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Cherenkov radiation and cathodoluminescence in different specimens under the excitation of electron beams

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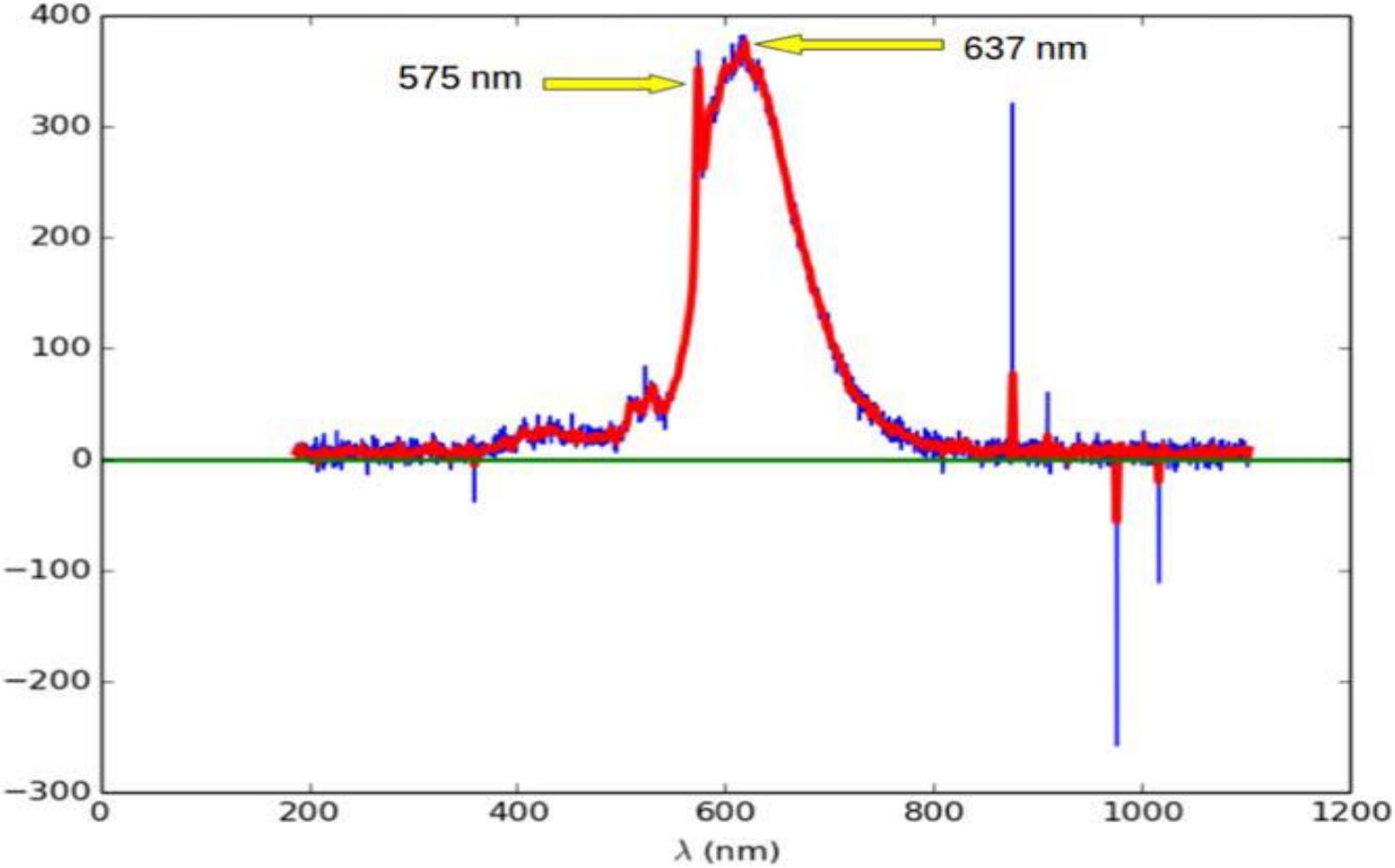
In recent years, great attention has been paid to the study of the generation and measurements of runaway electrons (RAEs) under different conditions. The largest number of publications are devoted to studies of RAEs in tokamaks; RAEs damage the internal walls of the vacuum vessel and prevent plasma heating. Various sensors and collectors are used for measuring RAEs. In different accelerators, direct measuring of electron beam current parameters is performed using collectors. Collectors with a small receiving area have the highest temporal resolution. Using such collectors, RAE beam current pulses with the duration of up to 20 ps were recorded in an accelerator with a gas diode. In tokamaks, collectors are not used yet. However, Cherenkov-type detectors (CTD) were developed for registration of RAEs. The receiving part is made of diamond and coated with metal films of various thickness to protect the CTD from plasma radiation. CR is recorded with a photomultiplier tube (PMT) situated outside the vacuum chamber. Quartz optic fibers are applied for transmitting CR to the PMT. However, besides CR, cathodoluminescence (CL) may occur in diamonds. In the works known to us, comparisons of the parameters of these types of radiation were not performed.

The main objective of this paper is to study the spectral and amplitude-time characteristics of the radiation of diamond specimens grown by different methods, sapphire, MgF_2 and KU-1 quartz, which is transparent up to 160 nm and to find the most suitable specimen. The specimens were excited by nanosecond and subnanosecond electron beams with different electron energies.

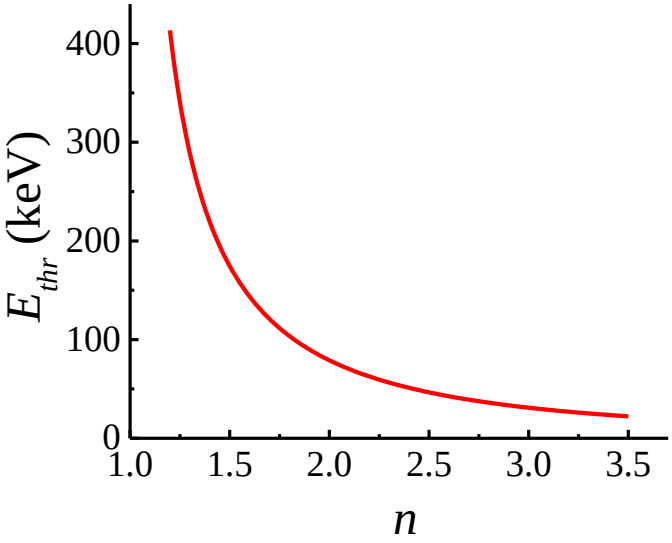
Bagnato, F., Romano, A., Buratti, P., Doria, A., Gabellieri, L.,... & Rabinski, M. (2018). Triple Cherenkov probe measurements on FTU: calibration and runaway energy spectra. *Plasma Physics and Controlled Fusion*, *60*(11), 115010.

Spectra of diamond under the excitation of runaway electrons

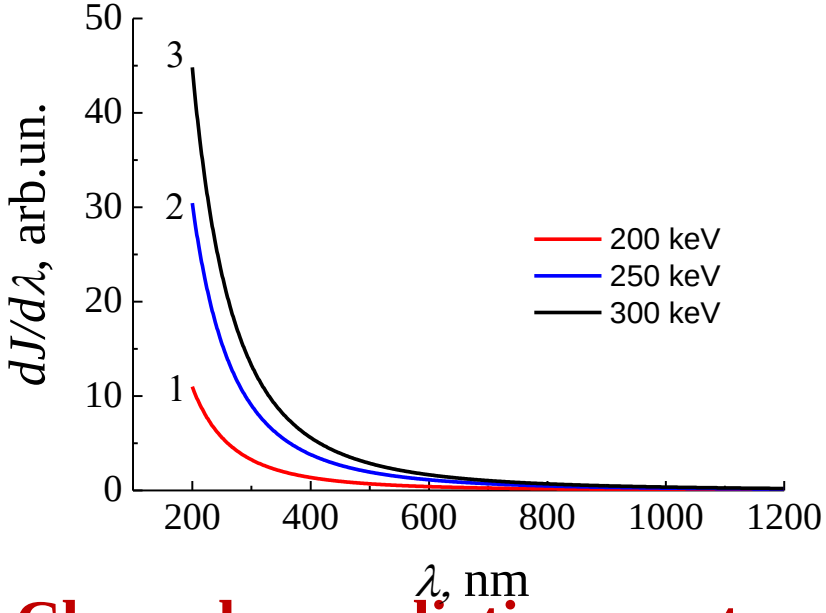


This is not Cerenkov radiation

The threshold energy ε_{thr} for Cherenkov radiation in diamond (n =2.42) is 50 keV.



The threshold energy E_{thr} for Cherenkov radiation.



Cherenkov radiation spectra for different electron energies in diamond.

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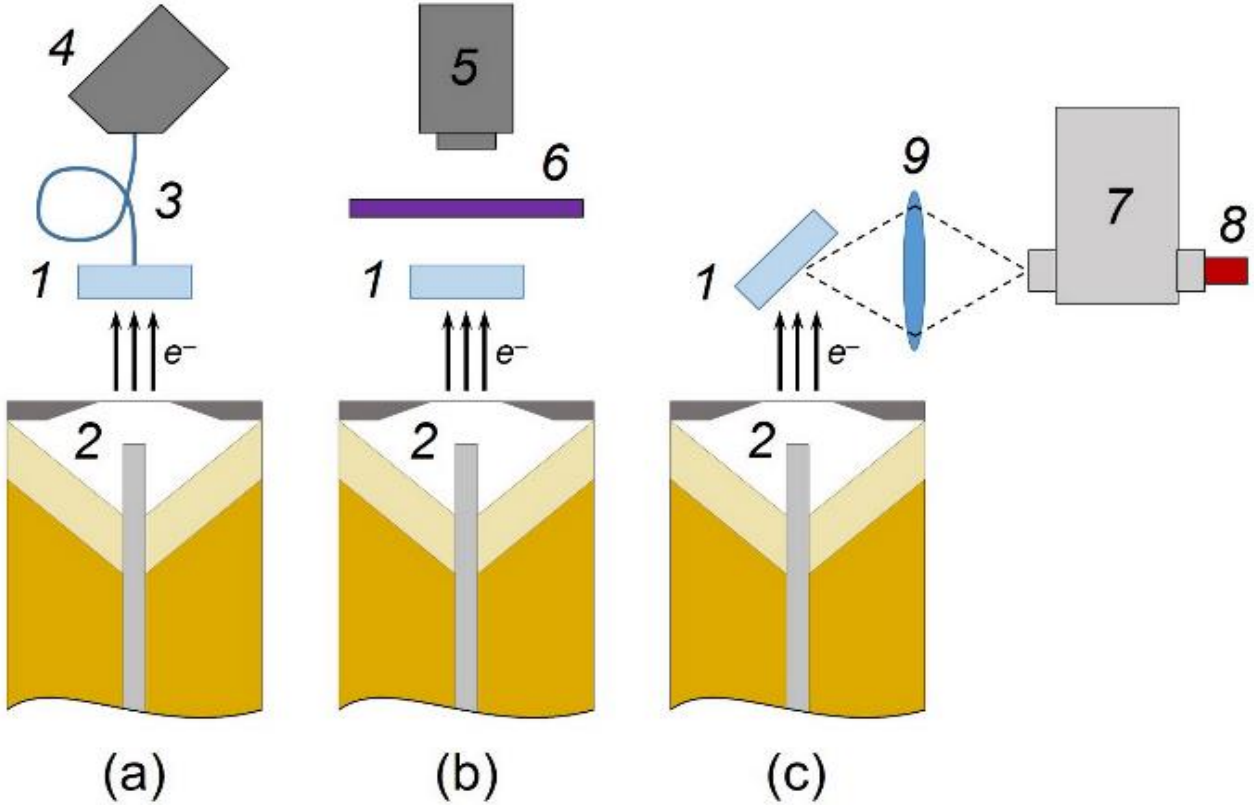
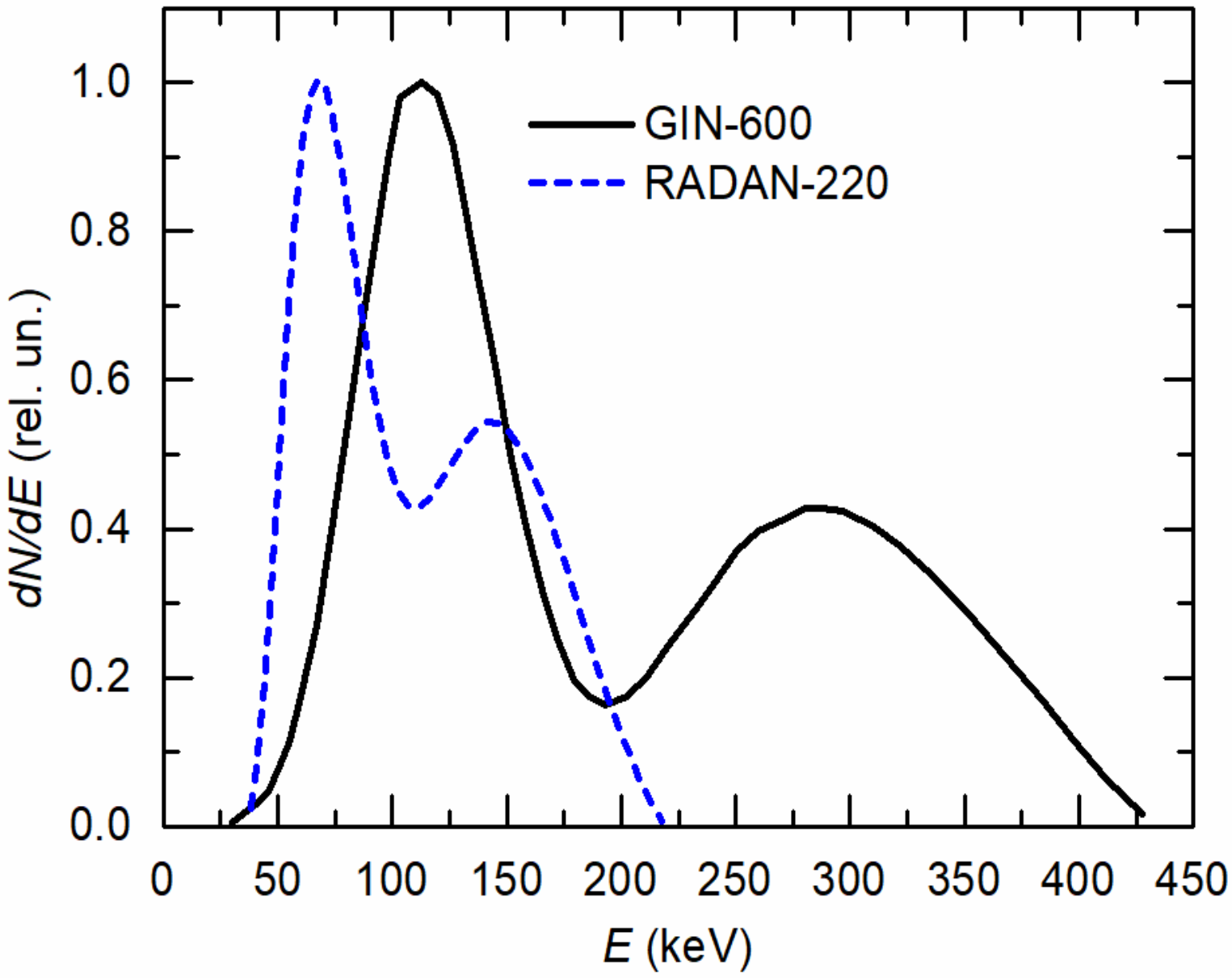


Sketch of the experimental setup for (a) taking emission spectra and (b, c) measuring the amplitude-time characteristics of the radiation: *1* – specimen, *2* – vacuum or gas-filled diode, *3* – optical fiber, *4* – spectrometer, *5* – PD025 photodiode, *6* – optical filter, *7* – monochromator, *8* – photomultiplier, *9* – lens.

Bandwidths B_w, sizes, refractive indices n and values of threshold electron energy ε_{thr} for different crystals.

Characteristic / Type of a crystal	B_w (μm)	Sizes (mm^3)	n_D	ε_{thr} (keV)
Diamond, IIa type, synthetic (C5)	0.225–5	10×10×0.5	2.42	**50**
Diamond, IIa type, synthetic (C6)	0.225–5	10×10×0.1	2.42	**50**
Diamond, IIa type, synthetic (CN3)	0.3–5	4.2×3.5 ×0.195	2.42	**50**
Diamond, IIa type, natural (C4)	0.225–5	∅5×0.25	2.42	**50**
Leucosapphire, Al_2O_3	0.18–2.3	∅30×4	1.77	**108**
KU-1 quartz, SiO_2	0.16–3	∅40×7	1.46	**190**



Electron energy distribution for different generators.

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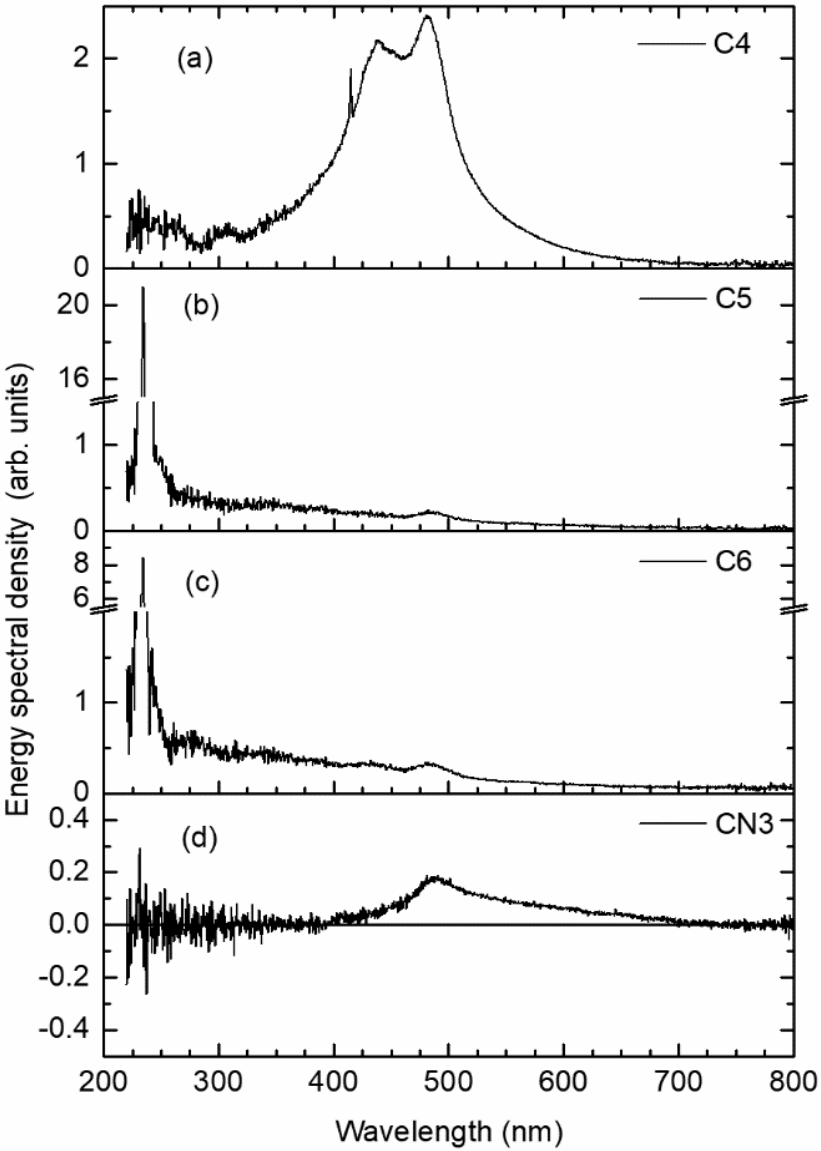

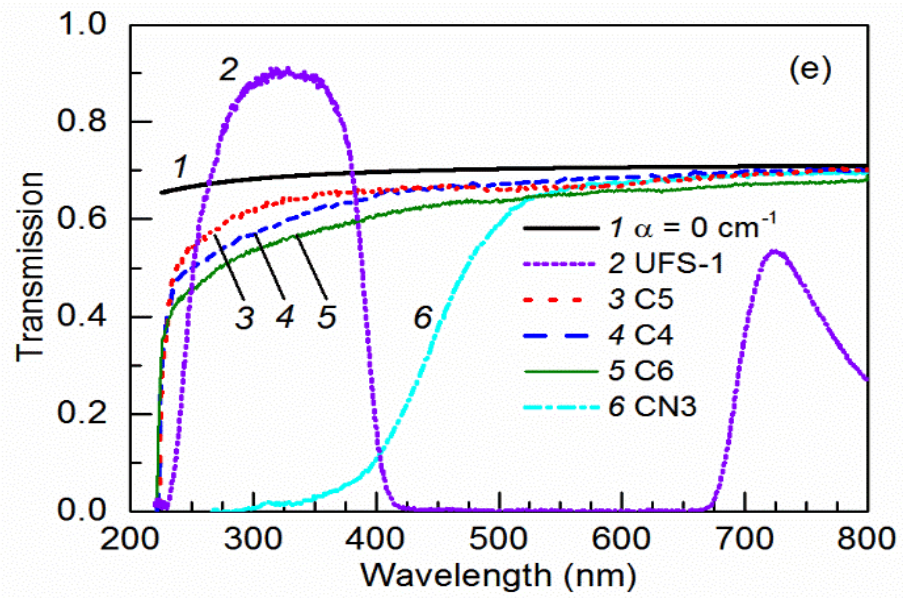

(a)–(d) – Emission spectra of four diamond specimens grown by various methods.
(e) – Transmission spectra of diamond specimens and UFS-1 filter.
***1* – Calculated transmission spectrum for an ideal diamond.**

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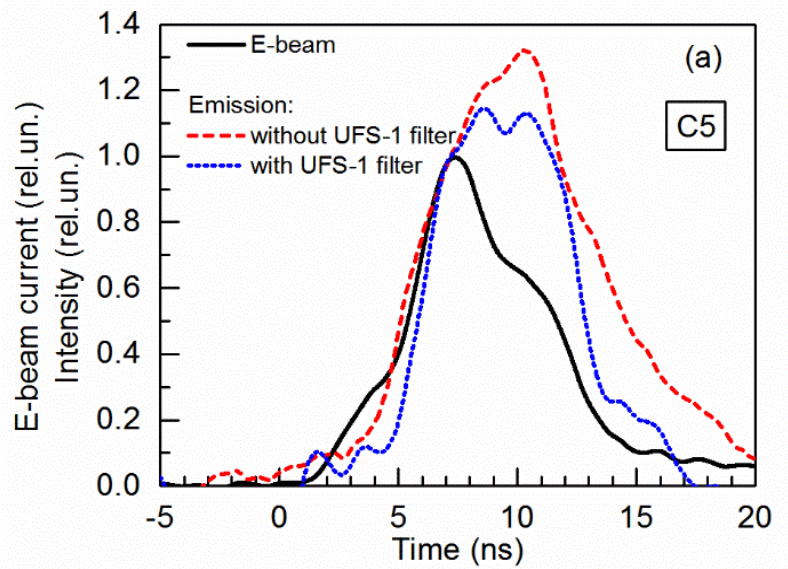

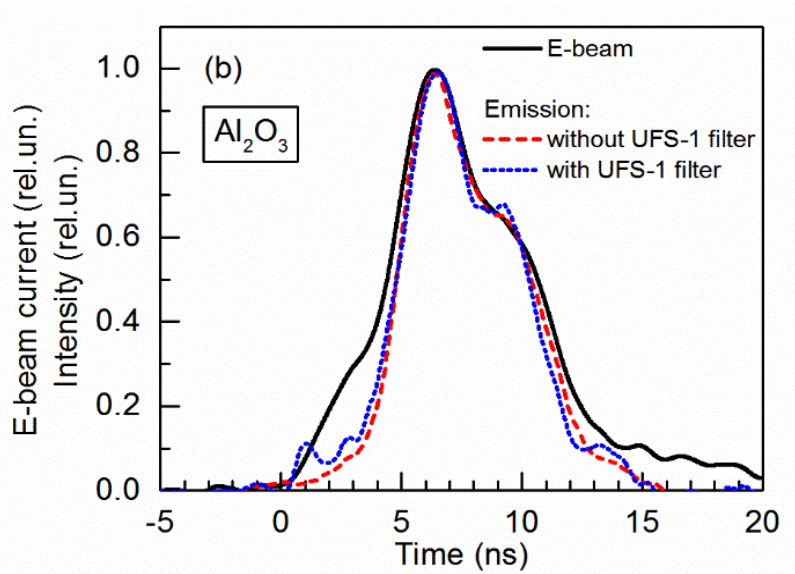

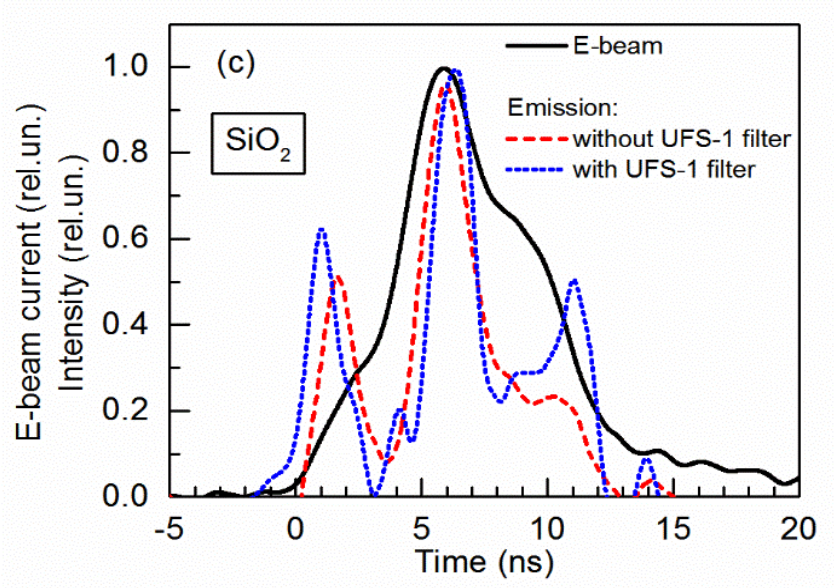

Waveforms of the electron beam current and radiation pulses. GIN-600 generator.

Conclusion

Data on the spectral and amplitude-time characteristics of the radiation of different specimens of diamonds, sapphire, MgF_2 and KU-1 quartz excited by nanosecond and subnanosecond electron beams were obtained.

Cerenkov radiation was observed in synthetic diamonds of IIa type, sapphire, MgF_2 and KU-1 quartz using a spectrometer. It was found that in sapphire and KU-1 quartz, the spectral region suitable for recording CR covers a wider spectral range than in diamond. CL in diamonds, sapphire, MgF_2 and KU-1 quartz was observed too.

These data are consistent with our results obtained previously [1-3].

1. D. A. Sorokin, A. G. Burachenko, D. V. Beloplotov, V. F. Tarasenko, E. Kh. Baksht, E. I. Lipatov, M. I. Lomaev, "Luminescence of crystals excited by a runaway electron beam and by excilamp radiation with a peak wavelength of 222 nm," Journal of Applied Physics, vol. 122, no. 15, pp. 154902, 2017.

2. V. F. Tarasenko, M. I. Lomaev, E. Kh. Baksht, D. V. Beloplotov, A. G. Burachenko, D. A. Sorokin, E. I. Lipatov, "Spectral and amplitude-time characteristics of crystals excited by a runaway electron beam," Matter and Radiation at Extremes, vol. 4, no. 3, pp. 037401, 2019.

3. V. F. Tarasenko, V. I. Oleshko, M. V. Erofeev, E. I. Lipatov, D. V. Beloplotov, M. I. Lomaev, A. G. Burachenko, Baksht, E. Kh. "Emission of diamonds, leucosapphire, and KU-1 quartz in the range of 200–800 nm excited by electron beams with a pulse duration of 0.5 and 12 ns," Journal of Applied Physics, vol. 125, no. 24, pp. 244501, 2019.