DEVELOPMENT AND STUDY OF CHARACTERISTICS OF STRIPPED DETECTORS ON THE BASIS OF CVD-DIAMOND

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The prototypes of the coordinate-sensitive semiconductor detectors based on polycrystalline diamond films (CVD-diamond) have been manufactured in the NSC KIPT. In this communication, a version of the detector with the strip-type contacts and its characteristics are described. The techniques of the detector calibration both as a whole and for separate groups of the strips against the absorbed dose rate of the electron and bremsstrahlung radiation are developed. By means of the computer simulations, an independent analysis of conditions of the radiation field registration with the detector has been conducted. The experiments carried out at the LU-10 accelerator at NSC KIPT have shown that the sensitivities of the separate elements (strips) of the detector are similar. The results of the measurements of the volume sensitivity of the detector are in agreement with the data received earlier for a single-contact detector. The possibility of the detector application in the study of transverse dynamics of an electron beam is shown.

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INTRODUCTION

The detectors based on the polycrystalline diamond films were manufactured by a plasma method, in which diamond is deposited on a silicon monocrystalline substrate from a mixture of the methane and hydrogen gases. The detectors were manufactured by an original technology developed at KIPT, in which the synthesis of the diamond coating is carried out in the plasma DC glow discharge in crossed E×H fields [1]. This approach provides the possibility of obtaining a high discharge power density (up to 150 W/cm^3), which allows the deposition of high-quality diamond coatings on large areas with fairly high speed.

With the help of this technology, the samples of coordinate-sensitive diamond detectors of ionizing radiation with strip contacts were manufactured. The developed detectors include a polycrystalline diamond film deposited on a silicon substrate, which is the common contact. On the growth surface of the diamond coating, the ten aluminum contacts (strips) 1 micron thick were deposited.

This article deals with the detector production technology and characteristics, as well as the conditions and results of the detector calibration at an electron accelerator in the fields of electron and bremsstrahlung radiation. The possibility of using the detector for measuring the profile of the ionizing radiation flux is described.

1. DETECTOR MANUFACTURING

When obtaining the diamond coating of the strip detectors, a holder of 42 mm in diameter was used, on which the three silicon substrates measuring 24×8×2 mm each were placed. The substrates were made from wafers, which were cut from a single crystal silicon ingot of KDB (111) grade with 50 mm diameter. The surfaces of the substrates were polished with the silicon carbide powder. Further the substrates were chemically etched to remove surface defect layers, which originated from the powder treatment. Before the application of the diamond coating, the surface of the substrate was treated with the diamond powder (particle size 2…3 μm) to create the desired density of growth nuclei of the diamond phase. The synthesis of diamond was performed in a mode that provides a coating thickness up to 200 μm and the detector-grade electrical resistivity of ~10^{14} Ω·cm. The average growth rate of the diamond film in this mode was ~3.7 μm/h. The detector is fixed to a mounting plate made of a metallized ceramic.

The size and appearance of the elements of the strip diamond detector (SDD) are shown in Fig. 1.

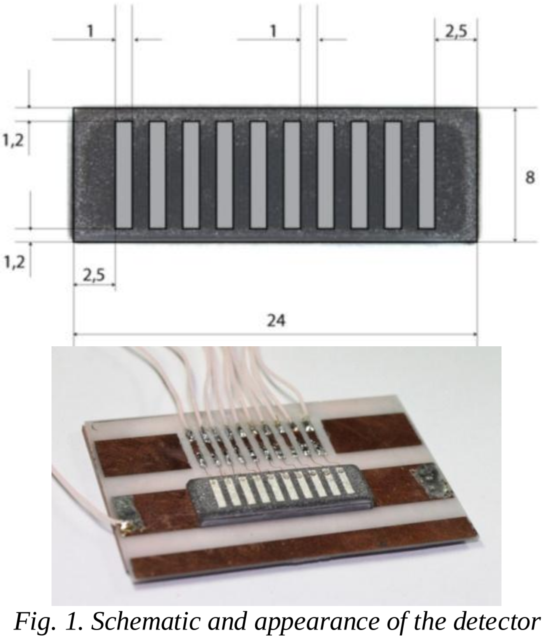

Fig. 1. Schematic and appearance of the detector

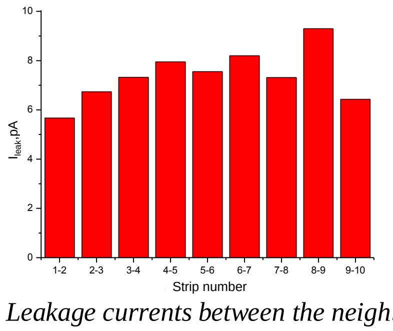

Fig. 2. Leakage currents between the neighboring strips of the detector (U=200 V)

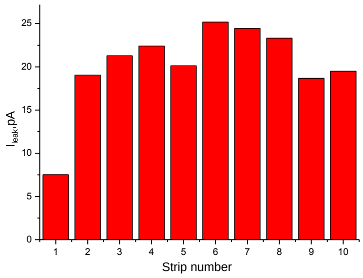

Fig. 3. Leakage currents between the strips and the common contact (U=200 V)

After detector fabrication, the dark bulk and creeping currents were measured with a Keithley 6487 picoammeter (Figs. 2 and 3).

2. SIMULATION

An investigation of the conditions of the nonuniform radiation field registration by the detector was performed by a computer simulation technique on the basis of a GEANT4 transport code. The detector model used in the calculation is shown in Fig. 4.

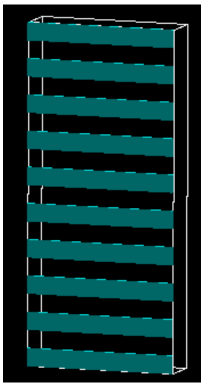

Fig. 4. Model of the strip detector

At the initial stage, the detector response to the exposure of axially symmetric electron beam with a Gaussian distribution of the particle density at a value of the standard deviation of 0.5 cm was analyzed. The electron energy distribution corresponds to the actual spectrum of the beam of a LU-10 electron accelerator at NSC KIPT with energy at the spectral maximum of 9.9 MeV.

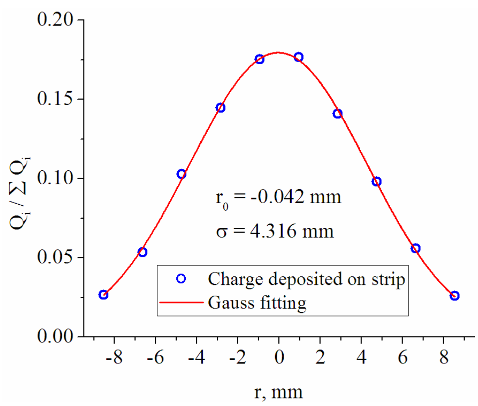

Fig. 5. Charge distribution for strips at detector irradiating with the Gaussian electron beam

Carbon with density of 3.515 g/cm^3 was used to describe the diamond. Considering the thickness of the detector sensitive volume to the strip width ratio, it was assumed that the active (ionization charge collecting) diamond zones correspond to the areas under the strips. Fig. 5 plots the results of the calculation of the ionization charge collection by different single strips when the detector is exposed to the electron beam with the above-specified parameters.

3. INVESTIGATION OF THE DETECTOR'S RADIOMETRIC PERFORMANCE

3.1. Radiometry of the α-radiation.

Studies have shown that, due to the low leakage currents and efficient collection of ionization charge, the detector can detect the individual α-particles. So Fig. 6 shows the data on the acquisition rate of α-particles from a ^{239}Pu source registered by the individual strips. The exposure time was 30 minutes. The bias voltage (U=300 V) was applied to the common contact.

When comparing the data shown in Figs. 3 and 6, a correlation between the observed leakage currents and the counting rates is seen.

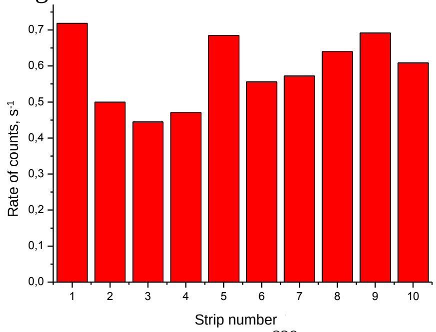

Fig. 6. Pulse count rate from the ^{239}Pu source registered by the individual strips

Fig. 7 demonstrates the pulse-hight distribution registered by the strip pairs under α-particle irradiation. The bias voltage (U=450 V) was applied to one strip of the pair, the exposure time was 30 minutes.

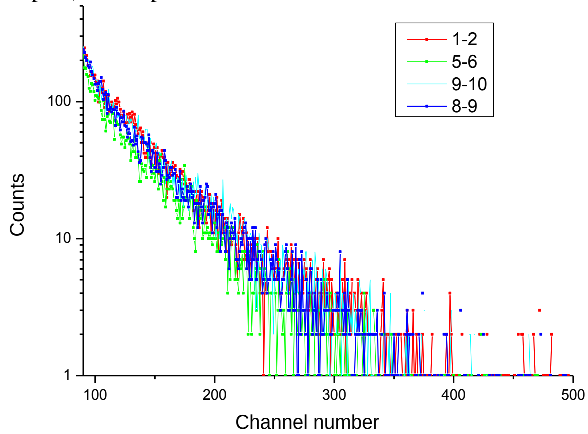

Fig. 7. Amplitude distribution of the signals from the strip pairs under α-irradiation

3.2. Radiometry of electron and bremsstrahlung radiation.

3.2.1. To investigate the possibility of the detector using in the radiation technological processes, its sensitivity to the high-intensity electron and bremsstrahlung field was studied. The measurements were carried out at the accelerator LU-10. The strip contacts were combined into the three groups comprising 3 neighbour strips (1-3, 4-6, 7-9). The analog sensitivity of each group to the absorbed dose rate was measured in such a way.

The detector calibration against the absorbed dose was performed using the Harwell Red Perspex 4034 (RP) dosimeters. Their calibration equation was provided by the manufacturer and obtained on a γ-radiation setup with the ^{60}Co γ-source. For the measurements in the electron flux, the RP detectors were pre-calibrated on-site using the reference calorimeter dosimeters RISO Polystyrene. In both cases, the traceability to the UK national standard of the absorbed dose was provided.

3.2.2. Fig. 8 illustrates the schematic of the measurements in the electron radiation field. The operation mode of the accelerator was:

- electron energy, MeV – 9.3;
- average beam current, mA – 777;
- beam pulse-repetition rate, Hz – 250;
- width of the beam scanning zone, cm – 42.

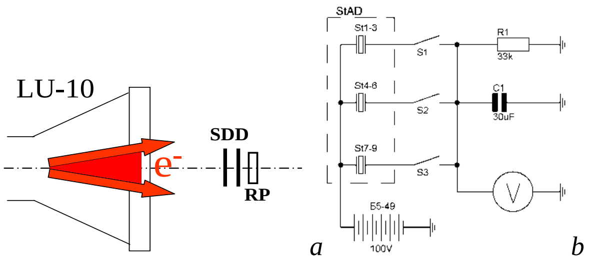

Fig. 8. Schematic for the measurements of detector sensitivity under the electron irradiation: a – geometry of the output device of the accelerator; b – detector connection diagram

The SDD and two RP dosimeters were placed at a distance of 150 cm from the output foil of the accelerator on its axis. The bias voltage U=100 V was applied to the SDD. A signal from the SDD went to the integrator (R1C1) with time constant 1 s. The voltage at the integrator's exit was measured by a voltmeter V (V7-40).

The output devices were irradiated for 10 seconds, while the current from each group of the strips was measured. The results are listed in Table 1.

Table 1

Sensitivity of the detector in the field of electron radiation

Contact group	Detector sensitiity, C/Gy
1-3	6.98E-11
4-6	6.51E-11
7-9	6.77E-11

The average value of sensitivity makes 6.75E-11 C/Gy (u=10%, k=2).

3.2.3. The geometry of the accelerator output devices and the metering circuit for determination of its sensitivity in the bremsstrahlung radiation are shown in Fig. 9. Taking into account the decrease of the average absorbed dose by ~2 orders of magnitude, the measurements were performed in a pulsed mode at the following beam parameters:

- electron energy, MeV – 9.5;
- width of the beam scanning zone, cm – 42;
- beam pulse duration, s – 3.3;
- pulse beam current, mA – 0.970;
- beam pulse-repetition rate, Hz – 250.

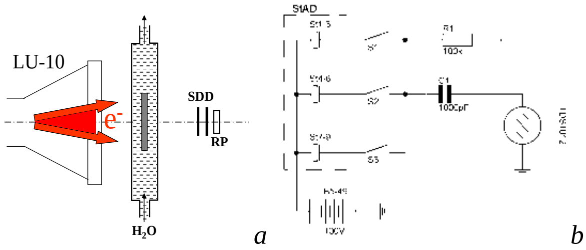

Fig. 9. Schematic for the measurements of detector sensitivity in the bremsstrahlung field: a – location of the accelerator and elements of the output device; b – detector connection diagram

The SDD with nearby RP dosimeters were placed at a distance of 40 cm downstream from the bremsstrahlung converter on the accelerator axis. The signal from the detector was registered with a digital oscilloscope TDS 1012.

Irradiation of SDD was conducted for 10 minutes with simultaneous current measurement for each group of the contacts. The results are shown in Table 2.

Table 2

Sensitivity of the detector in the bremsstrahlung field

Contact group	Detector sensitivity, C/Gy
1-3	4.9E-11
4-6	4.2E-11
7-9	4.7E-11

The average value of the SDD sensitivity makes 4.6E-11 C/Gy (u=10%, k=2) at the absorbed dose rate of ~ 20 Gy/s.

3.2.4. The experimental setup for studying the possibility of using the detector to characterize the beam profile is shown in Fig. 10. During this measurement the beam scanning was switched off. The accelerator was working at a beam pulse frequency of 1 Hz. The SSD unit was positioned on the beam axis at a distance of 40 mm from the accelerator exit window. A signal from the individual strips went to the switch located directly near the detector. The rest of the recording equipment had been taken out of the exposure area. The power supply provided a voltage bias U=100 V to the detector. The strips were switched sequentially by the control unit. The signal was recorded by the digital oscilloscope (TDS1012). The results obtained are shown in Fig. 11. It is evident, that the actual distribution of the electron flux density is not axially symmetric. During the measurements, the deviation of the beam axis on the detector with amplitude of about 1 mm and the period of about 15 s was observed.

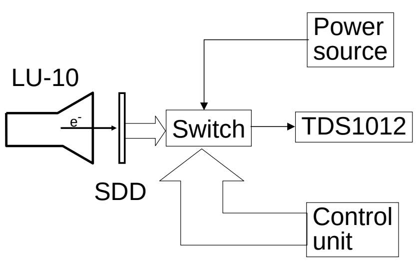

Fig. 10. Experimental setup for measuring the profile of the electron beam

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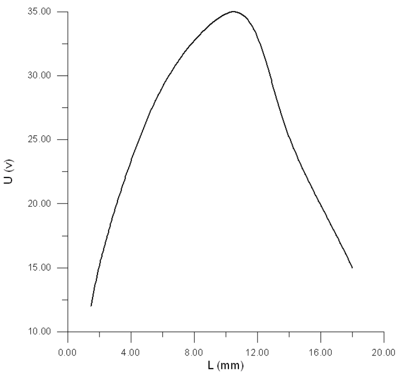

Fig. 11. Electron beam profile as measured by SSD

CONCLUSIONS

Previously, it was found that the radiation detectors based on CVD-diamond have high radiation resistance [1]. The investigation of the detector prototype with the strip contacts, undertaken in this work, has shown that it is also characterized by low dark leakage current (less than about 25 pA through the bulk and about 9 pA on the surface). The analog sensitivity of the strip detector, normalized to the diamond film volume, is similar to the previously obtained value for the single-contact detectors [2]. At the same time, the difference between the analog sensitivity for different groups of the strip contacts does not exceed 10%. This indicates a sufficient homogeneity of the CVD-film and the reproducibility of its characteristics.

In general, such properties determine a wide range of applications for the diamond detectors – from the radiometry and flux profile characterization of the radiation fields to the dosimetric maintenance of industrial radiation processes in the installations with the electron accelerators or γ-sources.

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РАЗРАБОТКА И ИССЛЕДОВАНИЕ ХАРАКТЕРИСТИК СТРИПОВЫХ ДЕТЕКТОРОВ НА ОСНОВЕ CVD-АЛМАЗА

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В ННЦ ХФТИ созданы опытные образцы координатно-чувствительных полупроводниковых детекторов на основе поликристаллической алмазной плёнки (CVD-алмаз). Описаны вариант детектора со стриповым типом контактов и его характеристики. Разработаны методики калибровки детектора в целом и его отдельных элементов (групп стрипов) по мощности поглощённой дозы электронного и тормозного излучений. Независимый анализ условий регистрации детектором полей излучения выполнен методом компьютерного моделирования. Проведенные на ускорителе ЛУ-10 ННЦ ХФТИ эксперименты показали, что значения чувствительности отдельных элементов (стрипов) детектора близки между собой. Результаты измерений интегральной чувствительности детектора согласуются с данными, полученными ранее в условиях полей излучения низкой интенсивности. Продемонстрирована возможность применения детектора в исследованиях поперечной динамики пучка электронов.

РОЗРОБКА ТА ДОСЛІДЖЕННЯ ХАРАКТЕРИСТИК СТРИПОВИХ ДЕТЕКТОРІВ НА ОСНОВІ CVD-АЛМАЗУ

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У ННЦ ХФТІ створені дослідні зразки координатно-чутливих напівпровідникових детекторів на основі полікристалічної діамантової плівки (CVD-алмаз). Описано варіант детектора із стриповим типом контактів і його характеристики. Розроблені методики калібрування детектора в цілому і його окремих елементів (груп стрипів) за потужністю поглиненої дози електронного і гальмівного випромінювань. Незалежний аналіз умов реєстрації детектором полів випромінювання виконаний методом комп'ютерного моделювання. Проведені на прискорювачі ЛУ-10 ННЦ ХФТІ експерименти показали, що значення чутливості окремих елементів (стрипів) детектора близькі між собою. Результати вимірювань інтегральної чутливості детектора узгоджуються з даними, отриманими раніше в умовах полів випромінювання низької інтенсивності. Продемонстрована можливість застосування детектора в дослідженнях поперечної динаміки пучка електронів.