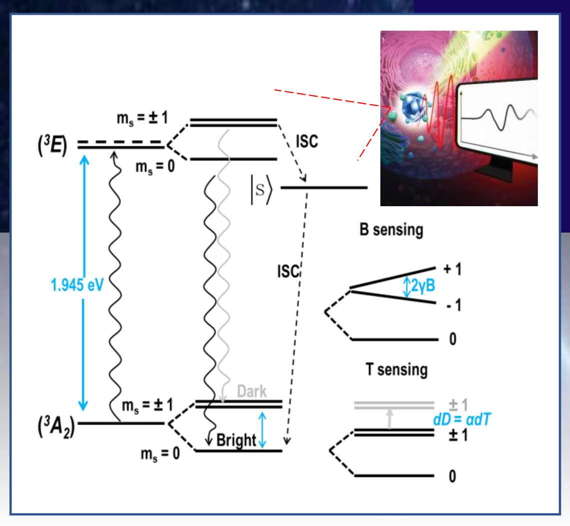
Color centers in diamond for intra- and extra-cellular quantum sensing – EXTRASENS



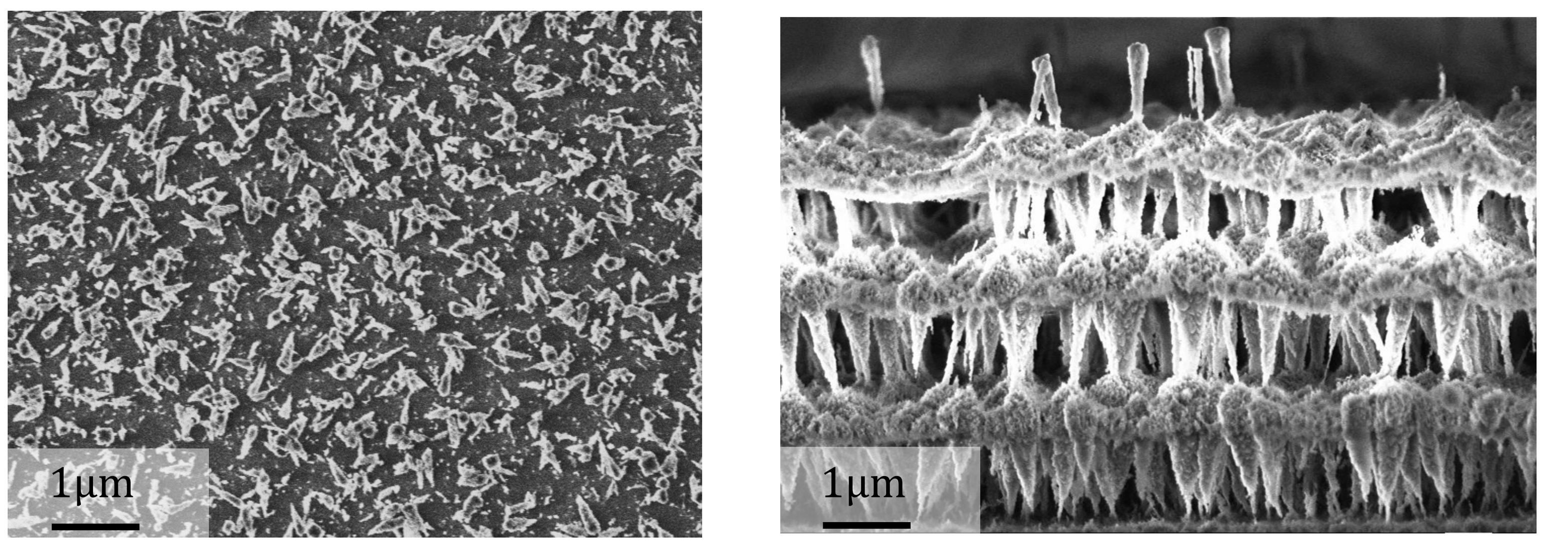
To advance both fundamental life sciences and practical medicine, EXTRASENS is developing a tool capable of measuring electromagnetic fields, temperature, and pH at nanometer precision. This multimodal quantum biosensor integrates super-resolution bioimaging capabilities and leverages nitrogen-vacancy (NV) and silicon-vacancy (SiV) color centers embedded in biocompatible diamond single-crystal nanoneedles.

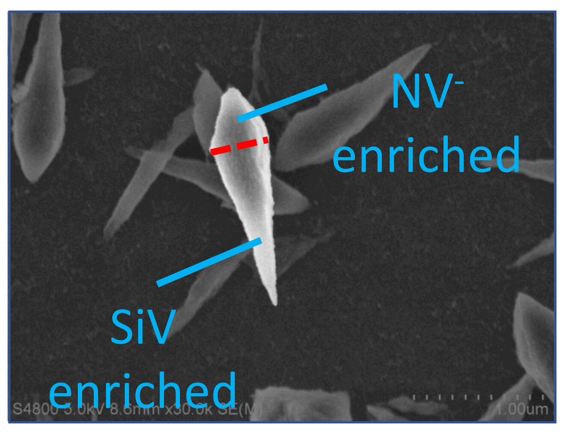
Objectives

O1. CVD synthesis of diamond nanoneedles (80–120 nm length, 20–25 nm base, 3–5 nm apex) with >5 NV centers near the surface and >5 SiV centers >10 nm from NVs for multimodal sensing.
O2. Biofunctionalization enabling safe endocytosis or membrane anchoring, compatible with quantum sensing.
O3. Diamond-PAINT/SOFI microscopy methods for multimodal sensing (fields, temperature, pH, ROS) and <20 nm resolution imaging.
O4. Automated calibration methods and software for super-resolution imaging with nanoneedles.
O5. Proof-of-concept demonstration of multimodal sensing and imaging in living cells or membranes.
O6. Exploitation plan covering DNN synthesis, biofunctionalization, sensors, and imaging.

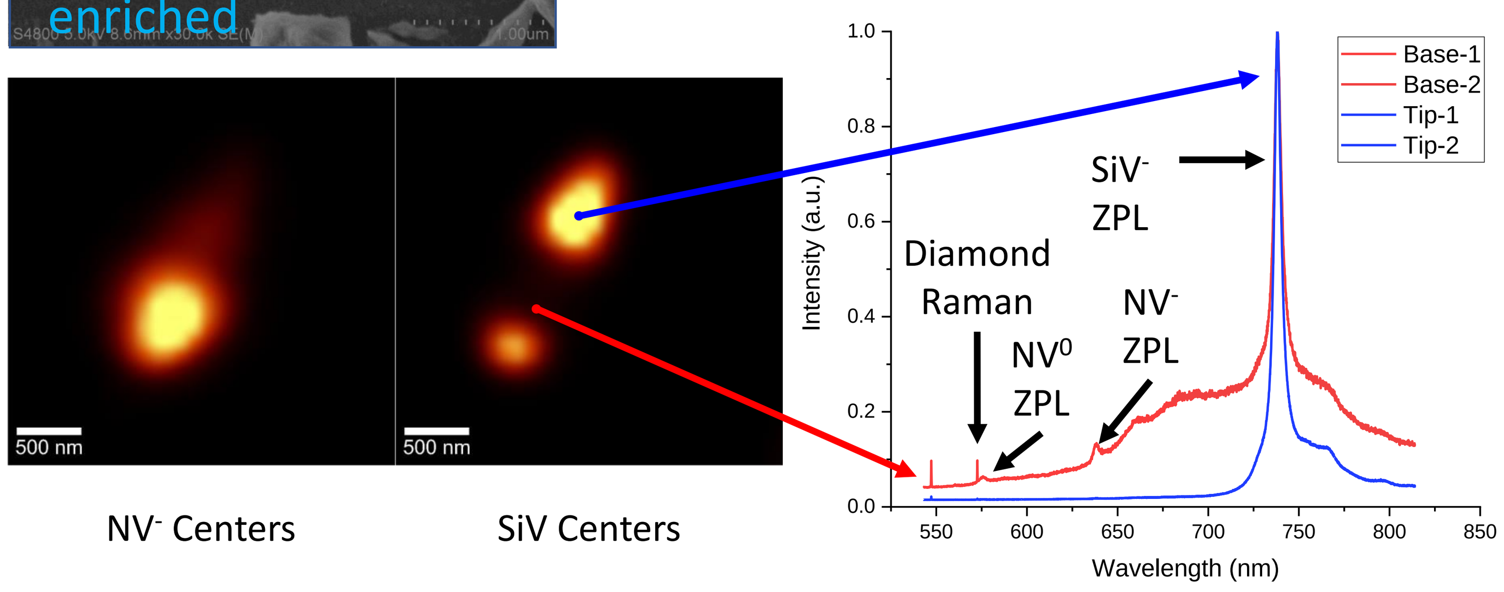
Diamond nanoneedles synthesis

- ❑ A robust and scalable synthesis technology has been developed for sub-200 nm diamond needles;
- ❑ To boost yield, a PECVD growth strategy enabling the formation of multiple nanoneedle layers in a single process is being developed.





- ❑ To optimize sensing performance, spatial engineering of color centers is being developed to form SiV⁻ at the tip and NV⁻ at the base.

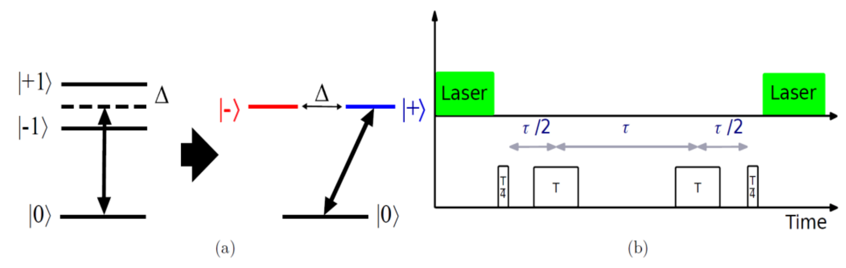


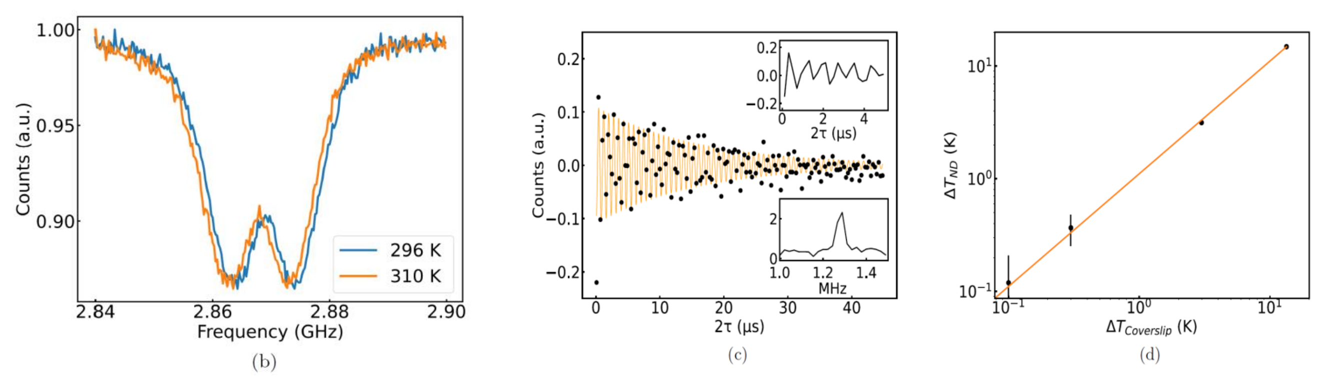
Intermediate conclusions

- ❑ Two synthesis strategies were realized: one for sub-200 nm nanocrystals, and another for high-yield multi-layer growth.
- ❑ Spatial engineering of SiV⁻ and NV⁻ centers was achieved within single nanoneedles for multifunctional sensing.
- ❑ A versatile nanodiamond-based sensing platform was successfully demonstrated for real-time intra-cellular detection of temperature, pH, and radicals, showcasing the multifunctionality of NV⁻ centers for precise, non-invasive measurements in living cells.

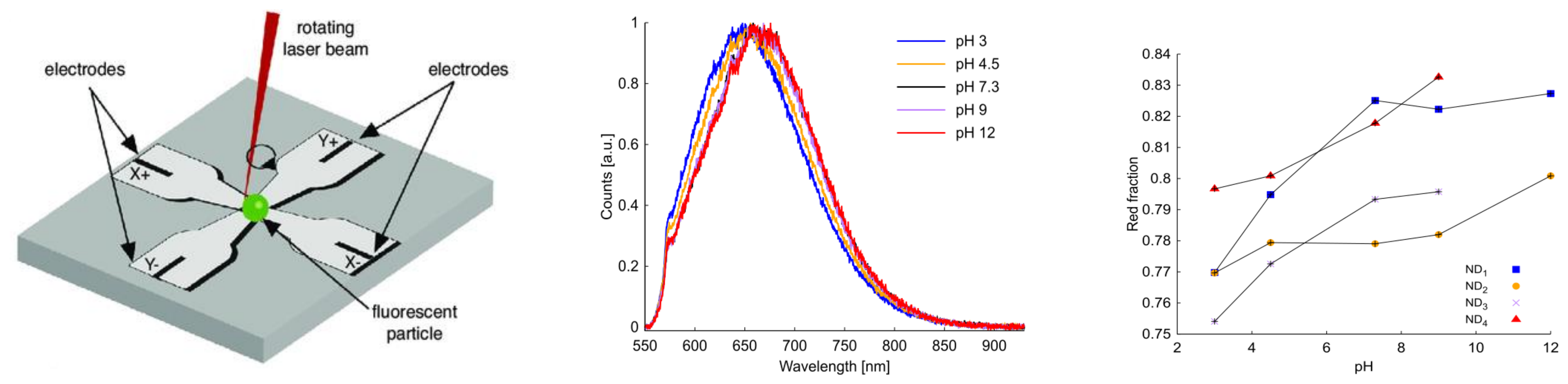
Quantum sensing and applications

❑ **Temperature sensing:** Intra-cellular nanodiamond thermometry was demonstrated in macrophages via ODMR of NV⁻ centers.

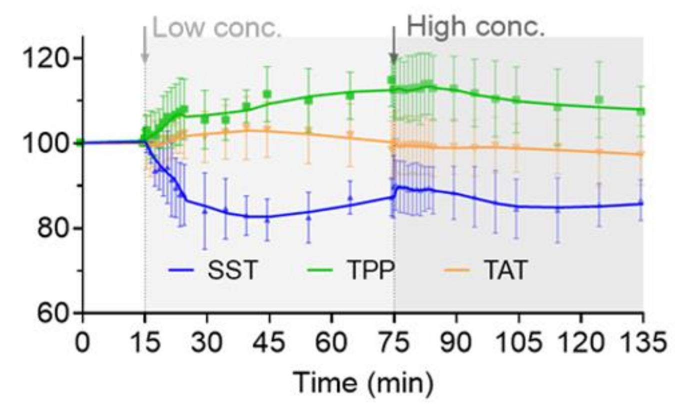


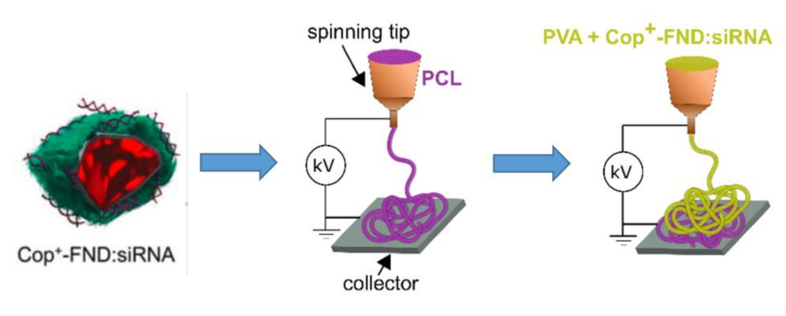


❑ **pH sensing:** Extended tracking of diffusing FNDs via ABEL trap; NV spin states probed through fluorescence lifetime.



❑ **Radical sensing:** Real-time detection of intra-cellular radicals was achieved using NV⁻ fluorescence. Changes in radical levels under ligand stimulation (SST, TPP, TAT) were monitored via ODMR microscopy in single living cell.





PVA – poly(vinyl alcohol)
PCL – poly(caprolactone)

❑ **Electrospinning producing:** Degradable polymer nanofibers embedded with a vector nanosystem – polymer-coated FNDs optimized for the binding of siRNA.

Published papers

1. Grimm et al., Phys. Rev. Lett. 134, 043603 (2025). https://doi.org/10.1103/PhysRevLett.134.043603
2. Spohn et al., arXiv 2503.18930 (2025). https://doi.org/10.48550/arXiv.2503.18930
3. Neuhoferova et al., J. Mater. Chem. B 13, 1037 (2025). https://doi.org/10.1039/d4tb01547a
4. Quarshie et al., Nanotechnology 35, 155301 (2024). https://doi.org/10.1088/1361-6528/ad18e9
5. Quarshie et al., Opt. Mater. Express 14, 965 (2024). https://doi.org/10.1364/OME.518724
6. Dementjev et al., Appl. Phys. Lett. 124, 211903 (2024). https://doi.org/10.1063/5.0202820
7. Quarshie et al., Nanotechnology 36, 165501 (2025). https://doi.org/10.1088/1361-6528/adb8f4
8. Filonenko et al., Nanotechnology 36, 185702 (2025). https://doi.org/10.1088/1361-6528/adc4f1

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