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Radiation hardness of subterahertz radiation source after neutron exposure

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The study of the radiation hardness of subterahertz radiation source from a Gunn diode oscillator and a multiplier, based on a semiconductor superlattice GaAs/AlAs was continued. The dependences of the output power on the frequency of a Gunn diode oscillator before and after neutron irradiation are experimentally measured. The dependence of the output power on the frequency of the source of subterahertz radiation to neutron radiation with fluences of $3.5 \cdot 10^{12}$, $2.85 \cdot 10^{13}$, $10^{14}\,\mathrm{cm}^{-2}$ has been analytically estimated.

Keywords: Radiation hardness, superlattice, Gunn diode, THz.

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1. Introduction

The sources of the subterahertz electromagnetic waves with a wide band of frequency retuning are applied in solving problems of the radio-astronomy [1,2], the spectroscopy [3], building the systems of communication [4–6] and security [7], the combat control and orientation systems [8]. Small overall dimensions, small supply voltages and ionising radiation hardness are the main requirements for designing transceiver equipment of military and space purpose. Such a device is based on a source of the Gunn diode (GD) heterodyne and the semiconductor superlattice (SCSL) multiplier [9]. Currently, the studies are actively undertaken for ionising radiation hardness of the traditional bulk [10] and planar Gunn diode [11], as well as the diodes based on the GaAs/AlAs-superlattices [12]. This article examines the radiation hardness of the subterahertz source based on GD and SCSL.

2. Experimental

The Gunn diode oscillator (GDO) used the Gunn diode on gallium arsenide produced by JSC „SPE“ „Salyut“, Nizhny Novgorod. The GaAs diameter was ~ 0.1 mm, so was the thickness $10{-}20\,\mu$m. The crystal is mounted on a heat sink crystal holder made as a copper rod of the diameter of 1.2 mm and the height of 2 mm. The carrier concentration in GaAs is $n_0 = 8 \cdot 10^{15}\,\mathrm{cm}^{-3}$, so is the active area size — $3\,\mu$m. The basic oscillating frequency of such diodes is within the 8-mm range. All the three GDs examined in this article (№ 1, 2, 3), have the similar parameters within the process accuracy.

In order to obtain the dependences of the power on the GD oscillating frequency, a special measurement chamber has been designed [13].

The characteristics of the oscillating frequency and power of GD were measured as per a scheme described in detail in the study [13]. At bias voltage supply to the diode, the electromagnetic oscillations with the frequency of ~ 30 GHz were induced in the chamber. From the chamber output, the SHF power is transferred through the guidewave of the cross section of 3.6×1.8 mm to the primary transducer M5-50 to be conversed, and the value of the output power is displayed on the indicator of the power meter M3-22. The oscillating frequency is measured using the resonant frequency meter Ch2-26.

After obtaining the dependencies of the signal output power on the frequency, the GDs were irradiated with fluences of the neutrons: GD № 1 — $3.5 \cdot 10^{12}$, GD № 2 — $2.85 \cdot 10^{13}$, GD № 3 — $10^{14}\,\mathrm{cm}^{-2}$. After 6 months the series of measurements was performed for all the examined GDs.

3. Results and discussion

The irradiation of the semiconductor diode results in the defects, the reduction of the mobility of the charge carriers and the ratio of the current in the maximum of the current-voltage characteristic to the current in the minimum. That is why the level of the output power and the diode efficiency is decreasing. At the same time, the accompanying γ-irradiation eliminates the mechanical stresses at the metal-semiconductor interface and reduces the contact resistance [14].

In accordance with the results of the measurements of the GD parameters before and after neutron irradiation, we

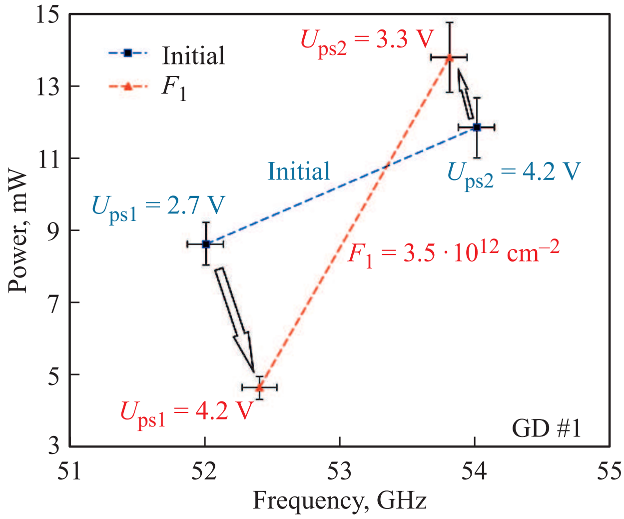

Figure 1. Dependences of the output power on the oscillating frequency for the GD № 1.

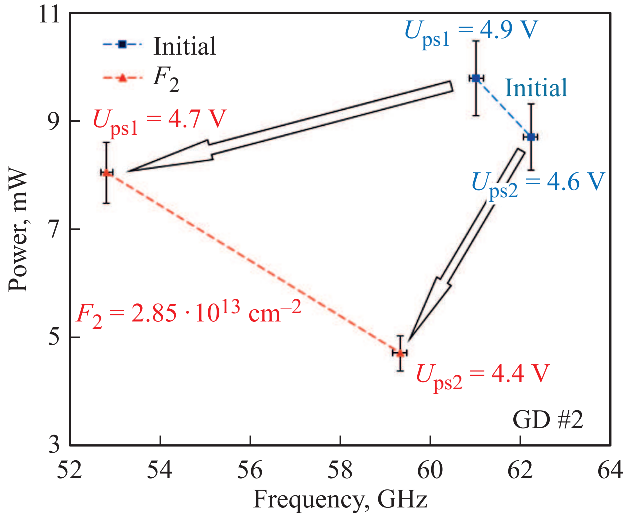

Figure 2. Dependences of the output power on the oscillating frequency for the GD № 2.

have observed: for the GD № 1 (Fig. 1) — the narrowing of the operating frequency band compared to the parameters before the irradiation by 30%, for the GD № 2 (Fig. 2) — the broadening of the frequency band by 440%, for the GD № 3 (Fig. 3) — the broadening by 220%. After the neutron irradiation, there is the decrease in the GD output power for almost all the samples.

When comparing the results before the irradiation and with the fluence of $3.5 \cdot 10^{12}$ cm^{-2}, for the GD № 1 there is evidently the narrowing of the operating frequency band by 30%, the reduction of the power by 46% for the operating points with the voltage of 2.7 V (before the irradiation) and 4.2 V (after the irradiation) the invariability of the parameters for the operating points with the voltage of 4.2 and 3.3 V (taking into account the measurement errors).

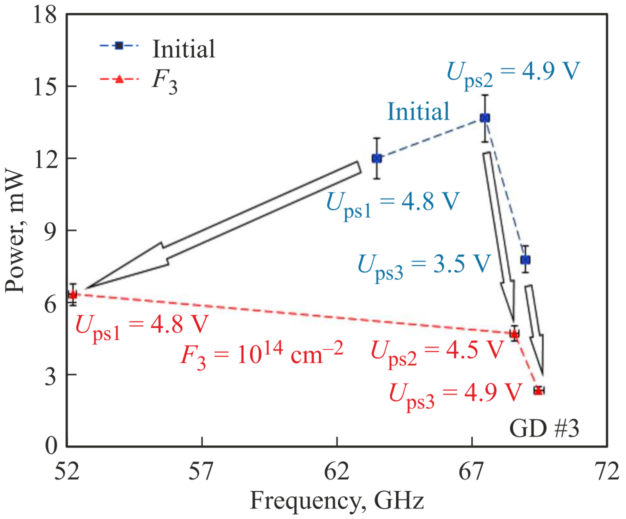

Figure 3. Dependences of the output power on the oscillating frequency for the GD № 3.

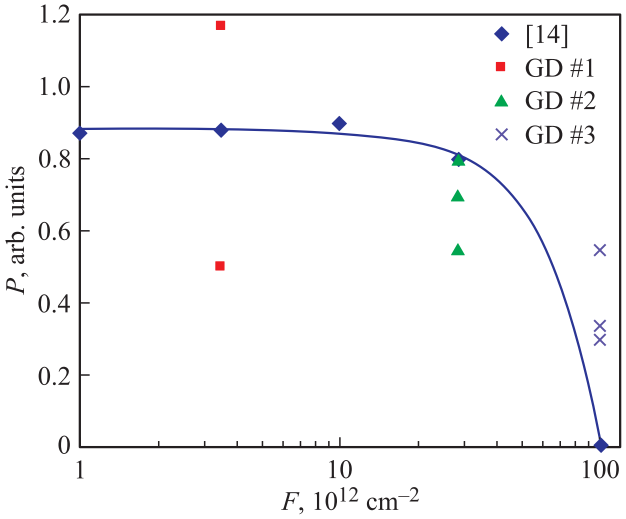

Figure 4. Dependence of the GD output power ratio on the neutron fluence.

At the fluence of $2.85 \cdot 10^{13}$ cm^{-2} for the GD № 2 — the broadening of the frequency band by 440%, the reduction of the power by 11% for the operating points 4.9 and 4.7 V and the reduction of the power by 46% (the operating points 4.6 and 4.4 V). At the fluence of 10^{14} cm^{-2}, for the GD № 3 there is the broadening of the operating frequency band by 318% and the reduction of the power: by 47% for the operating points before and after the irradiation by 4.8 V each, 65% — 4.9 and 4.5 V, 70% — 3.5 and 4.9 V.

As in the paper [14], the power ratio before and after the irradiation reduces in dependence on the value of the neutron fluence except for the operating point of 4.2 V. For this point, the lower limit of the measurement error after the irradiation exceeds the upper limit of the measurement

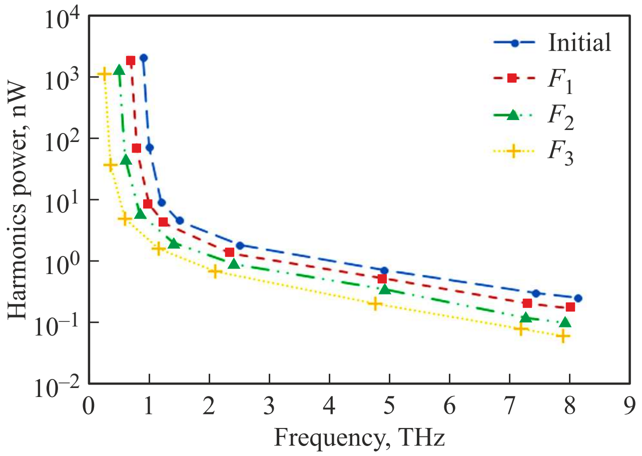

Figure 5. Dependence of the harmonics power on the oscillation frequency of the subterahertz radiation before the irradiation and at the various neutron fluences: $F_1 = 3.5 \cdot 10^{12}$, $F_2 = 2.85 \cdot 10^{13}$, $F_3 = 10^{14}\,\text{cm}^{-2}$.

error before the irradiation (Fig. 4) by several percent. Thus, the power level is almost unchanged. However, for the operating points 2.7 V (before the irradiation) and 4.2 V (after the irradiation) the power drop is up to 50%, which is most likely explained by an experimentally observed optimization of the diode design for the waveguide chamber with the decrease in the electron concentration to the optimum level and in the match type. Thus, the parasitic changes of the diode parameters are compensated. The reduction of the output power for the GD No 3 after the irradiation in several times, not by orders is explained by partial rebuilding of the defects after the structure annealing.

Due to the higher concentration of the impurity and the smaller formation of the radiation defects at the same neutron fluence, the output power of the planar Gunn diode is changing less than for the bulk diode [15].

The study [16] has obtained the values of intensity of harmonics of the frequency multiplier on SCSL in the frequency band of 0.4–6.5 THz; and the study [11] has presented the research of the radiation hardness of the diodes on GaAs/AlAs SCSL. Based on the powers of the harmonics of the SCSL frequency multiplier in the study [16], the obtained dependences of the power on the frequency for the GD, it is possible to evaluate the dependence of the power of the harmonics on the frequency of the subterahertz source (Fig. 5). The third harmonic of the oscillator ($3 \cdot 53.3$ GHz) on GD with a value of 160 GHz was selected as a reference frequency of the heterodyne. For the fluence in $3.5 \cdot 10^{12}\,\text{cm}^{-2}$, the heterodyne was selected to be the GD oscillator № 1, $2.85 \cdot 10^{13}\,\text{cm}^{-2}$ — GD № 2, $10^{14}\,\text{cm}^{-2}$ — GD № 3. When irradiating the heterodyne with the neutrons, with the increase in the fluence the level of the power of the harmonics of the THz source is decreasing.

4. Conclusion

The comparison of the measured dependences of the GD parameters with the data in the other studies might indicate a similar nature of the behavior of the output power ratio before and after the diode irradiation by the neutron fluence.

Based on the measurements of the operating characteristics of the GD heterodyne and the theoretical results of the radiation hardness of SCSL the conclusions were made on radiation hardness to neutron radiation of the subterahertz source in general.

Conflict of interest

The authors declare that they have no conflict of interest.

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