Q 5: Magnetometry

Time: Monday 11:00–13:00 Location: HS 1221

Invited Talk Q 5.1 Mon 11:00 HS 1221

Tailoring design of quantum sensor to biomedical applications
— •Victor Lebedev, Simon Nordenstroem, Stefan Hartwig, and Thomas Middelmann — PTB 8.2, Abbestr. 2-12, D-10587 Berlin, Germany

Atomic magnetometers are among the most established types of quantum sensors and can be flexibly engineered to match the signal properties specific to the given application. Biomagnetic studies call for extraordinarily broad parameter ranges – bandwidth, sensitivity and isotropy, to name a few – to be secured in view of burst-like, arbitrarily oriented biological magnetic fields [1]. This implies distinct design decisions for the sensor in the sense of geometry, atomic medium and operation mode, accounting also for the constraints of the clinical laboratory environment and practicality. Here we illustrate the approach by several application cases, and, in particular, with atomic magnetometers for magnetomyography [2], which is characterized by field patterns being beyond the reach of the conventional sensors used in industry and studied in labs. We discuss broader applications of the implemented magnetometer design and further improvements of the measurement technique.

[1] Lebedev et al, in Flexible high performance magnetic field sensors, Springer, 2023.
[2] Marquetand et al, Int. J. Bioelectromagn. 23, 2, 11 (2021).

Q 5.2 Mon 11:30 HS 1221

A Compact Optically Pumped Magnetometer for Biomagnetism in Space
— •Sascha Neinert[1,2], Kirti Vardhan[2], Jenichi Felizco[1], Marc Christ[1,2], Kai Gehrke[1], Andreas Thies[1], Olaf Krüger[1], Martin Jutisz[1,2], Mustafa Gündoğan[1,2], Victor Lebedev[3], Stefan Hartwig[3], Simon Nordenström[3], Thomas Middelmann[3], and Markus Krutzik[1,2] — [1]Ferdinand-Braun-Institut gGmbH, Berlin — [2]Humboldt-Universität zu Berlin — [3]Physikalisch-Technische Bundesanstalt, Berlin

Effectively monitoring and diagnosing astronauts' neuromuscular conditions during space missions is crucial for adapting their training. The MyoQuant project is dedicated to investigating the utility of magnetomyography with optically pumped magnetometers (OPMs) to surpass conventional methods in a non-invasive manner.

Leveraging warm alkali atom vapors, laser light, and external magnetic fields, OPMs offer a flexible and non-invasive solution. Our primary objective is to develop a compact Mx-type magnetometer utilizing cesium vapor, delivering high bandwidth and robustness suitable for moderately shielded environments in space.

We provide an overview of the current state of development for our compact OPM and discuss our progress in tailoring the sensor for biomedical applications. Facilitating additive manufacturing of ceramics and investigating wafer-based MEMS vapor cell fabrication techniques, we aim to develop a micro-integrated sensor package for extended space-borne missions.

Q 5.3 Mon 11:45 HS 1221

Integrated magnetic field camera based on diamond NV center infrared absorption ODMR
— •Julian M. Bopp[1,2], Hauke Conradi[3], Felipe Perona[2], Anil Palaci[1], Jonas Wollenberg[1], Thomas Flisgen[2], Armin Liero[2], Heike Christopher[2], Norbert Keil[3], Wolfgang Knolle[4], Andrea Knigge[2], Wolfgang Heinrich[2], Moritz Kleinert[3], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, 12489 Berlin, Germany — [3]Fraunhofer-Institut für Nachrichtentechnik, Heinrich-Hertz-Institut, 10587 Berlin, Germany — [4]Leibniz-Institut für Oberflächenmodifizierung e.V., 04318 Leipzig, Germany

Magnetic field sensors based on diamond nitrogen vacancy (NV) centers reveal outstanding sensitivities at room temperature. Such sensors are attractive for biological applications. Nowadays, multiple sensor types can be distinguished. While fiber-packaged sensors are small, hand-held devices, they cannot record magnetic field images. However, scanning magnetometers and camera-based approaches require bulky optics or moving parts, which render photonic packaging impossible.

In our work, we combine the advantages of fiber-packaged and imaging magnetometers. We propose and demonstrate a chip-integrated, fiber-packaged multi-pixel magnetic field camera (patents US11719765B2, EP4099041A1). The camera employs perpendicularly intersecting infrared and green laser beams to perform spatially resolved ODMR in a diamond substrate.

Q 5.4 Mon 12:00 HS 1221

Compact Fiberized NV based 3D Magnetic Field Sensor
— •Jonas Homrighausen[1], Frederik Hoffmann[2], Jens Pogorzelski[2], Peter Glösekötter[2], and Markus Gregor[1] — [1]Department of Engineering Physics, University of Applied Sciences, Münster — [2]Department of Electrical Engineering and Computer Science, University of Applied Sciences, Münster

In the field of quantum magnetometry, ensembles of NV centers in diamond offer high sensitivity, high bandwidth and outstanding spatial resolution while operating at room temperature. Furthermore, the orientation of the defect centers along four crystal axes form an inherent coordinate system that can be exploited to perform vector magnetometry in a single device. For recovering three-dimensional magnetic field information, an external known magnetic field is critical, typically provided by a 3D Helmholtz coil. This however leads to a bulky and lab-bound setup and inhibits any miniaturization of the sensor device. Here, we present a novel approach that facilitates the generation of a localized bias field at the fiber tip and consequently omits the use of external field generation like Helmholtz coils and rare earth magnets. Leveraging pre-selected orientations of diamond microcrystals, we demonstrate vector magnetometry with the uniaxial DC magnetic field. We achieve a sensitivity in the $nT/Hz^{1/2}$ range, microscale spatial resolution and a sensor cross section of $<1mm^2$.

Q 5.5 Mon 12:15 HS 1221

Drone-suspended quantum gradiometer for detection of unexploded ordnance and geo-prospecting (QGrad)
— •Gunnar Langfahl-Klabes, Denis Uhland, and Ilja Gerhardt — Leibniz University, Inst. of Solid-State Physics, Appelstr. 2, 30167 Hannover

The QGrad project aims to develop quantum sensors for unshielded airborne magnetometry. We use alkali vapour atoms and gradiometry to subtract signals from multiple magnetometers. This approach holds significance for uncovering hidden raw materials, pipelines, contaminated sites, foundations, and munitions, particularly addressing the challenge of locating land mines and explosive ordnance from past wars for safe clearance.

Our collaboration includes academic partner Leibniz Institute of Photonic Technologies Jena, and industrial partners Asdro GmbH, Optikron GmbH, Supracon AG, and Toptica Photonics AG exploring the gradiometer scheme, developing the required readout components, data processing capabilities and integration for flight use.

In Europe, such quantum magnetometers are commercially unavailable, making QGrad a pioneering initiative. We report on the current status of the project and the gradiometer scheme in particular.

Q 5.6 Mon 12:30 HS 1221

NV-Magnetometry in a two-media laser cavity
— •Yves Rottstaedt[1], Lukas Lindner[1], Felix A. Hahl[1], Florian Schall[1], Tingpeng Luo[1], Roman Bek[2], Jan Jeske[1], and Marcel Rattunde[1] — [1]Fraunhofer Institute for Applied Solid State Physics, Freiburg im Breisgau, Germany — [2]Twenty-One Semiconductors GmbH, Stuttgart, Germany

Laser Threshold Magnetometry (LTM) is a novel approach to measure magnetic fields with nitrogen-vacancy (NV) centres in diamonds which can enable a significant improvement in sensitivity while taking advantage of the NV magnetometry characteristics of room-temperature vector magnetometry and the ability to measure on background fields. Instead of simply collecting the photoluminescence emitted by pumping the NV centres, the idea of LTM is to build a cavity with diamond as the laser medium using the non-linear optical cavity to effectively amplify changes in the optical signal. So far it has only been achieved in an externally seeded amplification cavity due to strong absorption in the diamond.

We present an approach of building a cavity also including a second laser medium, in this case an optically pumped semiconductor disc laser. The additional gain provided by the disc laser yields an independent laser cavity for LTM with laser threshold behaviour without the need to seed the cavity externally.

Q 5.7 Mon 12:45 HS 1221

Physics-informed neural networks for analyzing NV-diamond wide-field images of magnetic field distributions measured with a lock-in camera — •Mykhailo Flaks[1,2], Joseph S. Rebeirro[1], Muhib Omar[1], David A. Broadway[2], Patrick Maletinsky[2], Dmitry Budker[1,3,4], and Arne Wickenbrock[3] — [1]Helmholtz Institut Mainz, 55099 Mainz, Germany — [2]Department of Physics, University of Basel, Basel, CH-4056, Switzerland — [3]JGU Mainz, 55128 Mainz, Germany — [4]Department of Physics, University of California, Berkeley, California 94720-7300, USA

We use a novel approach with physics-informed neural networks (PINNs) for analyzing magnetic field distributions. We focus on wide-field images acquired from nitrogen-vacancy center-ensembles in diamond using a lock-in camera. Our method allows to reconstruct source distributions such as currents or magnetization. The inverse reconstruction technique can be used for mapping current distributions in conductors, studying superconductor vortices, and exploring magnetization textures.

We apply these techniques to the images acquired with a microwave-free NV-based imaging device, that uses the ground state level anti-crossing (GSLAC) feature. With the addition of lock-in acquisition of the magnetic field image and the PINN to the inverse problem analysis, we alleviate the effect of the ill-posed nature of the inverse problem and the presence of noise in data. We address the improved sensitivity of the underlying source distribution to advance the measurement method towards a biocompatible sensor for neurons.