Quantum sensorics on silicon carbide single crystals: high-resolution spectroscopy study

Kirill Boldyrev[1,2,3*], **Daria Gutsenko**[1,2], **Eduard Sektarov**[1,3]

[1] *Institute of Spectroscopy of the Russian Academy of Sciences, Troitsk, Moscow, Russia*
[2] *Moscow Institute of Physics and Technology, Dolgoprydny, Moscow region, Russia*
[3] *Higher School of Economics, Physical faculty, Moscow, Russia*
*E-mail: kn.boldyrev@gmail.com

Nowadays, devices, in which the quantum properties of a substance are used, attract a growing interest, for example, quantum computers[1] and quantum memory for quantum cryptography[2]. In recent years, another class of applications has emerged, in which quantum-mechanical systems are used as sensors for various physical quantities, such as magnetic and electric fields, time and frequency, temperature and pressure. Quantum sensors — a new technology that uses quantum nature of phenomena for ultrasensitive detection[3]. They are of particular interest for detecting weak signals in nanoscale measurements. Quantum optical sensors use effects such as the Zeeman effect, the Stark effect, piezo-spectroscopic effects, effects associated with the temperature dependences of the electron-phonon interaction, effects associated with the Boltzmann distribution over energy states, etc., affecting parameters of a substance. The properties of symmetry and the presence of degenerate states are used. The classification of detected perturbations is time-dependent (violation of coherence and the corresponding registration technique), (quasi) static — fully symmetric and morphic (anisotropic) perturbations. In particular, on NV centers in diamond, using the above effects, highly sensitive quantum sensors of magnetic, electric fields, voltages, temperature and pressure were demonstrated (see review[4]). Moreover, such photon sensors are proposed to be used for the diagnosis of cancer (see, for example,[5]). In this regard, quantum detection is very promising from a practical point of view. Quantum sensors have unprecedented sensitivity and measurement range in a wide range of research, such as condensed matter physics, nanoscale magnetic resonance imaging, cell dynamics in individual cells, and even brain science. Quantum sensors use a feature of quantum systems — their strong sensitivity to external disturbances. This trend in quantum technology resembles the history of semiconductors: here sensors, for example, for measuring illumination, based on selenium photo cells [6], found commercial applications long before computers. Although quantum detection as a separate area of research in the field of quantum science and technology appeared relatively recently, many concepts in the physical community are well known and have arisen as a result of decades of high-resolution spectroscopy. Famous examples include atomic clocks, atomic gas magnetometers and superconducting quantum interference devices. Detection on such principles, called "quantum metrology", "quantum-improved detection" or "second-generation quantum sensors," was considered in [7]. In our work, we studied the high-resolution absorption and luminescence spectra of a high-quality silicon carbide single crystals in external magnetic and electric fields. Silicon carbide is interesting in that some of its color centers (V-centers) have spin 3/2 in the ground state [8], which makes it possible to use such states to obtain quantum qudits. Extremely narrow lines were detected in the infrared region of the spectrum, which reacted intensively to external conditions. Effects were observed similar to those previously observed by us in $^{7}LiYF_4$-Ho single crystals [9], where for the first time the anticrossing of hyperfine sublevels was observed in external magnetic fields.

A financial support by the Russian Science Foundation under Grant 19-72-10132 are acknowledged.

References

[1] *D.P. DiVincenzo*, The Physical Implementation of Quantum Computation // Fortschr. Phys. **48**, 771 (2000).

[2] *N. Gisin, G. Ribordy, W. Tittel, H. Zbinden*, Quantum cryptography // Rev. Mod. Phys. **74**, 145 (2002).

[3] *D. Budker, M. Romalis*, Optical Magnetometry // Nat. Phys. **3**, 227 (2007).

[4] *R. Schirhagl, K. Chang, M. Loretz, C.L. Degen*, Nitrogen-vacancy centers in diamond: nanoscale sensors for physics and biology // Annu. Rev. Phys. Chem. **65**, 83 (2014).

[5] *A.N. Generalova, V.V. Rocheva, A.V. Nechaev, D.A. Khochenkov, N.V. Sholina, V.A. Semchishen, V.P. Zubov, A.V. Koroleva, B.N. Chichkov, E. V. Khaydukov*, PEG-modified upconversion nanoparticles for in vivo optical imaging of tumors RSC Advances **6**, 30089 (2016).

[6] *E. Weston*, Exposure meter // U.S. Patent 2016469 (1931).

[7] *V. Giovannetti, S. Lloyd, L. Maccone*, Advances in Quantum Metrology // Nat. Photonics **5**, 222 (2011).

[8] *V.A. Soltamov, C. Kasper, A.V. Poshakinskiy, A.N. Anisimov, E.N. Mokhov, A. Sperlich, S.A. Tarasenko, P.G. Baranov, G.V. Astakhov, V. Dyakonov*, Excitation and coherent control of spin qudit modes with sub-MHz spectral resolution // Nat. Commun. **10**, 1678 (2019).

[9] *K.N. Boldyrev, M.N. Popova, B.Z. Malkin, N.M. Abishev*, Direct observation of hyperfine level anticrossings in the optical spectra of a $^7LiYF_4:Ho^{3+}$ single crystal // Phys. Rev. B **99**, 041105(R) (2019).