Universität Basel

Research Project

Surface functionalization of diamond nano-magnetometers for applications in nano- and life sciences

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Project title Surface functionalization of diamond nano-magnetometers for applications in nano- and life sciences
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Magnetic field imaging and sensing are fundamental and widely used experimental methods, which are routinely

applied in a variety of scientific disciplines from chemistry, biology to the physical sciences. While such use is wellestablished

at the macro-scale (such as in clinical magnetic resonance imaging), promoting these imaging approaches to the

nano-scale would open fascinating new avenues, ranging from the structural determination and dynamics of individual (bio)-

molecules to the imaging of complex electronic systems at the single electron level. Currently, such applications are

impossible, as existing approaches to magnetic imaging are hampered by poor spatial resolution and insensitivity to weak

fields, which in combination do not allow for nanoscale magnetic field imaging. However, recent research results [1][2][3]

give strong evidence that these limitations could be overcome by utilizing single electronic spins to enable a new generation

of magnetometers, which operate deeply in the nanoscale. A particularly useful system sin this context are single electronic

spins in the form of Nitrogen-Vacancy (NV) centers in ultrapure diamond [5]. The versatility of such NV magnetometers has

been demonstrated in first proof-of-concept studies to yield single electron spin sensitivity [7] and imaging resolutions down

to the nanoscale [4]. In order to fully exploit the potential of NV magnetometry in scientifically relevant settings and future

application in sensing, stable and highly quantum-coherent NV centers have to be created in close proximity to the diamond

surface [8], where they can positioned within few nanometers from an imaging target. However, such shallow NV centers

are highly susceptible to and influenced by the chemistry of the nearby diamond surface. Indeed, recent studies have shown

that such “shallow” NV centers exhibit significantly decreased spin coherence times as compared to their bulk counterparts

[9] and as a result show reduced performance in magnetic sensing. This detrimental influence of the surface is caused by

fluctuating fields generated by uncontrolled charges and spins (dangling bonds) present on the surface and could thus be

avoided by proper termination of the diamond surface. To realize high-performance nanoscale NV magnetometers, it is

therefore indispensable to gain a high degree of control of diamond’s surface chemistry by a targeted even termination with

different chemical funtionalities. Furthermore, such termination is an important prerequisite and starting point for further

surface functionalization, which are key elements for future sensing applications. For example, a target for NV

magnetometry, such as complex bio-molecules could be attached to the diamond surface and then be sensed and imaged by a

close by, shallow NV center. The ultimate goal of this approach would be to provide atomically resolved, structural

information of such molecules on the single-molecule level. This would provide deep insight into the structural behaviour of

a broad range of molecules and will open up a new route to biosensing applications with ultimate sensitivity.

In order to achieve these challenging, scientifically highly interesting and demanding goals, we here propose the

targeted engineering of the diamond surface by a defined chemical termination with a high degree of control with respect to

uniformity and density of the terminating chemical entities. This will allow for deterministic preparation of highly quantum

coherent NV centers in close proximity to the diamond surface for sensing. In the second phase of the proposed thesis

project, diamond’s surface chemistry will be further explored and expanded in first instance to the immobilization of small

molecules exhibiting interesting magnetic properties like e.g. the spinlable TEMPO or various metal complexes and in a

second phase more complex molecules like the haem-center or metalloproteins to point the direction towards first

scientifically valuable applications of NV magnetometry in nano-physics and the life-sciences. In summary, the goals of our

proposed project application are to obtain a well-defined, chemically terminated diamond surface, which protects the NV

spin from surface-induced spin dephasing. Furthermore, we will demonstrate the functionalization of the as-prepared

diamond surface with various molecules and molecular complexes with a particular focus towards future applications in the

life-sciences. Finally we will combine our highly coherent, shallow NV spins with the functionalized diamond surfaces to

study the physics and nano-chemistry of the attached molecules.

Keywords diamond, surface functionalization, spins, nitrogen-vacancy center, sensing, quantum-sensing
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