Q 30: Quantum Sensing I (joint session Q/QI)

Time: Wednesday 11:00–12:30 Location: HS V

Q 30.1 Wed 11:00 HS V

Coherent Control in Quartz-Enhanced Photoacoustics: Fingerprinting a Trace Gas at ppm-Level within Seconds — •Simon Angstenberger, Moritz Floess, Luca Schmid, Pavel Ruchka, Tobias Steinle, and Harald Giessen — 4th Physics Institute and Stuttgart Research Center of Photonic Engineering, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Quartz-enhanced photoacoustic spectroscopy (QEPAS) has become a versatile tool for detection of trace gases at extremely low concentrations, leveraging the high quality (Q)-factor of quartz tuning forks. However, this high Q-factor imposes an intrinsic spectral resolution limit for fast wavelength sweeping with tunable laser sources due to the long ringing time of the tuning fork. Here, we introduce a technique to coherently control the tuning fork by phase-shifting the modulation sequences of the driving laser [1]. Particularly, we send additional laser pulses into the photoacoustic cell with a timing that corresponds to a π phase shift with respect to the tuning fork oscillation, effectively stopping its oscillatory motion. This enables acquisition of a complete methane spectrum spanning 3050-3450 nm in just three seconds, preserving the spectral shape. Our measured data is in good agreement with the theoretically expected spectra from the HITRAN database when convolved with the laser linewidth of $< 2\,\mathrm{cm}^{-1}$. This will leverage the use of QEPAS with fast-sweeping OPOs in real-world gas sensing applications beyond laboratory environments with extremely fast acquisition speed enabled by our novel coherent control scheme.

[1] S. Angstenberger, M. Floess, L. Schmid, *et al.*, Optica, accepted.

Q 30.2 Wed 11:15 HS V

Photonic Integrated Circuit Platforms for Scalable Quantum Sensors — •Fatemeh Salahshoori[1], Suat Icli[1,2], Carl-Frederik Grimpe[1], Guochun Du[1], Rangana Banerjee Chaudhuri[1], Elena Jordan[1], Klaus Boller[3], Alexander Bachmann[5], Sonia M. Garcia-Blanco[4], and Tanja E. Mehlstäubler[1,2,6] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [3]Laser Physics and Nonlinear Optics Group, MESA+ Institute of Nanotechnology, University of Twente, Enschede, The Netherlands — [4]Integrated Optical Systems, MESA+ Institute of Nanotechnology, University of Twente, Enschede, The Netherlands — [5]TOPTICA Photonics, Gräfelfing, Germany — [6]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover, Hannover, Germany

As part of the EU project "QU-PIC," we aim to develop scalable photonic integrated circuit (PIC) modules designed to meet the stringent requirements of quantum sensor applications. These modules will feature multiwavelength tunable lasers ranging from UV to the near-IR, specialized light conditioning systems, and photonic-integrated ion trap chips, all engineered for the realization of an ion trap-based quantum sensor demonstrator. This talk will give an overview of the individual components and detail on ring resonator couplers for PIC-based lasers and grating outcouplers based on an Al_2O_3 platform, using benchmarking protocols for 3D beam tomography of the PIC-based ion-trap system.

Q 30.3 Wed 11:30 HS V

Vector Magnetometry Using Shallow NV Centers with Waveguide-Assisted Dipole Excitation and Readout — •Sajedeh Shahbazi[1], Giulio Coccia[2], Argyro N. Giakoumaki[2], Johannes Lang[1], Vibhav Bharadwaj[1], Fedor Jelezko[1], Shane M. Eaton[2], and Alexander Kubanek[1] — [1]Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany — [2]Institute for Photonics and Nanotechnologies (IFN) - CNR, Piazza Leonardo da Vinci, 32, Milano 20133, Italy

On-chip magnetic field sensing with NV centers in diamond requires scalable integration of 3D waveguides into diamond substrates. Here, we develop a sensing array device with an ensemble of shallow implanted NV centers integrated with arrays of laser-written waveguides for excitation and readout of NV signals. Our approach enables an easy-to-operate on-chip magnetometer with a pixel size proportional to the Gaussian mode area of each waveguide. The performed continuous wave optically detected magnetic resonance on each waveguide gives an average dc-sensitivity value of $195 \pm 3\mathrm{nT}/\sqrt{\mathrm{Hz}}$. We apply a magnetic field to separate the four NV crystallographic orientations of the magnetic resonance and then utilize a DC current through a straight wire antenna close to the waveguide to prove the sensor capabilities of our device. We reconstruct the complete vector magnetic field in the NV crystal frame using three different NV crystallographic orientations. The waveguide mode's polarization allows B-filed projection into the lab frame[1]. Ref.1: Shahbazi et al.(2024), arXiv:2407.18711

Q 30.4 Wed 11:45 HS V

Limits of absolute vector magnetometry with NV centers in diamond — •Dennis Lönard, Isabel Cardoso Barbosa, Stefan Johansson, Jonas Gutsche, and Artur Widera — Department of Physics and State Research Center OPTIMAS, University of Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

The nitrogen-vacancy (NV) center in diamond has established itself as a promising quantum sensing platform. Most notably, vector magnetometry can be performed by observing the Zeeman splitting of the NV's spin resonance frequencies. Relative magnetometry has been shown to reach magnetic-field sensitivities down to fT/rt(Hz), and the current literature contains many examples of how to improve these sensitivities. However, the accuracy of absolute magnetometry is limited by factors other than sensitivity, and formulas for computing the magnetic-field vector are often only approximated.

In this talk, we discuss exact, analytical, and fast-to-compute formulas for calculating the magnetic-field vector from measured resonance frequencies and vice versa. We do not use any approximations and find solutions that are exact within the measurement accuracy, valid for all ranges of magnetometry and all types of NV diamonds, and are much faster to compute than comparable numerical techniques. Finally, we discuss often-used approximations for these calculations and assess their validity and accuracy for different magnetic-field regimes. We developed an open-source Python package that includes all the shown formulas.

Q 30.5 Wed 12:00 HS V

Ultra-stable miniaturized optical systems for compactatom-based quantum sensors — •Conrad Zimmermann, Marc Christ, Sascha Neinert, and Markus Krutzik — Ferdinand-Braun-Institut (FBH), Berlin, Germany

The transition of atom-based quantum sensors from laboratory experiments towards compact field-usable devices demands for specialized miniaturization and integration technologies. On that path we develop and qualify a versatile technology toolbox enabeling robust and ultra-stable miniaturized optical systems to trap, probe and manipulate atomic ensembles. We set up a micro-integrated optical dipole trap system with a system volume of about 25 ml. It creates two high-power laser beams which precisely overlap in their focal points ($\omega_0 = 32\,\mu$m) at an angle of 45°. After two years of operation with up to 2.5 W of optical power and no signs of degradation, we share measurements demonstrating the mechanical stability and the capabilities and potentials of used technologies [1].

In addition, we utilize additive manufacturing of ceramics [2] and metals to realize functionalized components such as micro-optical benches, mounts and vacuum systems. We also report on our efforts regarding ultra-high vacuum (UHV) compatibility of components and bonds using our dedicated outgassing qualification system.

[1] M. Christ et al. *Opt. Express* 32, 40806-40819 (2024)
[2] M. Christ et al. *Adv. Quantum Technol.*, 2400076 (2024)

Q 30.6 Wed 12:15 HS V

A Miniaturized Fiber-Based Magnetic Field Sensor Based on Nitrogen-Vacancy Centers — •Stefan Johansson, Dennis Lönard, Isabel Cardoso Barbosa, Jonas Gutsche, and Artur Widera — Physics Department and State Research Center OPTIMAS, RPTU Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

Sensing based on quantum effects is believed to be one of the technologies of the near future. Among other quantum magnetic field sensors, such as optically pumped magnetometers and superconducting interference devices, the nitrogen-vacancy (NV) center in diamond is a prime candidate for measuring magnetic fields. It provides a solid crystalline platform operating under ambient conditions without extensive cooling or encapsulation. This chemically and physically robust diamond platform allows measurements in direct contact with a sample, making it highly sensitive to an emitted field, e.g., from muscle signals or magnetic surfaces. While many fiber-based sensors have been published, only a few are portable or provide the capability to measure vectorial magnetic fields using optically detected magnetic resonance measurements. Here, we present our flexible, portable, yet robust fiber-based sensor. The design allows the use of lithographic processes such as direct laser writing of elementary silver and polymer structures on the optical fiber tip. The silver structure allows excitations using microwaves, while the polymer waveguide structure guides excitation and fluorescence light and is used to fixate a 15 μm-sized diamond to the tip of the optical fiber. We verify the capabilities of our sensor in vectorial measurements of a magnetic coil system.