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Photosensitivity of a diamond detector to laser radiation in the 220 – 355-nm region

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***Abstract*. The photosensitivity of detectors of laser radiation based on the natural type IIa diamond (Alameda Applied Sciences Corporation, USA) are studied at the wavelengths 222, 308, 337, and 353 nm. The limiting intensities (0.5 – 4 MW cm^{-2}) of UV laser radiation are determined at which the detectors operate in a linear regime.**

Keywords: *diamond, photodetector, laser radiation, UV radiation.*

1. Introduction

The natural diamond attracts the attention of a number of researchers as a material for detectors of spontaneous X-ray [1] and UV laser radiation [2]. This interest in diamond is caused by its unique properties [3 – 7]. The natural diamond is the most rigid mineral known in the nature. It is inert under normal conditions with respect to many aggressive chemical reagents such as, for example, nitrohydrochloric and hydrofluoric acids. The thermal conductivity of the natural diamond equal to $(1.5 - 2.0) \times 10^3$ W K^{-1} m^{-1} exceeds that of copper by a factor of three. The energy gap width of diamond is ~ 5.5 eV, resulting in its high specific resistance (over 1 GΩ m) and high breakdown voltage ~ 1 GV m^{-1}. In addition, the natural diamond features a high radiation resistance, its damage threshold exceeding 50 MW cm^{-2} in the UV range.

All the above properties make the natural diamond a promising material for detectors of laser radiation.

Note also that synthetic diamonds grown by various methods and detectors based on them also have been recently studied [5 – 7]. However, modern photodetectors based on synthetic diamonds have a low radiation resistance and a low photocurrent, which limits the range of intensities at which they can be used and restricts their spectral sensitivity.

In this paper, we studied experimentally the sensitivity of a detector based on the natural diamond of the IIa type fabricated at Alameda Applied Sciences Corporation, USA to UV laser radiation in the 222 – 353-nm region.

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2. Experimental

Fig. 1 shows the scheme of the experimental setup. A laser pulse was generated by a universal Foton-2 laser (*1*), which was developed at the Laboratory of Optical Radiation of the High-Current Electronics Institute, SD RAS [8]. A part of laser energy was deflected with a beamsplitter (*2*) to control the pulse shape with a FEK-22 vacuum photodiode. To increase the density of radiation incident on a diamond detector (*3*), it was focused by lens (*4*) with the focal length $f = 10$ cm. The laser-pulse intensity incident on the detector was varied with the help of light filters (*5*) or by moving the diamond detector relative to the lens focus. The radiation energy propagated through an aperture (*6*) of size 3×1 mm was measured with an IMO-2N calorimeter.

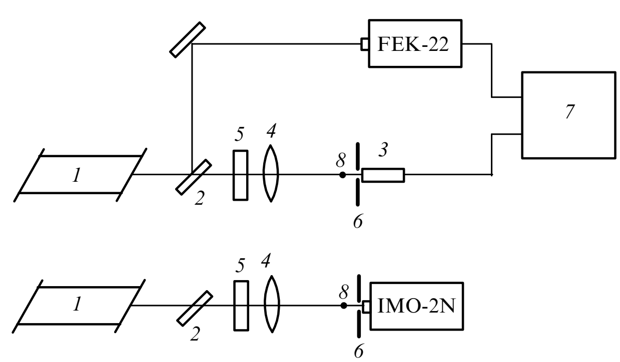

Figure 1. Scheme of the experimental setup: (*1*) universal laser; (*2*) quartz plate; (*3*) diamond detector; (*4*) convergent lens; (*5*) light filter; (*6*) aperture; (*7*) digital oscilloscope.

An equivalent electric scheme of the diamond photodetector is shown in Fig. 2. The capacitor $C_0 = 10$ nF was charged from a constant voltage supply up to 250 or 1000 V, depending on the photodetector geometry. The crystal resistance sharply decreased during irradiation of the detector by a laser pulse (switch S), and the capacitor C_0 was discharged through the resistances of diamond (R_d) and the load (R_{load}). The load signal was recorded with a digital TDS-220 Tektronix oscilloscope (*7*). The peak power was determined by integrating the output FEK signal.

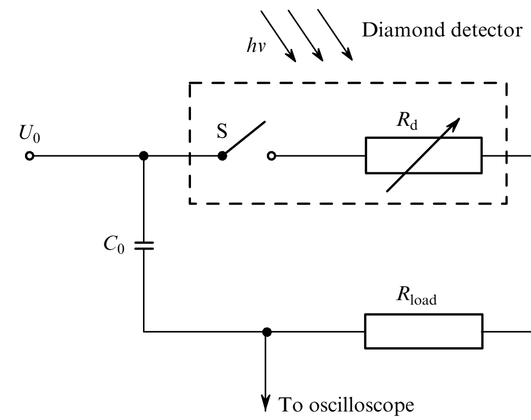

Figure 2. Equivalent electric scheme of a diamond photodetector: (U_0) constant charge voltage of the capacitor C_0; (S) switch denoting a sharp decrease in the diamond resistance upon irradiation; (R_d and R_{load}) resistances of diamond and the load, respectively. The voltage pulse is measured on R_{load} and is recorded with an oscilloscope.

Fig. 3 shows schematically two diamond photodetectors. The photodetector represents a natural diamond single crystal of the IIa type of size $3 \times 1 \times 0.5$ mm, the size of the irradiated surface being 3×1 mm. The ohmic contact was provided by metallisation of contact faces. The first photodetector had the interelectrode distance of 1 mm, which made it possible to charge the capacitor C_0 up to 250 V. The interelectrode distance of the second photodetector was 3 mm, providing a higher charge voltage, up to 1000 V.

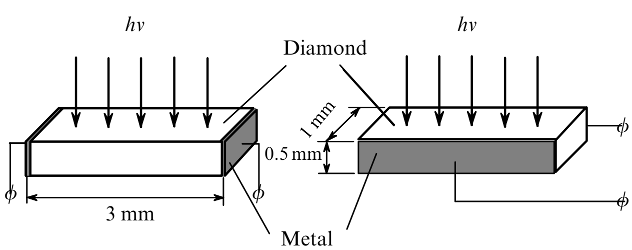

Figure 3. Schematic view of diamond detectors.

3. Experimental results and discussion

We studied first a diamond photodetector with the interelectrode distance of 1 mm. The photodetector sensitivity was measured at the wavelengths 222 nm (KrCl), 308 nm (XeCl), 337 nm (N_2), and 353 nm (XeF).

Fig. 4 shows laser pulses detected with a FEK-22 vacuum photodiode and a diamond photodetector. The shape of laser pulses recorded with a diamond photodetector was distorted for the radiation intensities above 2–4 MW cm^{-2} for the wavelengths 308, 337, and 353 nm and above 0.5 MW cm^{-2} for the wavelength 222 nm. The pulse duration at half maximum increased and the trailing edge of the pulse was distorted, however, its leading edge did not change. Therefore, the linear regime of this photodetector is limited by the radiation intensity of 0.5–4 MW cm^{-2}, depending on the wavelength.

Figs 5 and 6 show the dependences of the peak current and sensitivity of the photodetector on the peak radiation intensity. The peak current flowing through the crystal increases with increasing radiation intensity, whereas the photodetector sensitivity decreases. The maximum current flowing through the diamond photodetector was 3.2 A for the incident radiation intensity of 21 MW cm^{-2} at 222 nm. In this case, the photodetector sensitivity was 5.1×10^{-6} A W^{-1}. The maximum sensitivity equal to 9.7×10^{-5} A W^{-1} at 222 nm was obtained for the radiation intensity of 0.2 MW cm^{-2}.

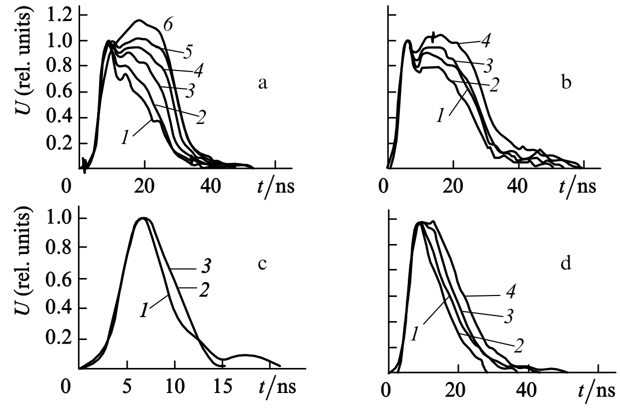

Figure 4. Laser pulses detected with a vacuum FEK-22 photodiode and a diamond photodetector: (a) $\lambda = 222$ nm, FEK-22 signal: (*1*) (pulse duration at half maximum is 14.1 ns); diamond detector signal: (*2*) (energy is 0.17 mJ, pulse duration at half maximum is 16.4 ns), (*3*) (0.56 mJ, 20.6 ns), (*4*) (1.19 mJ, 22.7 ns), (*5*) (4.56 mJ, 24.4 ns), (*6*) (21.3 mJ, 23.0 ns); (b) $\lambda = 308$ nm, FEK-22 signal: (*1*) (23.8 ns); diamond detector signal: (*2*) (2.2 mJ, 20.8 ns), (*3*) (5.3 mJ, 24.3 ns), (*4*) (19.0 mJ, 26.8 ns); (c) $\lambda = 337$ nm, FEK-22 signal: (*1*) (5.1 ns); diamond detector signal: (*2*) (0.75 mJ, 6.3 ns), (*3*) (1.63 mJ, 6.3 ns); (d) $\lambda = 353$ nm, FEK-22 signal: (*1*) (12.3 ns); diamond detectors signal: (*2*) (1.9 mJ, 10.3 ns), (*3*) (7.3 mJ, 13.6 ns), (*4*) 8.5 mJ, 16.2 ns).

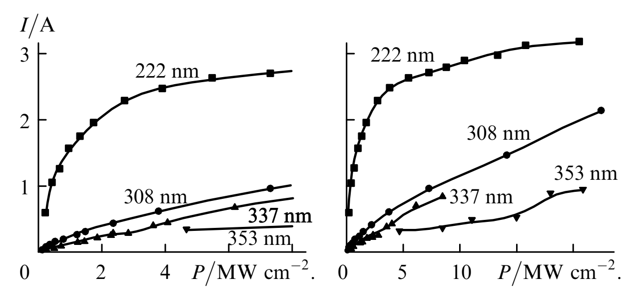

Figure 5. Dependences of the peak current on the peak radiation intensity.

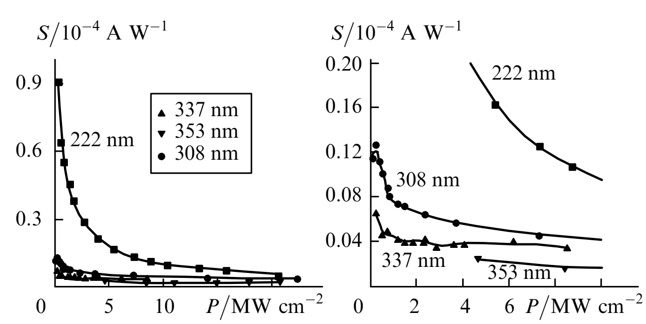

Figure 6. Dependences of the diamond photodetector sensitivity on the peak radiation intensity.

Fig. 7 demonstrates the spectral dependence of the diamond detector sensitivity at different radiation intensities. One can see that the sensitivity increases with decreasing wavelength. Fig. 8 shows the transmission spectra of the natural diamond of the IIa type in the UV and visible spectral regions. The solid curve corresponding to a diamond sample of thickness 1 mm is taken from paper [4]. The dashed curve was obtained by us for diamond of the IIa type of thickness 0.25 mm using Specord M-40 and SF-16 spectrophotometers. The spectral region shorter than 226 nm corresponds to the fundamental absorption of the natural diamond of the IIa type (the energy gap width of diamond is 5.5 eV). This explains a sharp enhancement of the sensitivity of the diamond detector at 222 nm, whereas at larger wavelengths the absorption is probably caused by defects of the crystal lattice, which form allowed states within the band gap.

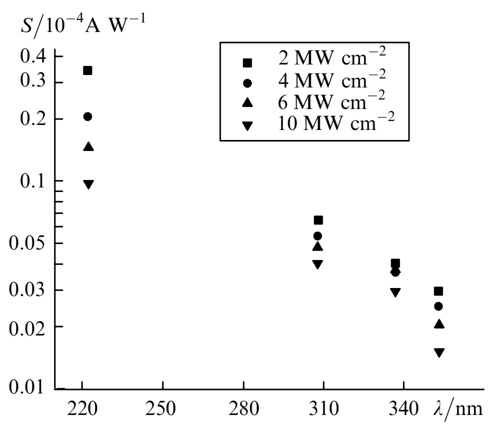

Figure 7. Spectral dependences of the diamond photodetector sensitivity for different incident radiation intensities.

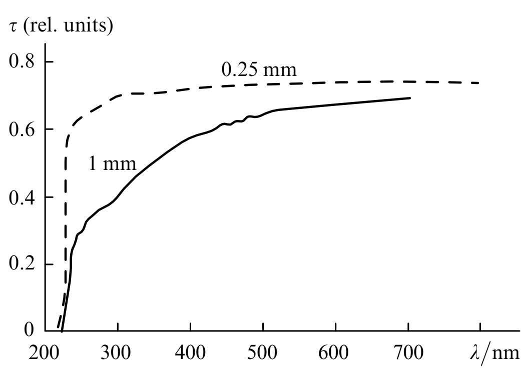

Figure 8. Transmission spectra of natural diamond of the IIa type for samples of different thickness.

We also studied the detector with the interelectrode distance equal to 3 mm. Fig. 9 shows the dependences of the peak current flowing through photodetectors with interelectrode distances equal to 1 and 3 mm on the laser radiation intensity at 337 nm (N_2). One can see that the dependences for the first and second detectors are almost identical, however, the charge voltage per crystal unit length for the first detector was 250 V mm^{-1}, whereas this voltage for the second detector was 333 V mm^{-1}.

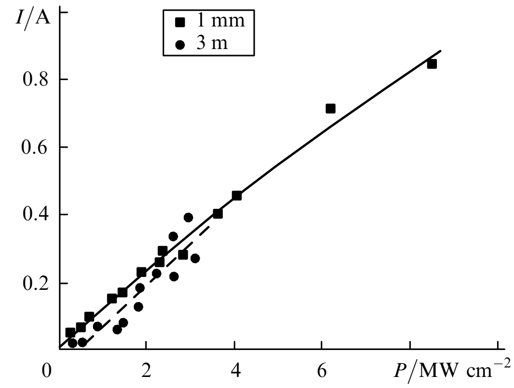

Figure 9. Dependences of the peak current on the radiation power at 337 nm for detectors with the interelectrode distances equal to 1 and 3 mm.

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