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## WHITE PAPERS & APPLICATION NOTES



### Technology leaps in quantum sensing

Advances in nano magnetometry using tailored electronics and fast-switchable lasers

Taking advantage of collective quantum effects has enabled the so-called first quantum revolution in the 20th century for technologies such as nuclear magnetic resonance spectroscopy, magnetic resonance imaging, and the development of transistors, LEDs, solar panels, and lasers. Today, amid the second quantum revolution new sensing schemes offer higher sensitivities and better resolution thanks to the possibility to detect and control individual quantum states in microscopic systems like atoms, quantum dots, or color centers.

Emerging quantum sensing techniques could lead to the improvement of sensing technologies ranging from quantum gradiometers and accurate atomic clocks to low-noise quantum interferometric microscopy and ultimately find commercial use in geophysics for oil-drilling sites, or bio-machine interfacing via magnetic-field sensing.

As quantum sensing technology has matured over recent years, one of the outstanding techniques for commercially developed systems is based on nanoscale magnetometry with Nitrogen-Vacancy (NV) centers in diamond. These centers act as optically addressable, highly sensitive quantum sensors which are highly miniaturized and localized to atomic length scales. Employing a scanning-probe approach with one NV center at the tip of an AFM (Atomic Force Microscope) cantilever allows measuring magnetic fields with a spatial resolution on the nanometer scale and an extreme measurement accuracy.

Irrespective of which quantum sensing technology prevails, current solutions rely on the availability of state-of-the-art components. Efforts towards commercialization drive improvement of the techniques for capturing or cooling these quantum centers and techniques for initializing, manipulating, and reading out single quantum states. This in turn drives the development of new lasers and electronics as well as miniaturization and innovative ways to allow mass production. In this white paper we give an overview of the current proposed solutions for quantum sensors based on NV center magnetometry.

#### Nanoscale quantum magnetometry

Over the last decade, single electron spins in diamond have been established as nanoscale quantum sensors that exhibit excellent sensitivity and nanoscale resolution for imaging and sensing of magnetic fields and other quantities, such as electric fields or temperature [1]. Spins couple naturally to magnetic fields through the Zeeman effect. They can exhibit long quantum coherence times that can be exploited to yield excellent magnetic field sensitivities.

Local spins can be localized to atomic length scales that, in turn, enables imaging with nanoscale resolution. These quantum sensors can measure magnetic fields, and thus, electric currents with an unprecedented sensitivity and spatial resolution. Applications include determining magnetic structures on surfaces of multiferroic or antiferromagnetic materials or mapping high-frequency currents (GHz) flowing in electronic circuits.

Nitrogen vacancy (NV) centers in diamond have been recently identified as suitable candidates because the point defect provides an isolated spin state which can be manipulated using microwaves. These combined properties allow for optical detection of magnetic spin resonance (ODMR) at the level of individual NV electronic spins (Figure 1). Magnetometry based on NV center spins measures the energy shifts — or, equivalently, shifts in the quantum-mechanical phase — that a spin experiences in the presence of a magnetic field. These ODMR lines represent the simplest method of implementation of such single-spin magnetometry, where the splitting between the observed ODMR resonances is directly proportional to the magnetic field the NV spin experiences.

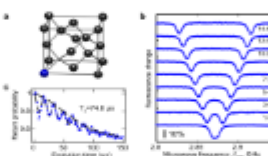


Figure 1. The structure of NV center spins in diamond. (a) Crystal structure of the NV center. (b) Optically detected electronic spin resonance, which gives rise to the characteristic ODMR spectra. (c) ODMR spectra showing the splitting between the observed ODMR resonances. The splitting between the observed ODMR resonances is directly proportional to the magnetic field the NV spin experiences.

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