Pulse cathodoluminescence and Cherenkov radiation in diamond, sapphire and quartz under the electron beam excitation with an energy up to 350 kev

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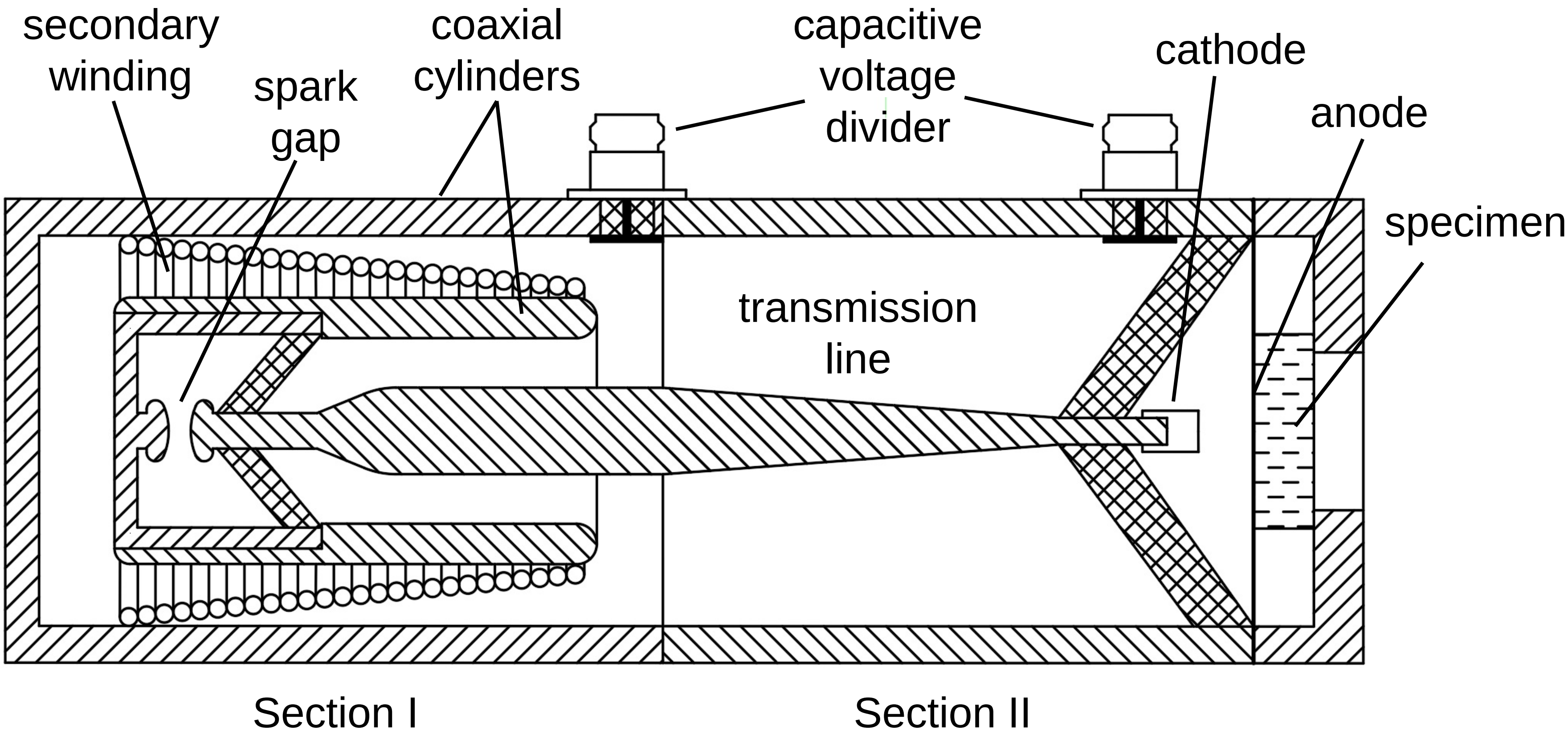
When an electron beam acts on various transparent materials, an emission of a different nature can arise – Cherenkov radiation (CR) and (or) cathodoluminescence (CL). CR is widely used for registration of high-energy particles. It is known that CR is easiest to detect in those substances that have a high refractive index and are also transparent in the UV region and have a low CL intensity in this region. One such material are met is diamond. Diamond also has high thermal conductivity and radiation resistance, so it is often used as a radiator in Cherenkov detectors in Tokamaks, where high temperatures are reached during operation. The energy of runaway electrons in Tokamak systems can range from tens of kilo- to tens of mega-electron volts. However, earlier it was shown that the intensity of CR in diamond at electron energies of up to 200 keV is much lower than the intensity of pulsed CL in the UV and visible regions and its detection is difficult. Also it was shown that, CR in a synthetic and natural diamonds at an electron energy of up to 200 keV was detected with a monochromator and photomultiplier. At an electron energy of up to 200 keV, it was difficult to isolate CR against the background of the radiation of CL bands using ordinary Ocean Optics spectrometers. For registration of CR at electron energies of tens to hundreds keV, materials such as sapphire and quartz are also of interest. The refraction indices of sapphire and quartz are much lower that diamond but fundamental absorption edge in sapphire and quartz lies in the VUV region (< 200 nm). Moreover, the intensity of pulsed CL in sapphire and quartz in UV range is below its value in diamonds.

The purpose of this research is to study the radiation of different specimens (diamond, sapphire, and quartz) under excitation by an electron beam with an electron energy of up to 350 keV produced by specially developed accelerator and to check the presence of Cherenkov radiation in the UV spectral region.

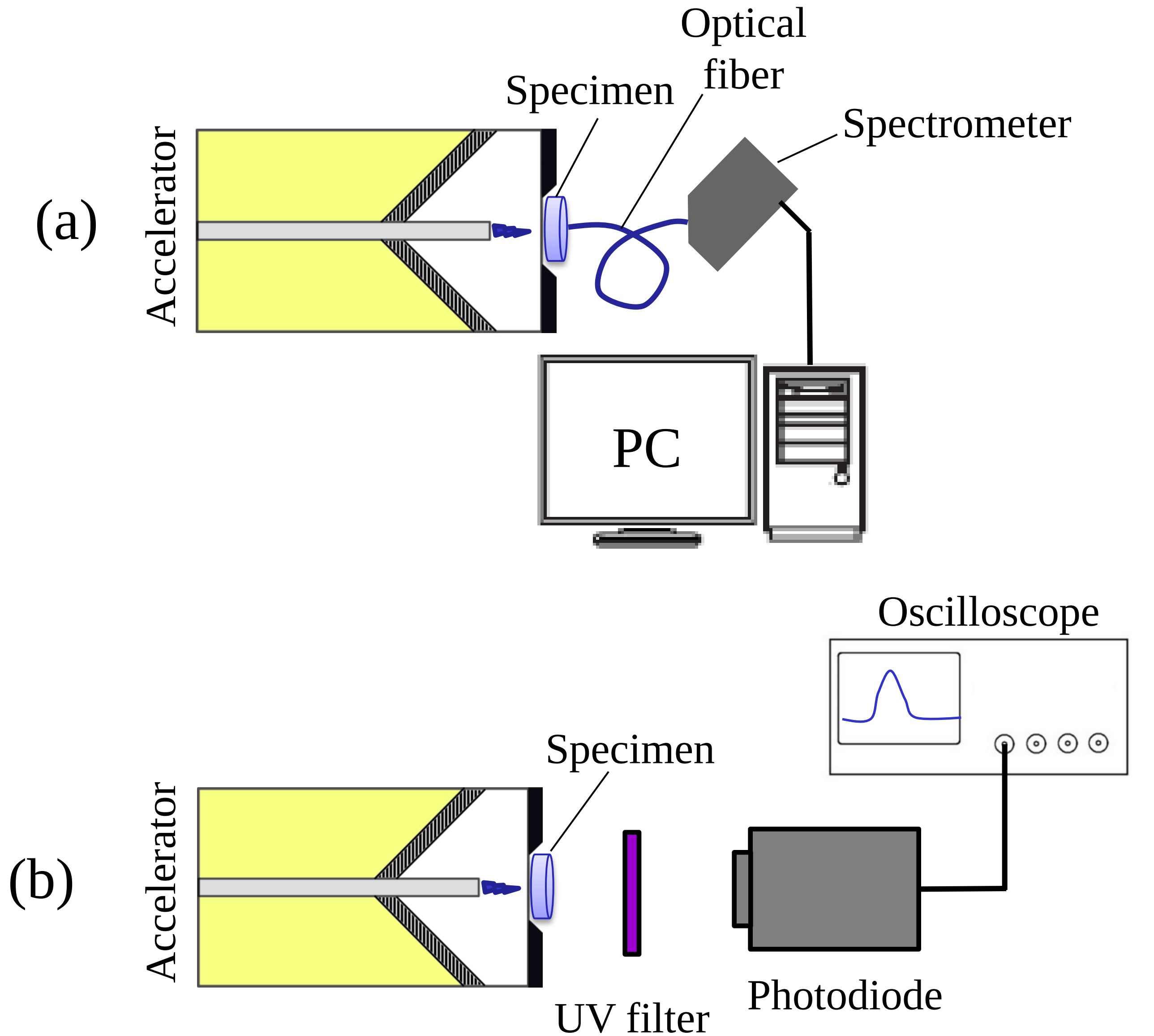
Accelerator with a double forming line that was used to irradiate the specimens



Parameters vacuum diode:
$U \approx 350$ kV
$I_{beam} \approx 700$ A
$\tau \approx 1.25$ ns

$E_e \leq 350$ keV
$U_{id} \approx 500$ kV

Sketch of the experimental setup for (a) taking emission spectra and (b) measuring the amplitude-time characteristics of the radiation



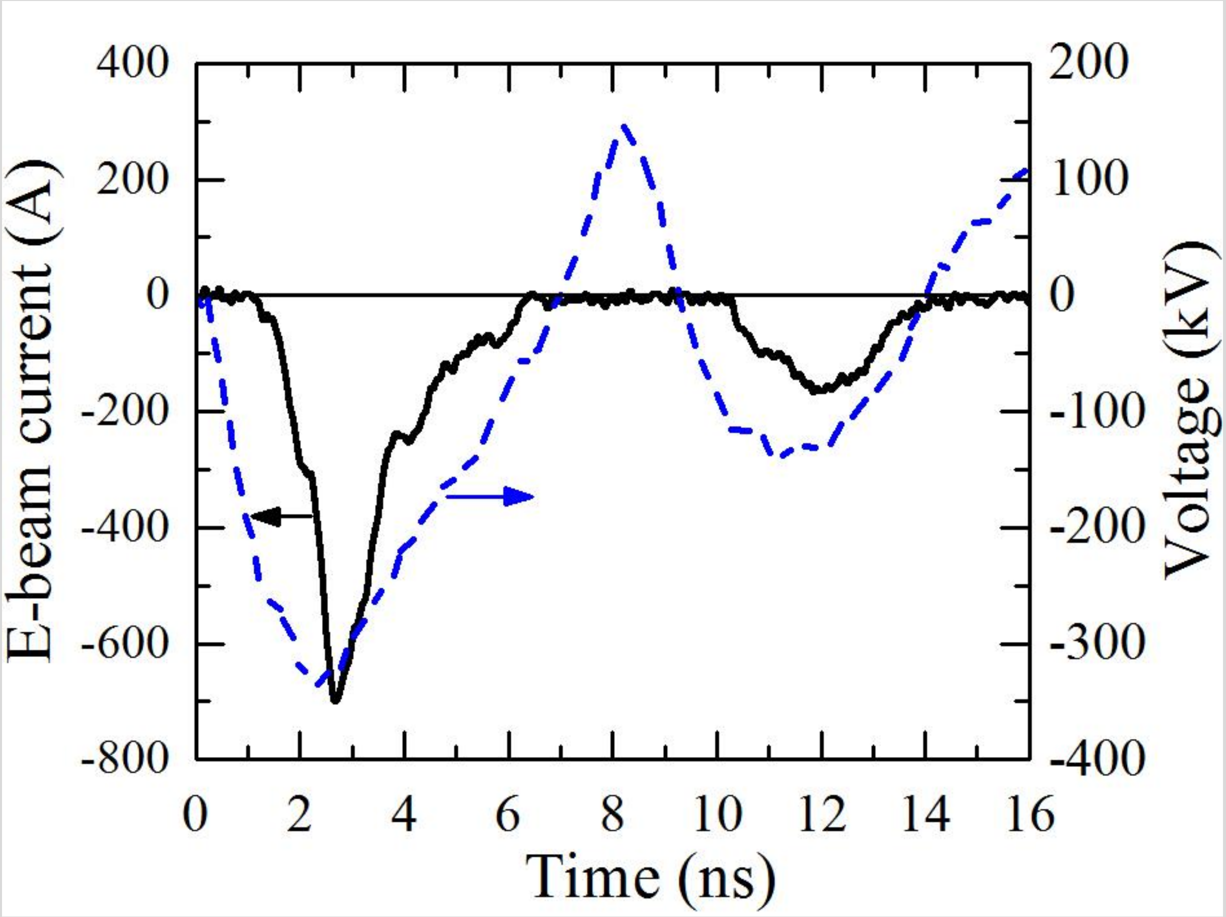
Spectrometer – Ocean Optics HR2000+ES (190-1100 nm, 0.9 nm);

Oscilloscope – Keysight DSO X6004A (6 GHz, 20 GSa/s);

Photodiode – Photek PD025 (200-700 nm, 0.1 ns);

UV filter – UFS-1, UFS-2;

Waveforms of voltage and current of the e-beam passed through the AlMg foil with a thickness of 40 μm



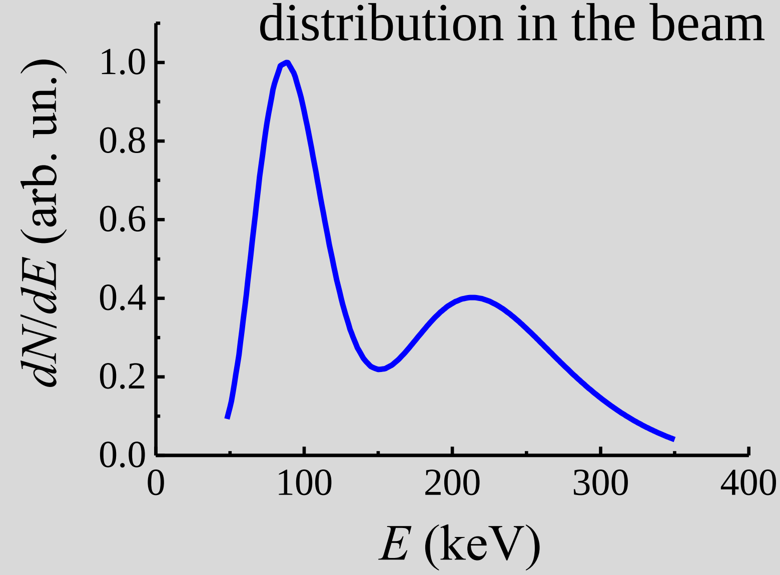
Specimens under study and their characteristics (bandwidths B_w, refractive indices n, threshold electron energy ε_{thr} for CR and sizes)

Type of a specimen	B_w (μm)	n_D	ε_{thr} (keV)	Sizes (mm)
Diamond, IIa type, synthetic	0.225–5	2.42	50	10×10×0.5
Sapphire, Al_2O_3	0.18–2.3	1.77	108	∅60×5
KU-1 quartz, SiO_2	0.16–3	1.46	190	∅60×8

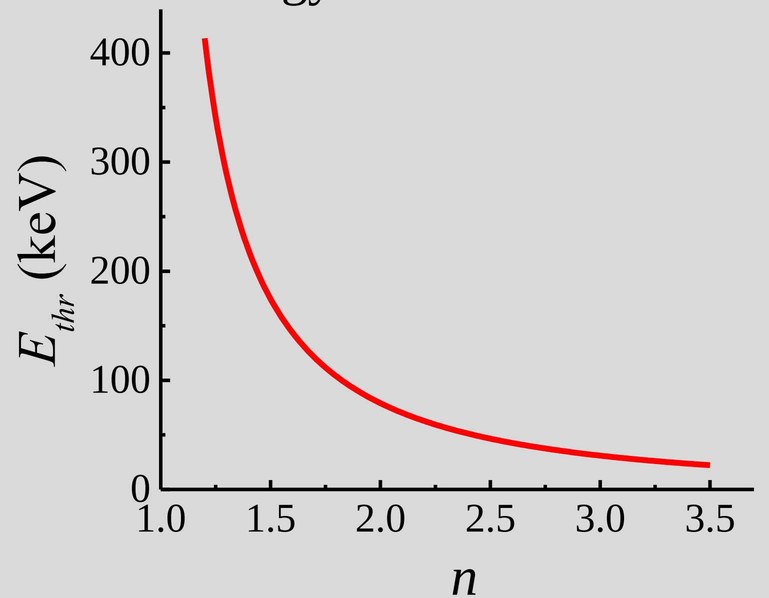
The power spectral density of CR :

$$\frac{dP(\lambda)}{d\lambda} = 4\pi^2 e^2 V\left(1-\frac{1}{\beta^2 n(\lambda)^2}\right)\frac{1}{\lambda^3},\ \text{где}\ \beta = \frac{V}{c}$$

The electron energy distribution in the beam

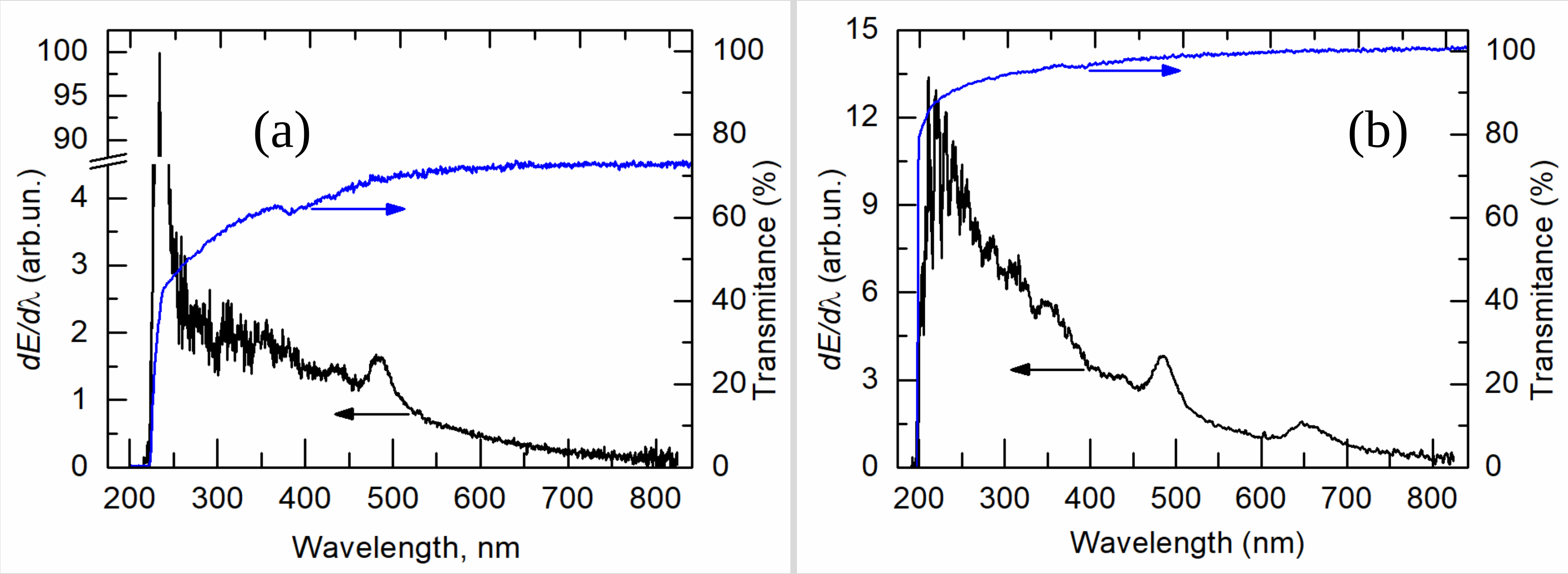


The dependence of the threshold electron energy on the refractive index

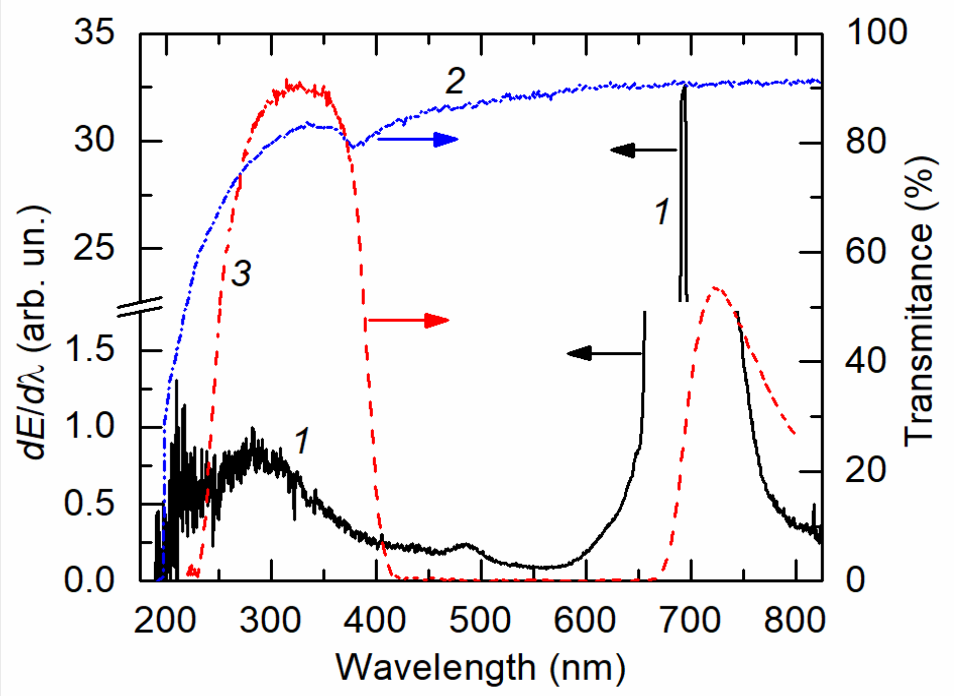


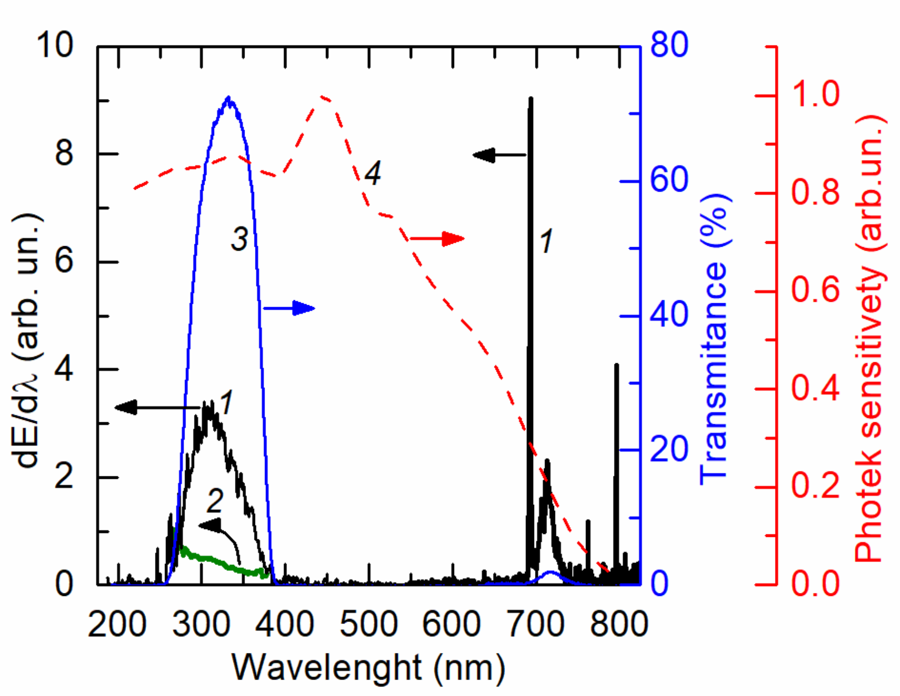
Results:

Emission and transmission spectra of synthetic diamond (a) and KU-1 quartz (b)



Results:

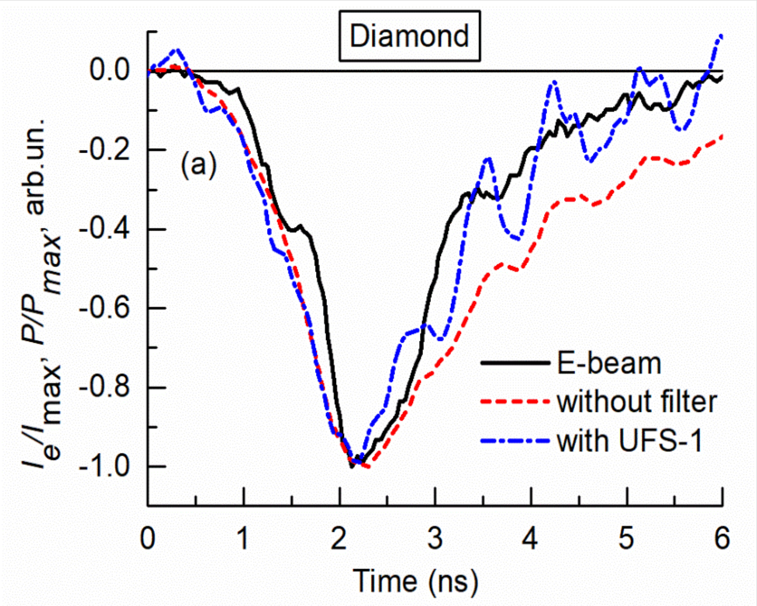




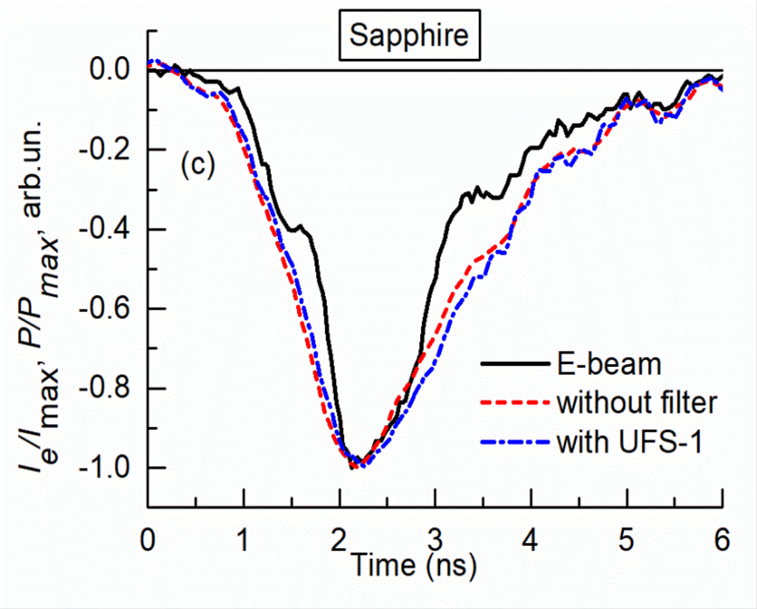
Emission and transmission spectra of sapphire (*1*, *2* respectively) as well as transmission spectra of UFS-1 filter (*3*)

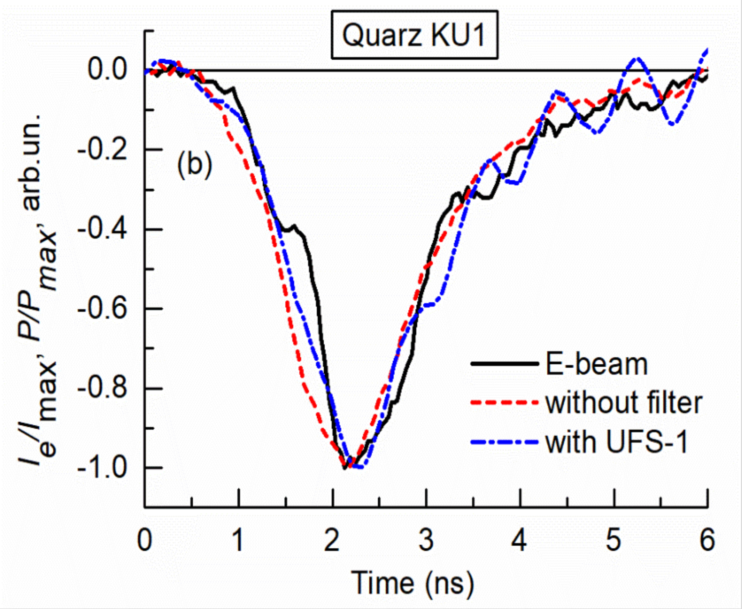
Emission spectrum of sapphire (*1*) obtained using the UFS-2 filter (*3*). Spectrum (*2*) is the emission spectrum of sapphire in the range 260–380 nm, reconstructed taking into account the absorption of radiation in the filter (*3*). Photodiode spectral sensitivity (*4*).

Results:



Waveforms of the e-beam current pulse and the emission of specimens under the study





Conclusion

It has been shown that CR of specimens of synthetic diamond, sapphire and KU-1 quartz was reliably detected by a standard spectrometer in the spectral region of 200–400 nm and in which there are no intense CL bands.

Moreover registration of CR in the UV region in all specimens is confirmed by measurements of the amplitude-time parameters of the emission using the photodiode and the UV filter. Synthetic diamond, sapphire and KU-1 quartz are promising materials for Cherenkov detectors rated at electron energy ≈ 200 keV.

It has been shown that in synthetic diamond, CR is superimposed by pulsed CL, including an intense exciton band with its maximum at 235 nm. Accordingly, when creating Cherenkov detectors, the influence of the exciton band, as well as other CL bands, on an optical signal must be taken into account.