

A color center is a defect in diamond whose light and spin respond to the surrounding environment.
Group-IV vacancy (G4V) centers contain silicon, germanium or tin next to a vacancy.

NV center

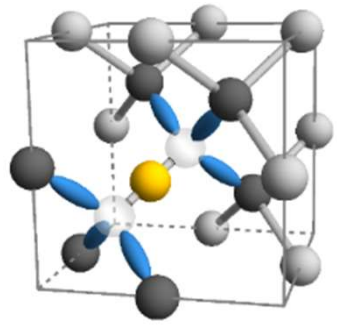


The SENSEXTREME objectives

Use these centers to measure pressure and magnetic fields where conventional local probes are difficult to operate.

Strong magnetic fields, very high pressure
and cryogenic temperatures

G4V center



Optical access to individual spins offers a route to local measurements of quantum materials.

Collaboration across five countries

Theory and interpretation

FTMC (P5, Lithuania)
Wigner RCP (P6, Hungary)
Joint calculations, frequent exchanges
and a one-month research visit

Materials and sensing

ENS Paris-Saclay (P1, France) - Coordination
University of Basel (P2, Switzerland)
Saarland University (P3, Germany)
Ulm University (P4, Germany)



Shared samples and research visits connected defect engineering to high magnetic field and high-pressure experiments.

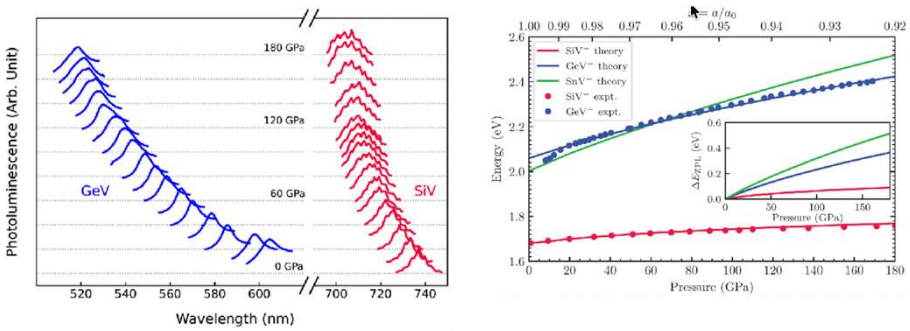
SUCCESS STORY

Diamond defects remain optically readable at 180 GPa

Measured optical shifts

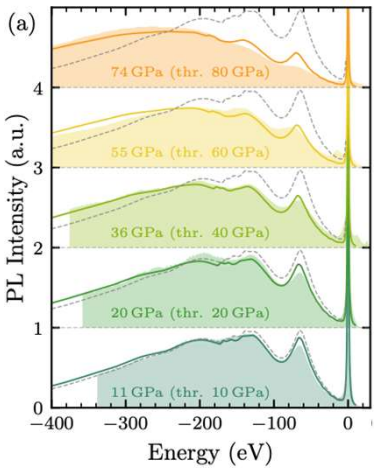
SiV: 70 meV
GeV: 320 meV
At pressures up to 180 GPa
(1.8 million times atmospheric pressure)

Theory reproduced the measured shifts



Complementary diamond defects

NV: optical properties
up to 120 GPa
with FTMC and CEA



MgV: pressure and temperature sensing up to 28 GPa at 87 K with Wigner RCP and the University of Torino

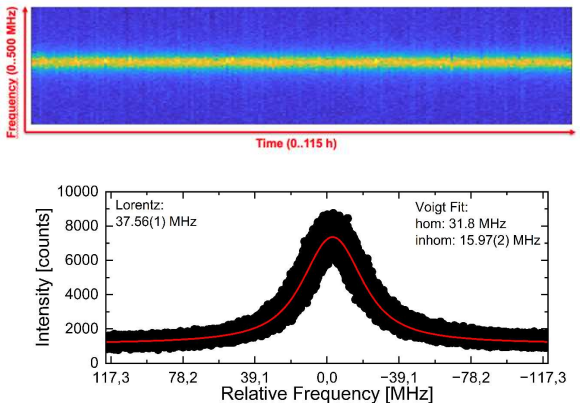
These results support optical pressure calibration.
They do not yet demonstrate magnetic sensing at 180 GPa.

SUCCESS STORY

Shallow sensors approach the natural linewidth

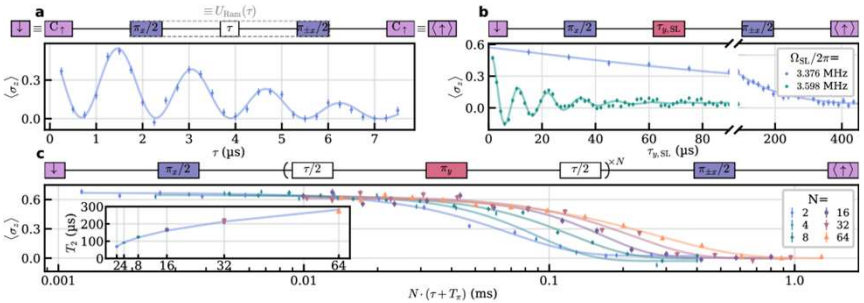
50 nm from the diamond surface

UNIBAS: optical linewidth ≈100 MHz
Natural lifetime limit: 94 MHz
About 30% of centers approached this limit
Blue light stabilized the charge state needed for optical measurements



Why this matters for sensing

A shallow defect can approach a sample closely for nanoscale measurements.
USAAR: stable, narrow SnV emission over 24 hours
UULM: >10× longer SiV spin coherence



npj quantum information: doi.org/10.1038/s41534-025-01049-2

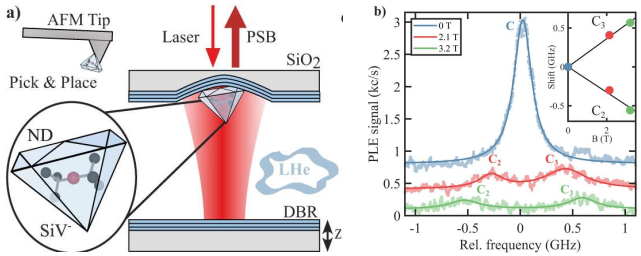
Material preparation and charge control help preserve quantum properties close to a surface.

SUCCESS STORY

Optical spin readout works for magnetic measurement

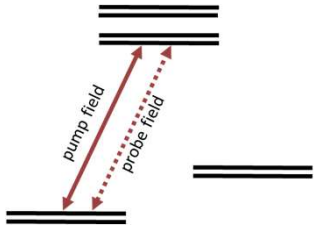
High-field demonstration at UULM

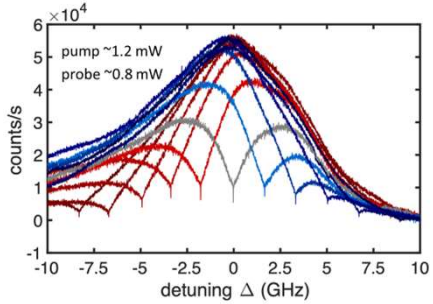
A SiV nanodiamond in an optical cavity sensed magnetic fields without microwaves.
Demonstrated operation at 3.2 T
Sensitivity: 180 ± 60 mT/√Hz



Communications Physics: doi.org/10.1038/s42005-023-01422-7

Sensing using CPT in a SiV ensemble at USAAR





Toward scanning measurements at UNIBAS

Optical spin readout at 7 K
Sensitivity: 21 μT/√HzScanning probes with shallow SiV centers
Instrument commissioned for fields to 5 T

Optical sensing and probe fabrication advanced.
High-field scanning images remain a follow-up objective.

Reusable methods and scientific outputs

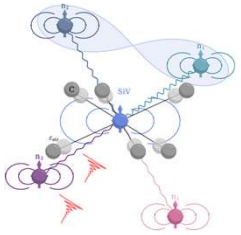
Less expensive ab-initio calculations

FTMC and Wigner RCP: comparable accuracy to hybrid-functional methods at about 100× lower computational cost

Open-source Exe.py software models coupled electronic and vibrational states

Outputs beyond individual experiments

Joint publications and open-access results
Protocols for persistent charge control
UULM: three-qubit nuclear-spin register





Nature Communications:
doi.org/10.1038/s41467-026-70154-3

10 associated doctoral theses, completed or ongoing

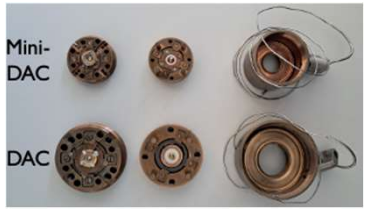
Shared methods connect quantum sensing, materials modeling, quantum information processing and high-pressure measurements.

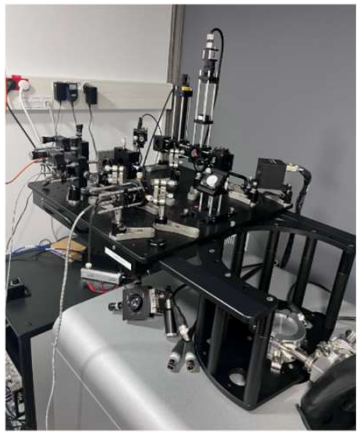
IMPACT

Industrial links and potential users

Cryogenic high-pressure instrumentation

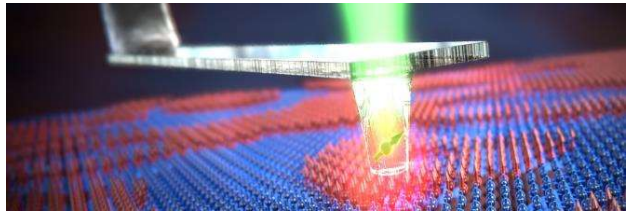
ENS-PS, attocube and BETSA developed custom diamond anvil cells for integration into the attoDRY2100 cryostat.





Scanning quantum magnetometry

UNIBAS works with Qnami on potential transfer of SiV sensing to scanning-probe instrumentation.



Ion implantation

ENS-PS collaborates with Orsay Physics on Quiin. Adapting the ion source for Si and Ge implantation offers a future development route.



Better local measurements can support superconductivity and quantum-materials research. Device benefits remain longer-term.

RESULTS AND LIMITATIONS

Remaining limits and remedial actions

Optical broadening under pressure

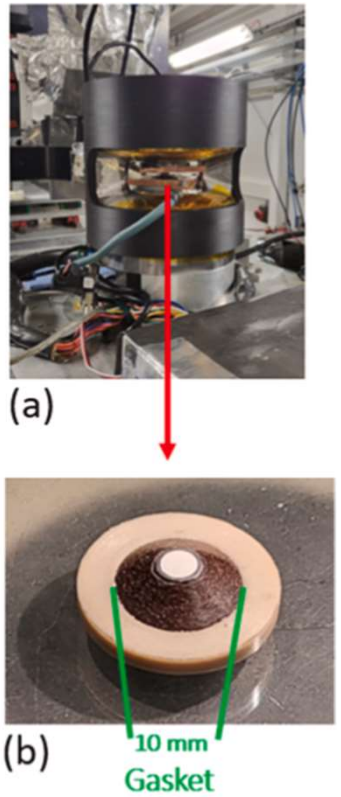
Implanted SiV ensembles retained resolved fine structure to 20 GPa.
Higher pressure broadened the lines.
Mitigation strategy: HPHT annealing using Paris-Edinburgh press

High-field imaging

Stabilizing shallow sensors took longer than expected.
The planned magnetic images remain a follow-up objective.

Project continuity

A 12-month extension addressed recruitment and equipment delays.
The consortium reorganized coordination after A. Alkauskas's death.



All planned theoretical tasks were completed.
Key experimental integration milestones remain open.

FOLLOW-UP

Next steps toward reliable extreme-condition sensing

High-pressure sensing

ERC Advanced Grant QPRESSE 2025–2029, ENS Paris-Saclay
NV sensing of superconductivity complements the G4V platform investigated in SENSEXTREME

Scanning sensors and charge stability

SNSF Sinergia microscope project 2024–2028, with UNIBAS

FTMC, Wigner RCP and Quantum Brilliance submitted a QuantERA proposal on defect charge dynamics

Established: optical calibration, improved materials and first sensing demonstrations.
Next: reliable magnetic imaging.

Deliverables requiring further work

D2.3: narrow ensembles for high-pressure use

Target: spectral width below 5× the Fourier limit. Not achieved.
Investigate post-implantation annealing at ambient and high pressure.

WP3: high-field scanning images

No α-Fe_2O_3 images during the project.
Continue shallow-sensor development and scanning integration.

D4.3: photonic nanostructures in diamond anvil cells

Canceled during the project.
Cryostat and custom diamond anvil cell development continued.

Demonstrated spectroscopy, sensing and instrumentation are distinct from these unfinished integrations.

BACKUP

Selected outputs

Pressure response

Phys. Rev. B 106, 214109 (2022)
doi.org/10.1103/PhysRevB.106.214109

Shallow SiV centers and high-field sensing

Nano Letters: doi.org/10.1021/acs.nanolett.3c03145
Communications Physics: doi.org/10.1038/s42005-023-01422-7

Theory and complementary sensing

SCAN methods: doi.org/10.1063/5.0154319
NV optical properties to 120 GPa: arxiv.org/abs/2606.02399

Additional papers and conference contributions appear in the final report :
17 articles published or accepted, 3 under review, >16 conference contributions

BACKUP

Open science and a wider research community

Access to methods and results

Open-access publications and arXiv
Reusable open-source software

Shared fabrication expertise
and cross-border research visits

Training and public engagement

Doctoral research across the consortium

Quantum-technology schools
in Trieste, Erice and Palermo

Public lectures and outreach in Basel
and Hungary (national radio broadcast)

FTMC and Wigner RCP led theoretical advances and strengthened research capacity in widening countries.