CALIBRATION OF CVD-DIAMOND BASED DOSIMETER IN HIGH-POWER ELECTRON AND X-RAY RADIATION FIELDS

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Results of a study of dosimetry characteristics of a prototype of the detector based on a polycrystalline diamond film (CVD-diamond) produced in NSC KIPT are summarized. The techniques of the detector calibration against the electron and X-ray radiation dose rate are developed. The conditions of calibration were studied by means of computer simulation. For determination of detector sensitivity to electron radiation, it was placed inside of a standard polystyrene phantom. An additional filter of electrons was used at measurement in the X-ray field. Every time detector irradiation was carried out together with the Harwell Red Perpex 4034 dosimeters, which registrations provided the calibration data. The measurements, executed at the LU-10, EPOS and LU-40 linacs of NSC KIPT, have demonstrated, that the values of detector sensitivity against each type of radiation are close and conform to ones obtained earlier for the low-intensity radiation fields. Considering significant radiation durability of the CVD-diamond, it enables its application in technological dosimetry.

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INTRODUCTION

Natural diamond has a unique combination of electrophysical properties: wide gap (Eg=5.5 eV), high electrical strength (> 10^7 V/cm) and specific resistance (> 10^{11} Ohm·cm), and also, large energy of atom displacement from lattice (43 eV). These features allow to use diamond in radiation and nuclear physics, in particular in detectors of γ- and β-radiation (see, for example, [1]). An additional possibility of diamond application in radiometry has appeared with the development of synthesis of the polycrystalline diamond films (PDF) and wafers by a method of chemical vapor deposition (CVD). This method has allowed to realize a large-scale manufacturing of detectors with the specific parameters for application in nuclear instrumentation [2], high energy physics [3], medicine [4], etc.

The data obtained recently on radiation hardness of CVD-diamond detectors [5] open also perspectives for their application in dosimetry of electron and X-Ray (bremsstrahlung) radiation at industrial accelerators. A specificity of such installations lays in the large average (> 10 kW) and pulsed (up to 10 MW) power of an electron beam, determining the range of radiation and thermal loads on the detector. In this paper, the results of the measurement of analog sensitivity of the CVD-diamond detectors, developed in NSC KIPT, in the fields of the high-power electron and bremsstrahlung radiation are discussed.

1. METHODS AND MATERIALS

1.1. The PDF films for detectors were synthesised by the CVD method from a gas phase by activation of a carbon-hydrogen mixture with the glow dicharge, stabilized by a magnetic field. The samples obtained had the area up to 1 cm^2 and thickness up to 350 microns. The quality of PDFs was checked by a method of infra-red spectroscopy. The parametrization of films was carried out by a measurement of their current-to-voltage characteristics. These measurements were made after each operation of annealing, etching, and exposure to radiation. With a specific electrical resistance $\geq 10^{12}$ Ohm·cm, samples meet the requirements, which the material for detector should comply with.

In the process of detector manufacturing, its growth and substrate surfaces were polishied. The metal contacts (Al, Ti) of various geometry (strip, planar, coplanar) were then applied by the plasmochemical and photolytographic techniques.

1.2. The sample of the diamond detector (DD) (Fig. 1), used in experiments, was grown on a n-type silicon substrate of 1.5 mm thick. The thickness of PDF was 180 microns. On its growth surface, the two Al contacts were evaporated and used as a single common contact. The substrate was an another contact. The total area of the contact (the detector surface) was 10 mm^2. The dark resistance of the detector before the exposure was $1.2 \cdot 10^{11}$ Ohm.

Fig. 1. Diamond detector

1.3. During the calibration measurements, the irradiation of the detector was monitored using the Red Perspex 4034 dosimeters [6]. Commonly, they are used as the routine dosimetry systems in radiation technology with the use of electron and gamma radiation in the dose range 5…50 kGy. In our case, they were used for determination of a dose absorbed in DD.

1.4. Considering the high pulsed dose rate (~10^6 Gy/s), a study of the DD sensitivity under electron irradiation was carried out in an analog mode (Fig. 2).

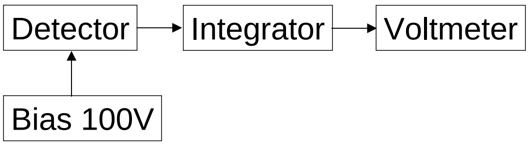

Fig. 2. Coupling of DD at exposure to electron beam

In the measurements with DD, a bias voltage of 100 V from an external source was applied to the detector. The integral action time was 1 s. The integrator output voltage was measured with a digital voltmeter B7-40. After a beam cut off, its value did not exceed 0.3 mV.

1.5. Determination of the DD sensitivity to X-Ray was carried out in a pulse mode (Fig. 3). The voltage drop at a load resistance R_1 was measured with a digital oscilloscope TDS1012.

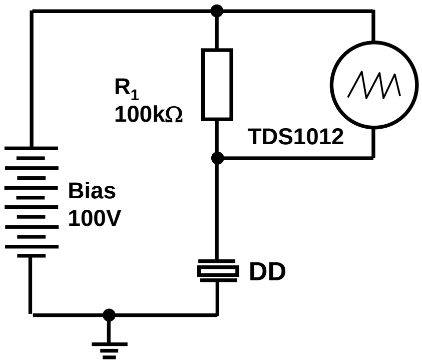

Fig. 3. Coupling of DD at exposure to X-ray

1.6. The analysis of an irradiation field, as well as of its interaction with the elements of measuring devices was carried out using a computer simulation technique based on the program system PENELOPE-2008 [7].

2. ELECTRON RADIATION

2.1. Calibration in a field of the electron radiation was carried out at an accelerator LU-10 in NSC KIPT [8] (Fig. 4). The DD was placed inside a standard polystyrene RISO phantom [9], positioned at a distance of 110 cm from the outlet window of the accelerator. The phantom corresponds a parallelepiped *1* from foam polystyrene measuring 29×29×10 см, in which centre, an absorber *2* in form of a disk from polystyrene 13.8 cm in diameter and 1.8 cm thick is placed. In the median plane of the disk, there is a 3 mm wide cavity *3*, in which, the DD was positioned. In the same cavity, the routine dosimeters Red Perspex (RP) were placed. Their calibration was preliminarily conducted using the reference polystyrene calorimetric dosimeters RISO, similar in structure to the phantoms [9].

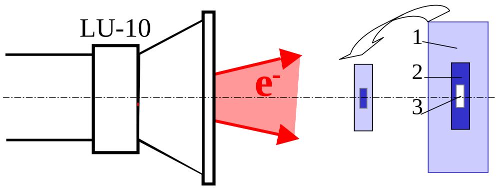

Fig. 4. Calibration of the detector in electron beam

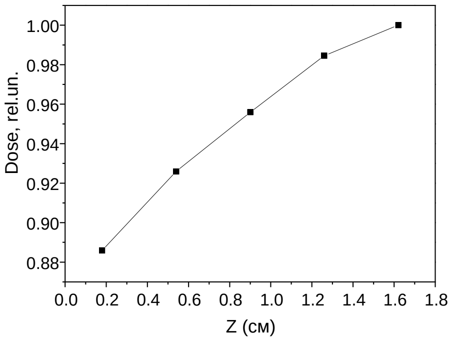

Fig. 5. Depth dose distribution in absorber of phantom

2.2. The results of simulation of the dose distribution within the phantom absorber are shown in Fig. 5. It is seen, that the dose in the median plane of the phantom (z = 0.9 cm) corresponds to its average value over the volume of the absorber, measured by a calorimetric method.

2.3. The phantom and detector were irradiated with the electron beam having the parameters:

▪ electron energy, MeV	9.8;
▪ mean current, μA	760;
▪ pulse rate, Hz	250;
▪ pulse duration, μsec	3.5;
▪ width of the beam scanning zone, cm	32;
▪ scanning frequency, Hz	3.

The results of measurements are given in Table 1.

Table 1

Parameters of DD calibration in electron beam

Dose rate, kGy/s	DD current, μA	DD sensitivity $\times10^{10}$, C/Gy
2.13	0.77	3.61
1.08	0.36	3.34
0.54	0.17	3.09

3. X-RAY

3.1. For measurement of detector sensitivity in the bremsstrahlung field with end-point energy 10 MeV, a converter, cooled with water, was installed at the output of the LU-10 accelerator (Fig. 6). The converter design and the parameters of the radiation field are described in details in Ref. [10]. In particular, it was demonstrated that the electrons of a primary beam are almost completely absorbed in the converter. So a practically "pure" X-ray flux affected the DD. The latter was stacked with the RP dosimeter and positioned at a distance of 40 cm downstream the converter. Following them, a free-air wide-aperture ionization chamber (WIC), which monitored the energy flux of X-ray, was placed at a distance of ~1.5 m.

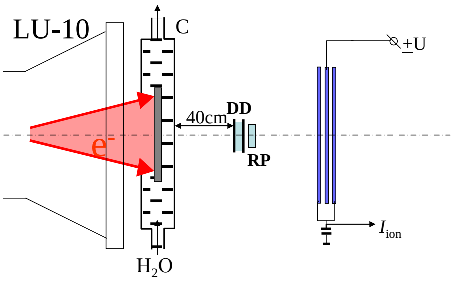

Fig. 6. Calibration of DD in X-ray radiation

The measurements were conducted at a different pulse repetition rate of the accelerator: 250, 125 and 62.5 Hz. The exposition changed in the range 20…60 min providing the absorbed dose values within an operating range of the RP dosimeters (Table 2).

Table 2

Results of DD calibration (X-ray, 10 MeV)

Pulse repetition rate, Hz	Average dose rate, Gy/s	DD current, nA	DD sensitivity $\times10^{10}$, C/Gy
62.5	2.97	0.8	2.75
125	5.72	1.8	3.14
250	13.32	4.0	3.0

3.2. Determination of detector sensitivity to the X-ray radiation with end-point energy 26 MeV was carried out at an accelerator EPOS. In this case, the bremsstrahlung field was formed by interaction of a scanned electron beam with a technological target [11]. In the measurements, the accelerator generated the beam with following parameters:

o electron energy, MeV	26;
o average beam current, µA	420;
o pulse duration, µsec	4.2;
o pulse repetition rate, Hz	150.

The average dose rate of bremsstrahlung, measured with the RP detectors, was 4.90 Gy/s. The DD current was 1.25 nA, that corresponds to the detector sensitivity of 2.6×10^{-10} C/Gy.

3.3. Measurement of the DD sensitivity to bremsstrahlung with end-point energy 40 MeV was conducted at an accelerator LU-40 [12] (Fig. 7). A converter C consisted of four tantalum plates, each of 1 mm thick and 30 mm in diameter and divided with the gaps of 1 mm for cooling. Downstream the converter, a filter-absorber of electrons F (an aluminum cylinder having the diameter and thickness of 40 mm) was positioned followed by the DD detector and RP dosimeter.

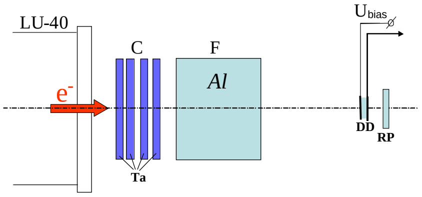

Fig. 7. Scheme of DD calibration (X-ray, 40 MeV)

The accelerator provided the beam with following parameters:

▪ electron energy, MeV	40;
▪ average beam current, µA	4.5;
▪ beam pulsed current, mA	55
▪ pulse width, µs	1.5;
▪ pulse repetition rate, Hz	50.

The measurements have shown, that the average bremsstrahlung dose rate in DD was 3.0 kGy/s and the DD current -0.9 nA. Thus, the detector sensitivity makes 3.0×10^{-10} C/Gy.

3.4. For an independent analysis of the measurement data, a computer simulation of the DD calibration conditions in the bremsstrahlung field was carried out. The developed simulation model included the description of a primary beam with the actual spatial and energy distribution of electrons, its interaction with the converter and the influence of a secondary radiation produced on the target system.

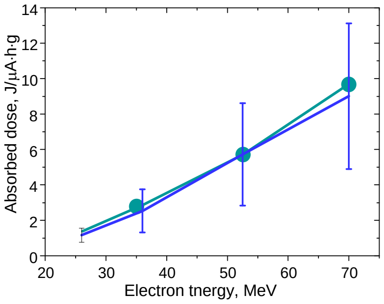

Fig. 8. Dependence of absorbed dose in DD and RP on electron beam energy

Fig. 8 displays the calculated absorbed dose in DD and RP (solid lines) as well as the measured dose in the RP (dots). It is seen, that the calculated and measured data are in good agreement confirming the correctness of the DD calibration. This result was expected, taking into account the proximity of atomic numbers (~6) of sensitive volumes in DD and RP.

3.5. The results of evaluation of a specific sensitivity of DD to the electron and X-ray radiation are summarized in Table 3. These data show that the DD sensitivity within an error of measurement (±15%) does not depend on the type and energy of radiation. The major sources of the error are those, connected with application of the Red Perspex dosimeters, as well as with determination of the detector average current using its pulse value.

Table 3

Specific sensitivity of DD

Radiation	Energy, MeV	Specific sensitivity $\times10^{10}$, C/Gy·mm^3
Electron	9.8	1.81
Photon	10.0	1.64
	26.0	1.45
	40.0	1.67

CONCLUSIONS

The CVD-diamond detectors can be applied for technological dosimetry of electron and bremsstrahlung radiation in the range of dose rate 3…2500 Gy/s at the electron and photon energy 10…40 MeV with radiation durability not less than ~10^7 Gy.

The average value of specific sensitivity, obtained in this work for an experimental detector, is twice as much as that determined at the DD calibration under low radiation dose rate [4]. The difference is most likely due to the specificities of the applied techniques for the CVD-diamond grows and, as a result, to the detector parameters obtained.

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КАЛИБРОВКА ДОЗИМЕТРОВ НА ОСНОВЕ CVD-АЛМАЗА В ПОЛЯХ ЭЛЕКТРОННОГО И ТОРМОЗНОГО ИЗЛУЧЕНИЙ БОЛЬШОЙ МОЩНОСТИ

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Описаны результаты исследования дозиметрических характеристик изготовленного в ННЦ ХФТИ опытного образца детектора на основе поликристаллической алмазной пленки (CVD-алмаз). Разработаны методики калибровки детекторов по мощности поглощенной дозы электронного и тормозного излучений. Условия калибровки исследованы методом компьютерного моделирования. Для определения чувствительности детектора к электронному излучению его помещали внутри фантома из полистирола. При измерениях в поле тормозного излучения использовался дополнительный фильтр электронов. В каждом случае облучение детектора выполнялось совместно с дозиметрами Harwell Red Perspex 4034, по показаниям которых производилась калибровка. Проведенные на ускорителях ЛУ-10, ЭПОС и ЛУ-40 ННЦ ХФТИ измерения показали, что значения чувствительности детектора для каждого вида излучения близки и согласуются с полученными ранее в условиях полей излучения низкой интенсивности. Учитывая высокую радиационную стойкость CVD-алмаза, это обеспечивает возможность его применения в технологической дозиметрии.

КАЛІБРУВАННЯ ДОЗИМЕТРІВ НА ОСНОВІ CVD-АЛМАЗУ В ПОЛЯХ ЕЛЕКТРОННОГО ТА ГАЛЬМІВНОГО ВИПРОМІНЮВАНЬ ВЕЛИКОЇ ПОТУЖНОСТІ

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Описано результати дослідження дозиметричних характеристик виготовленого в ННЦ ХФТІ дослідного зразка детектора на основі полікристалічної алмазної плівки (CVD-алмаз). Розроблено методики калібрування детекторів за потужністю поглинутої дози електронного та гальмівного випромінювань. Методом комп'ютерного моделювання досліджені умови калібрувань. Для визначення чутливості детектора до електронного випромінювання його розміщували усередині стандартного фантома з полістиролу. При вимірюваннях у полі гальмівного випромінювання використовувався додатковий фільтр електронів. У кожному випадку опромінювання детектора виконувалося спільно з дозиметрами Harwell Red Perpex 4034, за показаннями яких проводилося калібрування. Проведені на прискорювачах ЛУ-10, ЕПОС та ЛУ-40 ННЦ ХФТІ вимірювання показали, що значення чутливості детектора для кожного виду випромінювання є близькі і узгоджуються з такими, що одержані раніше в умовах полів випромінювання низької інтенсивності. Зважаючи на значну радіаційну стійкість CVD-алмазу, це забезпечує можливість його застосування в технологічній дозиметрії.