New IR color centers of silicon carbide for the quantum sensors

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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.
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Introduction

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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.

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 mm³ 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.

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.
**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. Room-temperature 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 of 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
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.

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.
### Introduction

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### Structure

#### Transmission and luminescence spectra

<table>
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<tr>
<th>Wavenumbers (cm⁻¹)</th>
<th>Wavelength (nm)</th>
<th>eV</th>
<th>descript</th>
<th>Wavenumbers (cm⁻¹)</th>
<th>Wavelength (nm)</th>
<th>eV</th>
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### Setup

#### Experimental Details

**Sample Preparation:**

- Silicon carbide (SiC) substrates were grown using the CVD technique.
- The substrates were cut into smaller pieces for spectroscopic analysis.

**Measurement Techniques:**

- Optical absorption and photoluminescence (PL) spectra were recorded using a spectrophotometer.
- Temperature-dependent PL measurements were performed to understand the thermal stability of the centers.

### Results

- **Transmission spectra:**
  - The transmission spectra show absorption peaks at specific wavenumbers, indicating the presence of color centers.

- **Luminescence spectra:**
  - PL spectra reveal emission peaks corresponding to the absorption peaks, confirming the presence of the color centers.

### Conclusion

The results demonstrate the presence of new IR color centers in silicon carbide, which are promising for quantum sensor applications. Further research is needed to optimize their properties for practical use.

**Acknowledgments:**

The authors thank the MIPT and the Russian Foundation for Basic Research for financial support.

**References:**


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 \( \mu \)m the energy structure of the levels for both 4H and 6H modifications was obtained.

Thank you for attention!

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