2025.

In 2025, our research group has made further substantial steps towards developing elementary hardware elements for quantum information processing via the phenomenon of optically detected magnetic resonance (ODMR). The underlying elements are solid-state quantum bits, in most cases point defects which show magneto-optical behavior which can be harnessed to store and process quantum information. A proper investigation of such systems include their precise physical description, as for both their actual molecular structure and electronic system properties, as well as proposing a set of so-called quantum protocols which make them really usable as quantum bits, and finally validating their fundamental chemical and engineering properties for the usage in real quantum information processing environments. In almost every case, these systems are also promising candidates for nanometrology (nanosensing, biosensing) applications, as the physics of these two fields are closely related. We carried out experiments in our laboratories and also executed *ab initio* calculations on modeling the qubits by KIFÜ high-performance computing units as well as our local high performance computation cluster.

Bioinert room-temperature SiC quantum sensor. We demonstrated a pathway to non-invasive sensing by using near-surface SiC qubits with bioinert, chemically stable surface termination, maintaining high sensitivity and near-infrared optical readout suitable for aqueous/biological environments [1] (see Fig. [1]).

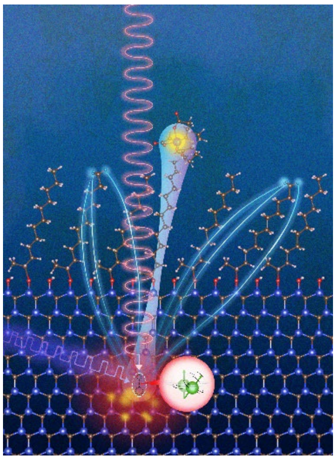

Figure 1. The scheme of shallow quantum bits (so-called divacancy defect) of silicon carbide observing paramagnetic molecules with innovative surface termination design

Coherence protection for ultra-shallow NV sensors. For 0.5–2 nm deep nitrogen-vacancy (NV) centers, we proposed a coherence-protection protocol that leverages surface-induced strain together with small constant magnetic fields, pushing coherence toward the spin–phonon limit and enabling improved vector magnetometry [2].

Quantum emission and defect identification in hBN. We linked variability in optical spectra, lifetimes, and ODMR signatures to coupled donor–acceptor spin pairs in hBN, providing a unified microscopic picture of a bright class of quantum emitters [3]. We combined isotope substitution with polytype control to identify the ultraviolet color center in hBN, showing how stacking-dependent fingerprints can pin down the defect structure [4].

Optically active, electrically inactive defect emitters. We reported a class of point defects that are bright optical emitters but have no electrical activity in the ground state, challenging a common assumption in semiconductor defect engineering and opening routes for independent optical and electrical functionality in the same host material [5].

Development of experimental setups and materials. In the optically detected magnetic resonance laboratory (ODMR), we continued our work to combine fluorescence lifetime imaging and electron spin resonance techniques in a user friendly design. This project is carried out in cooperation with R&D Ultrafast Lasers Ltd, University of Ulm and qutools GmbH in the framework of EUREKA program. We further developed materials showing persistent luminescence upon X-ray excitation, the so-called XEOL process.

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