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RAMAN AND FTIR SPECTRA ANALYSIS OF RADIATION EFFECTS ON NEUTRON-IRRADIATED CVD DIAMOND CRYSTALS

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RESEARCH RELEVANCE

The research is supported by *Latvian Research Program* **«High-energy Physics and Accelerator Technologies»** (*Agreement No: VPP-IZM-CERN-2022/1-0001*).

The project is focused on assessing the radiation resistance of CVD diamond, a material employed as a detector at CERN. We investigate its structural response to radiation exposure, crucial for its suitability on CERN's challenging environment. Additionally, we analyze the impact of varying radiation levels on its properties, providing insights into its sensitivity.

This research aims to determine CVD diamond‘s efficacy as a detector in high-energy experiments at CERN and its potential applications in fields such as nuclear engineering and medical radiation therapy. Ultimately, our goal is to ascertain its ability to withstand high levels of radiation, contributing to the development of improved detectors and versatile materials.

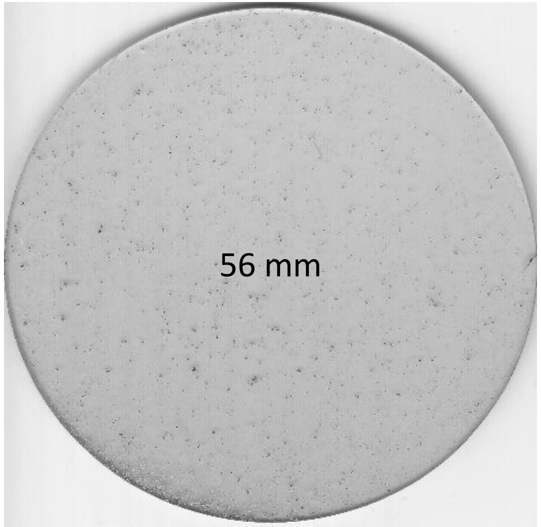
The research partners of this project are **Karlsruhe Institute of Technology** (Germany), **Institute of Solid State Physics**, University of Latvia (Latvia) and **Institute of Physics, University of Tartu** (Estonia).

RESEARCH OBJECTIVES

- To characterize defects in non-irradiated and neutron-irradited diamond crystal samples by measuring and analyzing their Raman and FTIR spectra;
- To analyze the correlation between the spectral properties of the samples and the radiation dose;
- To compare the spectra of neutron-irradiated and non-irradiated samples and determine the impact of radiation on the sample structure.

RESEARCH METHODS AND SAMPLES

In this research, using Raman and FTIR spectroscopy, the effect of neutron radiation on functional ceramics synthesized on a synthetic diamond crystal base was examined.



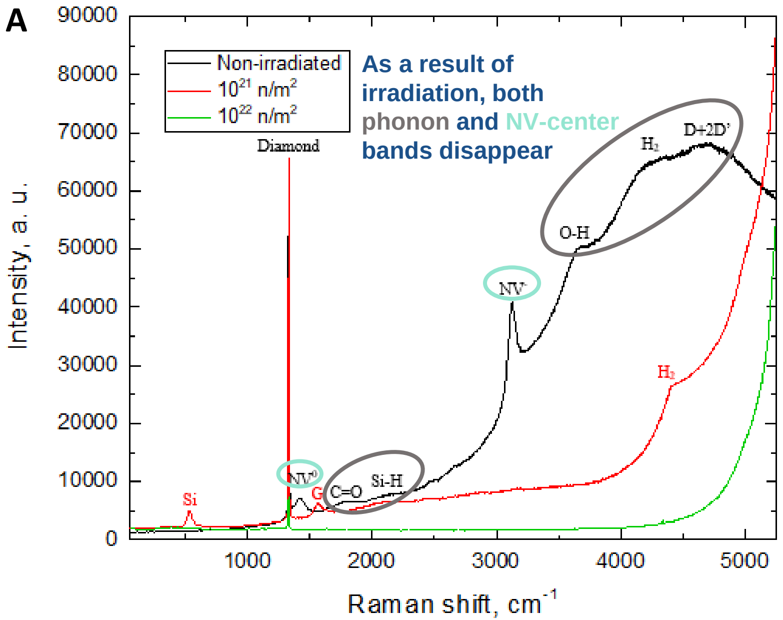
Undoped polycrystal diamond optical window

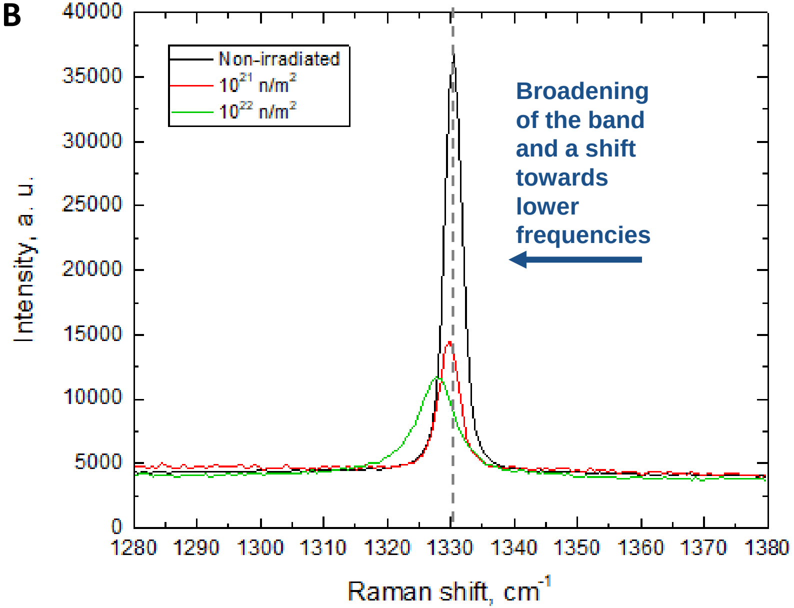
The samples were obtained from research partners of the Karlsruhe Institute of Technology in Germany, but their irradiation was carried out in Sweden.

The sample price is up to 100 000€ (one average-sized non-irradiated diamond optical window).

Non-irradiated and neutron-irradiated diamond samples

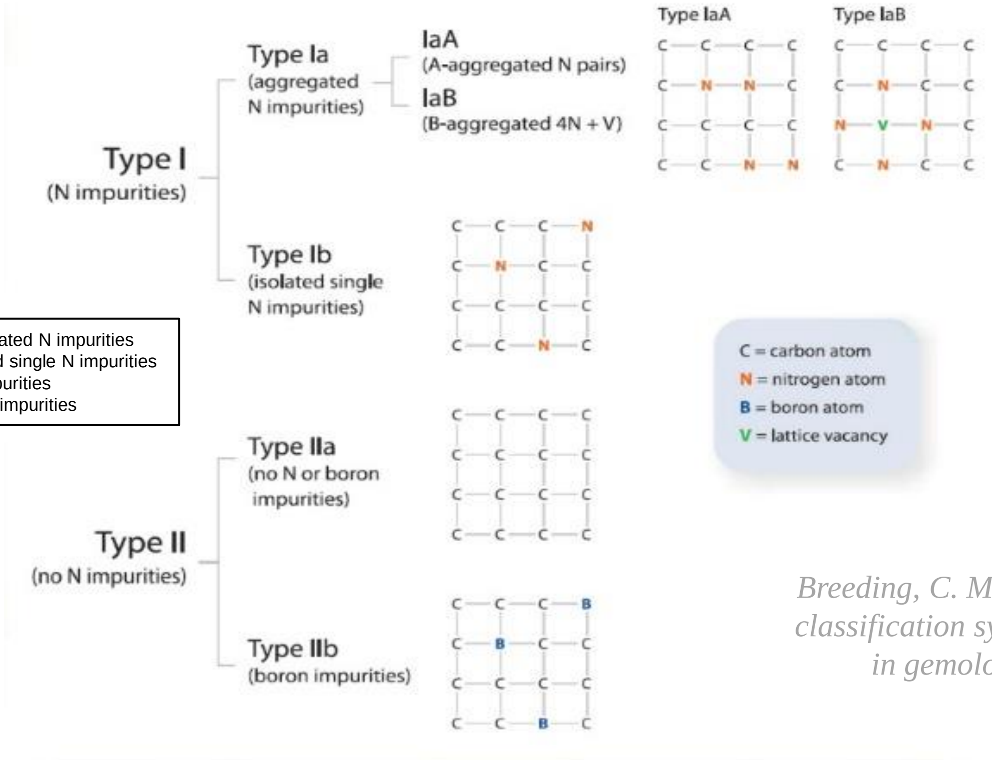
RESULTS: DIAMOND RAMAN SPECTRA





Non-irradiated and neutron-irradiated diamond Raman spectra (A) and its enlargement in the 1280-1380 cm^{-1} range (B) at 532 nm laser excitation

CLASSIFICATION OF DEFECTS IN DIAMOND



Ia–type – Aggregated N impurities
Ib–type – Isolated single N impurities
IIa–type – No impurities
IIb–type – Boron impurities

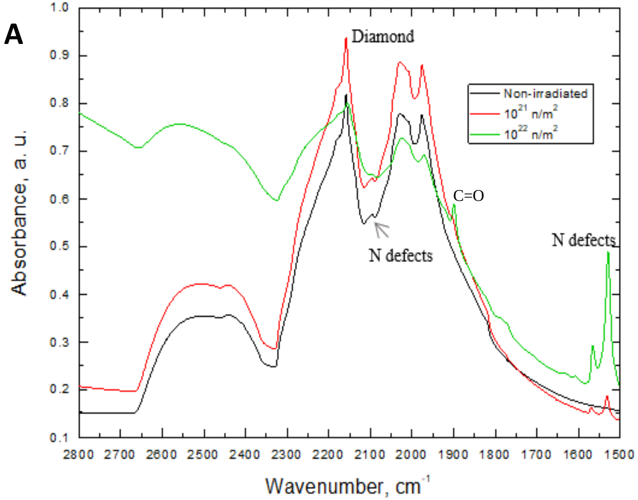
A–center – N impurity pair
B–center – N impurity cluster
B'–center – N impurity platelet
C–center – Isolated single N impurities

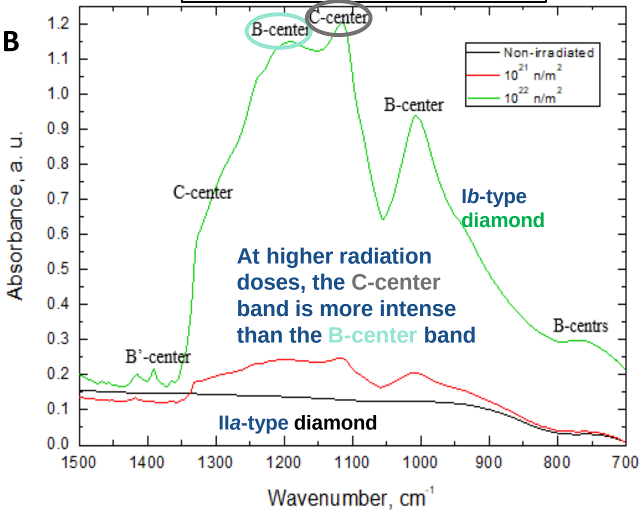
Breeding, C. M., & Shigley, J. E. (2009). The "type" classification system of diamonds and its importance in gemology. Gems Gemol, 45(2), 96-111

RESULTS: DIAMOND FTIR SPECTRA

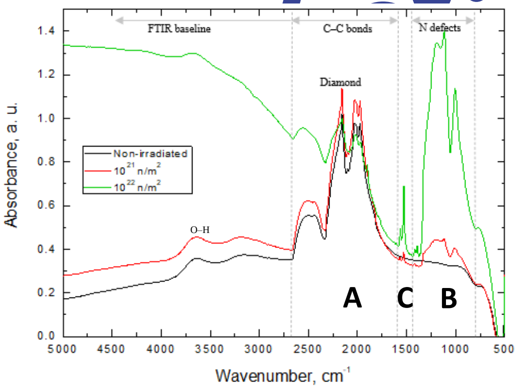
I*a*–type – Aggregated N impurities
I*b*–type – Isolated single N impurities
II*a*–type – No impurities
II*b*–type – Boron impurities

A–center – N impurity pair
B–center – N impurity cluster
B'–center – N impurity platelet
C–center – Isolated single N impurities

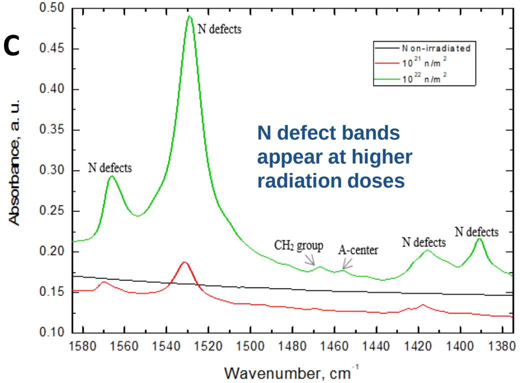




Enlarged non-irradiated and neutron-irradiated diamond FTIR absorption spectra in the C–C bond (A) and N defect (B) regions

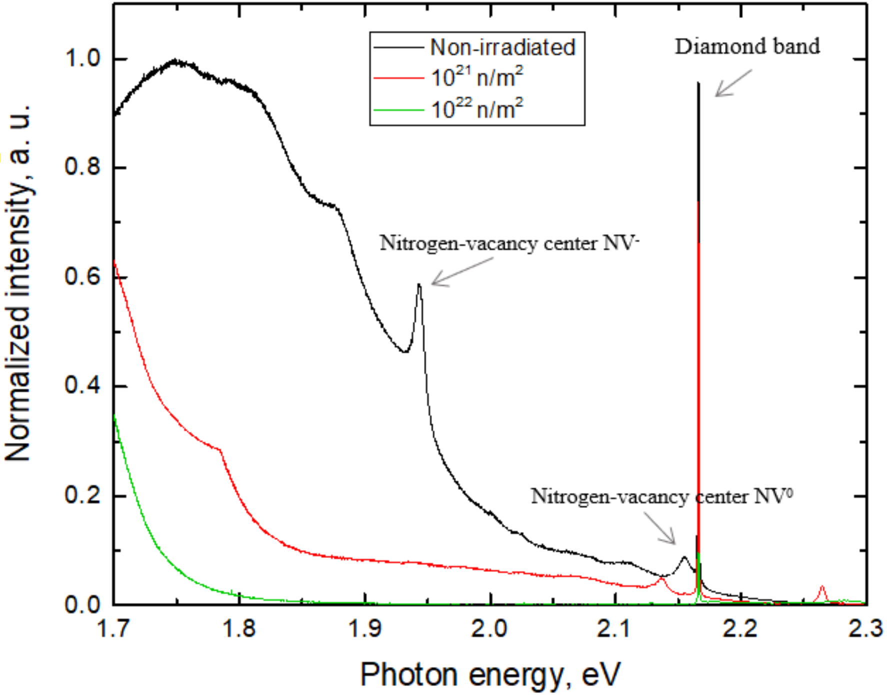


Non-irradiated and neutron-irradiated diamond FTIR absorption spectra



Enlarged non-irradiated and neutron-irradiated diamond FTIR absorption spectra in the N defect region (1580-1380 cm^{-1})

RESULTS: DIAMOND PL SPECTRA



Normalized luminescence spectra of non-irradiated and neutron-irradiated diamond at 532 nm laser excitation

The spectral band positions of NV-centers in diamond photoluminescence spectra

	Obtained position, eV	Literature position [1, 2, 3], eV
NV^-	1.943	1.945
NV^0	2.155	2.156

[1] Ganesan, K., Ajikumar, P. K., Ilango, S., Mangamma, G., & Dhara, S. (2019). Si and N-Vacancy color centers in discrete diamond nanoparticles: Raman and fluorescence spectroscopic studies. *Diamond and Related Materials*, *92*, 150-158.

[2] Iakoubovskii, K., & Adriaenssens, G. J. (2000). Luminescence excitation spectra in diamond. *Physical review B*, *61*(15), 10174.

[3] Su, Z., Ren, Z., Bao, Y., Lao, X., Zhang, J., Zhang, J., ... & Xu, S. (2019). Luminescence landscapes of nitrogen-vacancy centers in diamond: quasi-localized vibrational resonances and selective coupling. *Journal of Materials Chemistry C*, *7*(26), 8086-8091.

$$\omega_{eV} = \frac{\omega_{cm^{-1}}}{8065.6} = \frac{\omega_L - \omega_R}{8065.6} = \frac{18797 - \omega_R}{8065.6}$$

ω_{eV} – band position [eV]
$\omega_{cm^{-1}}$ – band position [cm^{-1}]
ω_L – laser frequency [cm^{-1}]
ω_R – Raman shift [cm^{-1}]

$$1\ eV \approx 8065.6\ cm^{-1}$$

CONCLUSIONS

- No new spectral bands arising from radiation-induced defects were observed in the diamond Raman spectra after neutron irradiation.
- The diamond crystal synthesized using the CVD method belongs to the II*a* type of synthetic diamond group. When irradiating II*a*-type synthetic diamonds with neutron radiation, its modification into type I*b* diamond occurs, resulting in the formation of nitrogen defects (A, B, and C centers).
- At lower neutron radiation doses, diamonds exhibit a high concentration of N impurity clusters. However, with increasing neutron radiation dose, the N atoms become more isolated from each other.
- Increasing the neutron radiation dose results in the broadening of the diamond Raman “1332 cm^{-1}” band and a shift to lower frequencies, as well as the disappearance of practically all phonon bands in the diamond Raman spectrum due to the structural disordering of the diamond.
- Nitrogen-vacancy NV luminescent centers are observed only in non-irradiated diamond, as radiation-induced recombination occurs for these defects.

THANK YOU

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