New IR color centers of silicon carbide for the quantum sensors

Kirill Boldyrev [1,2] and Daria Gutsenko [2]

[1] Institute of Spectroscopy RAS, Troitsk, Moscow, 108840, Russia

[2] Moscow Institute of Physics and Technology, Dolgoprudny, Moscow Region, 141701, Russia

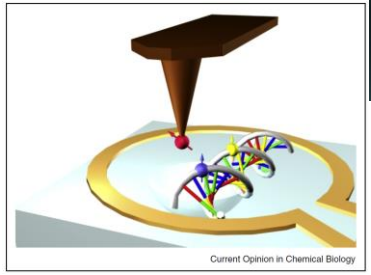
METANANO 2020 online

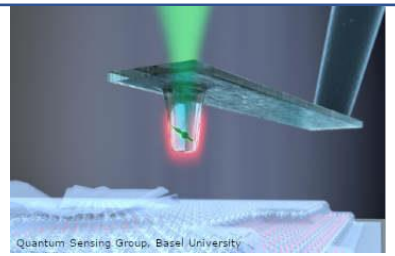
Quantum systems are **extremely sensitive** for external environment disturbance.

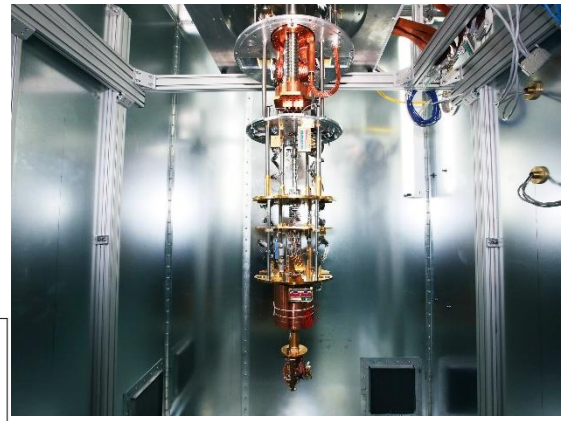
Quantum sensor is a quantum device that responds to an external stimulus.

There are 4 criteria for quantum sensors:

- The system has to have discrete, resolvable energy levels.
- You can initialize the sensor and you can perform readout (turn on and get answer).
- You can coherently manipulate the sensor.
- The sensor interacts with a physical quantity and has some response to that quantity.







The most investigated material for quantum sensor is Diamond. On NV centers in diamond, highly sensitive quantum sensors of magnetic and electric fields, voltages, temperature and pressure were demonstrated.

Compared to NV centers in diamond, defects in silicon carbide have several advantages:

- a long coherence time even at room temperatures;
- the photoluminescence of color centers in silicon carbide is observed in the near and middle infrared spectral range;
- the greater manufacturability of using silicon carbide in comparison with diamond.

It can be concluded that various lattice defects of silicon carbide are suitable as an alternative to NV centers in diamond.

New IR color centers of silicon carbide for the quantum sensors

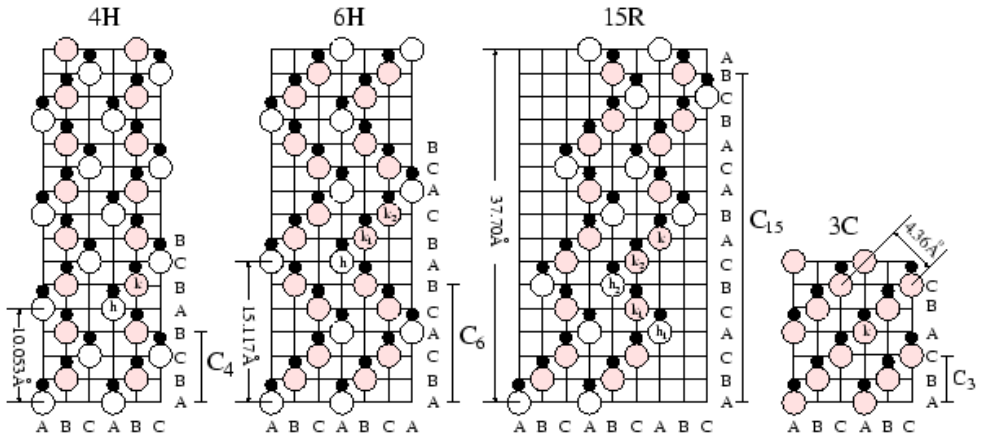
Kirill Boldyrev and Daria Gutsenko

METANANO 2020 online

MIPT

Introduction | Structure | Setup | Results | Conclusion

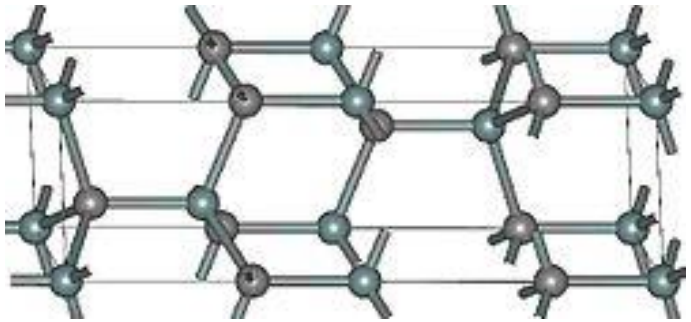
Crystal structure



Silicon carbide exists in the form of a number of crystalline forms - polytypes characterized by different packing methods of atoms - 2H, 3C, 4H, 6H, 15R.

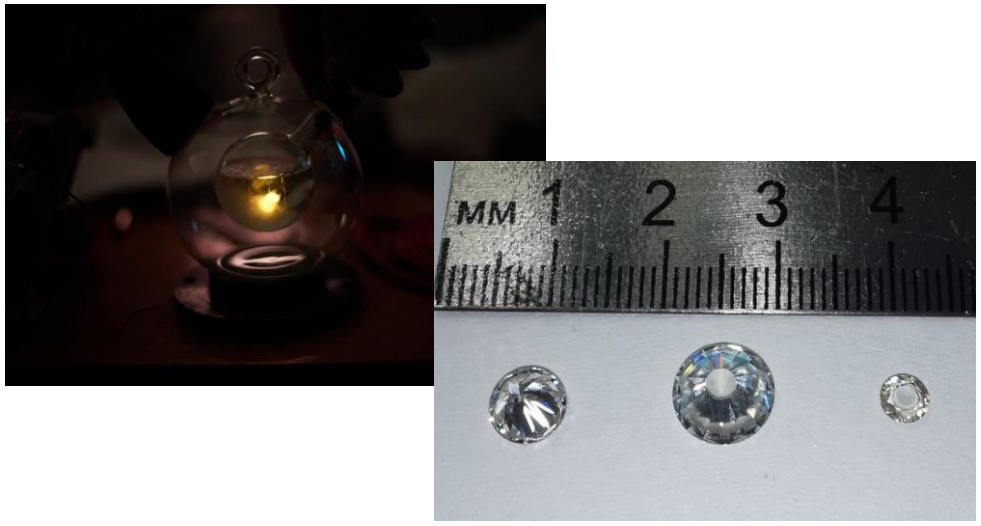
Different polytypes are atomic layers (A, B, C) located in a certain sequence.

Luminescence and absorption are determined by electronic transitions in lattice defects — **color centers**. A wide variety of color centers characteristic of various polytypes allows the use of SiC spectral analysis to study the quantum properties and structure of vacancy color centers.



Synthesis

Samples for the study were obtained by physical vapor deposition (PVD) in the temperature range 1750–2750 K in a discharged neutral atmosphere. As a feedstock, high-purity polycrystalline silicon carbide was used. Samples up to 10 × 10 × 10 mm^3 in size were homogeneous crystals, slightly colored in yellow. The orientation of the samples was carried out by optical methods. To confirm the crystal structure (polytype), the method of Raman scattering and IR reflection was used.



New IR color centers of silicon carbide for the quantum sensors

Kirill Boldyrev and Daria Gutsenko

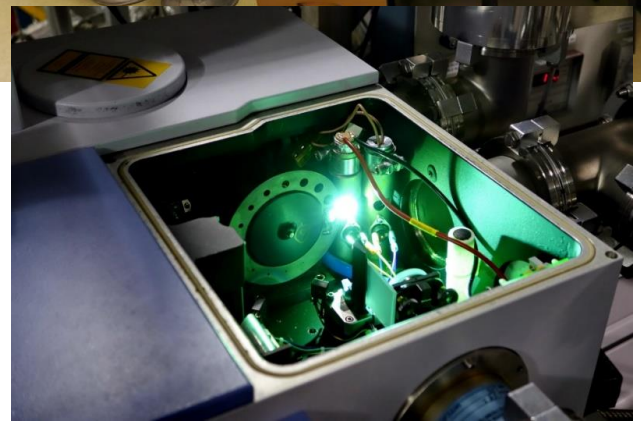
METANANO 2020 online

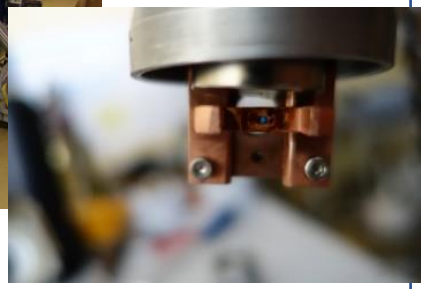
MIPT

Introduction | Structure | Setup | Results | Conclusion

Research methods and setups

Room-temperature reflection spectra in the midIR range were obtained on a Bruker IFS 66V Fourier transform spectrometer using an attachment with a 15° reflection angle (close to normal); As a radiation detector, a DLaTGS pyrodetector was used. Roomtemperature Raman spectra were obtained on a multichannel spectrometer with a triple monochromator in the dispersion subtraction mode in the backscattering geometry. Raman spectra were excited with an argon laser with a radiation wavelength at 514.5 nm; registration was performed using a liquid-nitrogen cooled CCD camera (Princeton Instruments); the spectral resolution was 2 cm^{-1}. Absorption and luminescence spectra were measured using a Bruker IFS 125HR high-resolution Fourier spectrometer equipped with a CryoMech ST403 closed-cycle optical helium cryostat and a homemade luminescent attachment module. To excite luminescence, a diode laser with a wavelength of 405 nm and a radiation power of 50 mW (the diameter the focal spot was 0.5 mm) was used. The luminescence spectra were recorded using a highly sensitive InGaAs detector





Spectral region: 10–35000 cm^{-1}
Resolution: up to 0.001 cm^{-1}
Temperature region: 1.2 – 800 K
Diode lasers: 365, 405, 523, 635 nm

New IR color centers of silicon carbide for the quantum sensors

Kirill Boldyrev and Daria Gutsenko

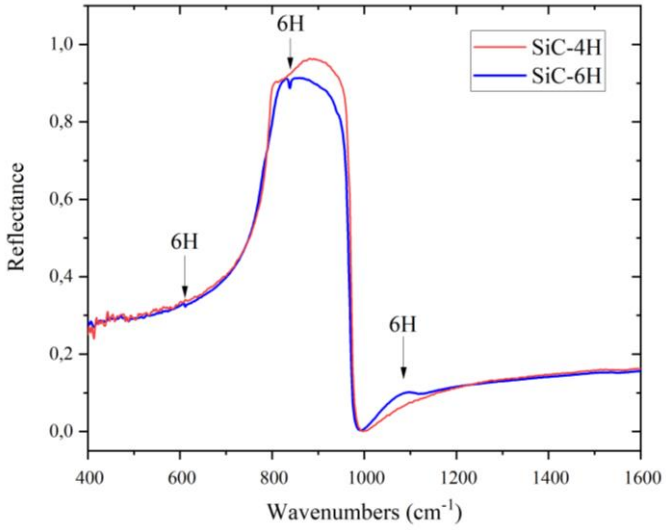
METANANO 2020 online

MIPT

Introduction | Structure | Setup | Results | Conclusion

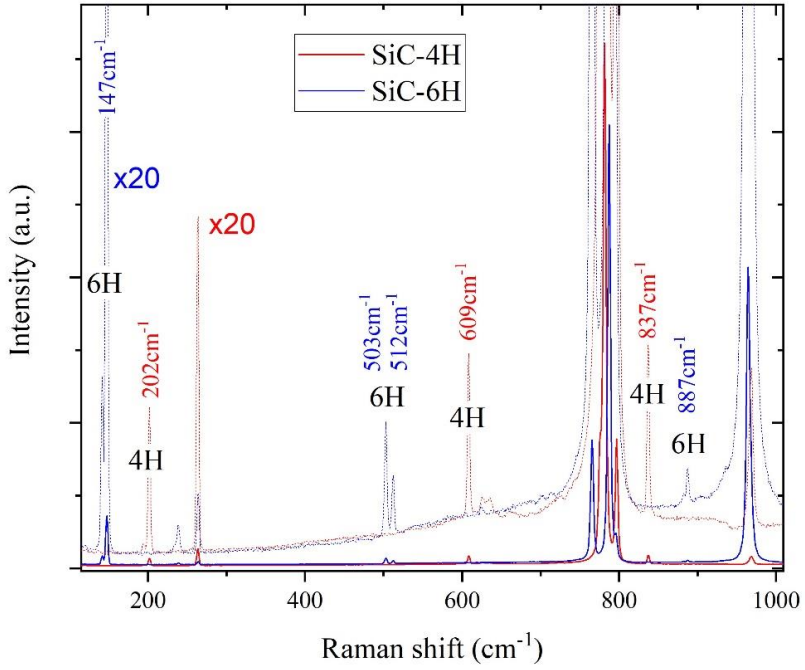
Reflection spectra

Polytypes of samples of examined SiC crystals were determined by methods of IR reflection and Raman scattering. These methods yield complementary information about the phonon spectrum. In addition, whereas information in reflection spectra is obtained from a subsurface layer at a depth on the order of the wavelength, in Raman spectra in the case of transparent crystals, such as silicon carbide under study, it is possible to obtain information from deeper bulk layers, which is important in analysis of the homogeneity of the obtained samples. Here there are reflection spectra of two single crystals. One of these samples (blue spectrum) showed a richer structure in comparison with the other (red spectrum), which is due to the appearance of new phonons in the case of the SiC-6H polytype.



Raman spectra

The Raman spectra for two examined SiC-4H and SiC-6H samples were presented from which it was possible to unambiguously identify their polytype structures. As in the case of IR reflection spectra, a larger number of vibrational modes were observed for the SiC-6H sample. The low-frequency range of the spectrum, in which lines that appear due to the Brillouin zone folding are observed, is the most informative for the identification of the of the SiC polytypes.



New IR color centers of silicon carbide for the quantum sensors

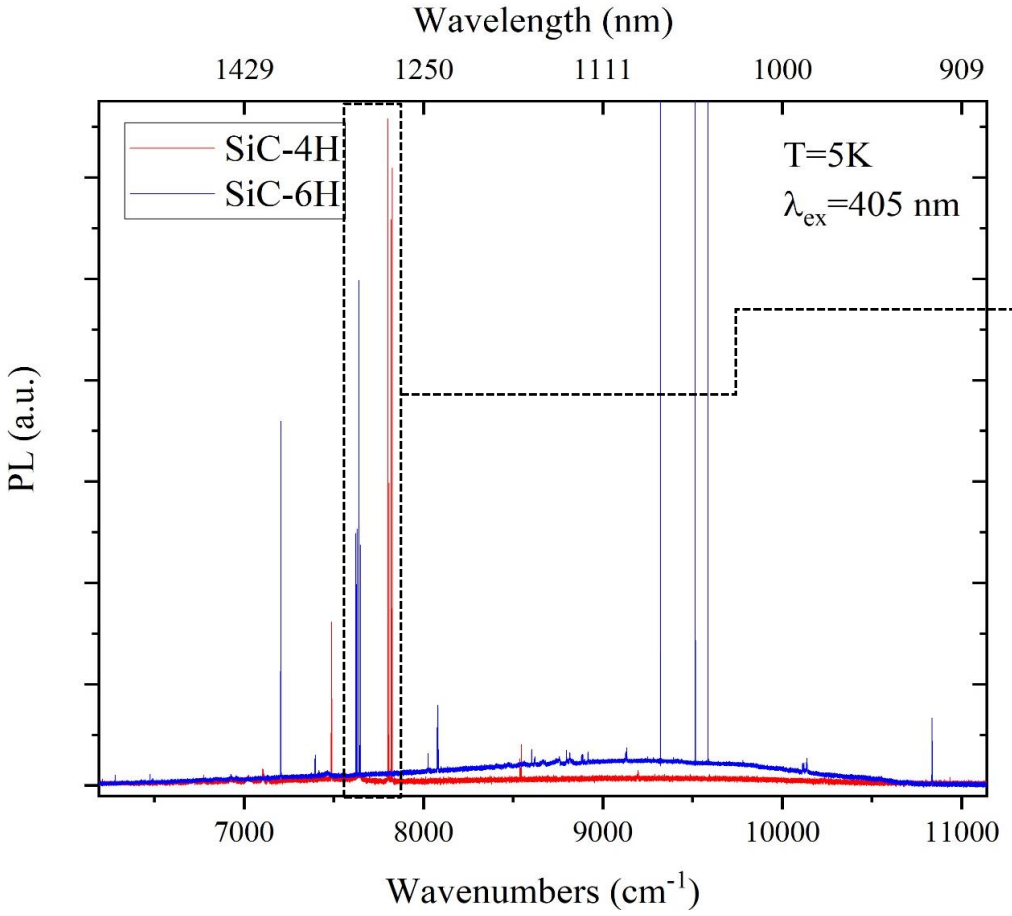
Kirill Boldyrev and Daria Gutsenko

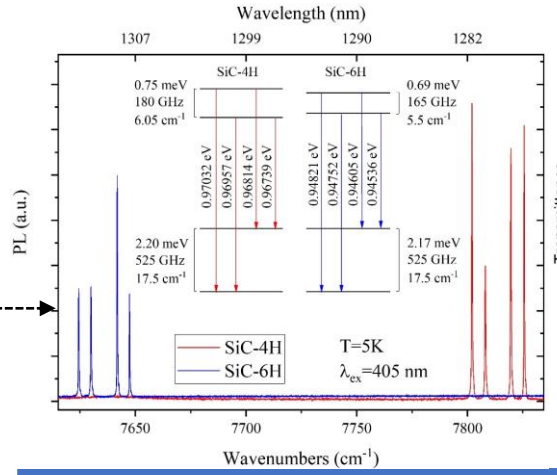
METANANO 2020 online

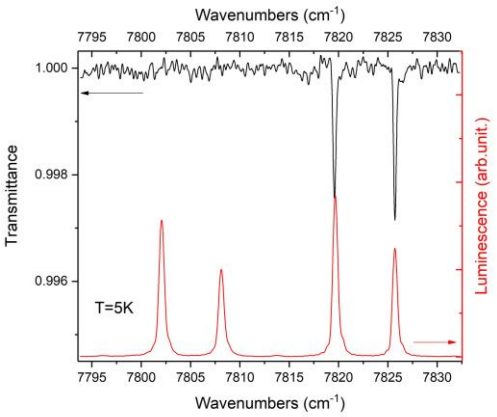
MIPT

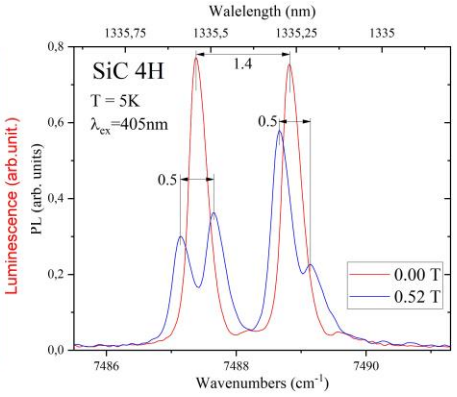
Introduction | Structure | Setup | Results | Conclusion

Transmission and luminescence spectra









SiC-4H				SiC-6H			
cm^{-1}	nm	eV	descript	cm^{-1}	nm	eV	descript
7825.6	1277.86	0.97025	V.strong and narrow	7647.4	1307.63	0.94816	V.strong and narrow
7819.6	1278.84	0.96951	D=23.5 cm^{-1}	7641.9	1308.58	0.94747	D=23cm^{-1}
7808.1	1280.72	0.96808		7630.0	1310.62	0.94600	
7802.1	1281.71	0.96734		7624.4	1311.58	0.94531	
7638	1309.24	0.94699	weak	7462	1340.12	0.92517	weak
7488.68	1335.349	0.92848	Doublet	7397.4	1351.83	0.91716	Doublet
7487.24	1335.606	0.92830	D=1.5 cm^{-1}	7396.5	1351.99	0.91705	D=0.9 cm^{-1}
7133.9	1401.76	0.88449	Doublet (+3rd line)	6956.5	1437.50	0.86250	Doublet (+3rd line)
7109.40	1406.588	0.88145	D=24.5-29.2 cm^{-1}	6931.5	1442.69	0.85940	D=29.5 cm^{-1}
7104.72	1407.515	0.88087	d=4.7 cm^{-1}	6927	1443.63	0.85884	d=4.5 cm^{-1}

New IR color centers of silicon carbide for the quantum sensors

Kirill Boldyrev [1,2] and Daria Gutsenko [2]

[1] Institute of Spectroscopy RAS, Troitsk, Moscow, 108840, Russia

[2] Moscow Institute of Physics and Technology, Dolgoprudny, Moscow Region, 141701, Russia

METANANO 2020 online

- ✓ Extremely narrow lines were obtained in the infrared luminescence and absorption spectra of the hexagonal modification of SiC (4H, 6H).
- ✓ Partial identification of the spectral lines was carried out; some of the lines were observed for the first time.
- ✓ Blue shift of the spectral lines for SiC-4H was found.
- ✓ For the most intense quartet in the region of 1.3 μm the energy structure of the levels for both 4H and 6H modifications was obtained.

Thank you for attention!

kn.boldyrev@gmail.com