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ELECTROMAGNETIC COMPATIBILITY OF SEMICONDUCTOR DEVICES EXPOSED TO TRANSITION RADIATION

Abstract. The **subject** of the paper is an analysis and a physical model of the occurrence of reversible failures in semiconductor diodes (when current-voltage characteristics of the devices are influenced by electromagnetic radiation (EMR)). The model is based on the mechanism with which the energy of currents induced by external EMR is converted into the energy of natural electromagnetic oscillations of solid-state components of radio units (transition radiation effect). The **aim** of the paper is to justify experimental studies on the basis of the proposed physical model of reversible failures (occurrence of negative resistance sections in current-voltage curve of semiconductor diodes). We determined external electromagnetic radiation and semiconductor device parameter ranges with which this physical model can be applied. We conducted some experiments to study the influence of pulsed electromagnetic radiation on the current-voltage characteristics of direct current diode sections. The experiments justified the presence of areas with negative differential resistance characteristic for the natural oscillation generation mode (an increase in forward current when the voltage drops). Our **objectives** are to perform experimental study of interactions between the currents induced by external EMR and electrostatic oscillations of a semiconductor structure. Such interactions results from conversion of energy of moving charges (induced currents) into energy of electromagnetic oscillations under conditions of transition radiation when the particle flux goes along the normal to a semiconductor structure boundary. The **methods** used are analytical methods, i.e. solving Maxwell's equations and medium equations in the framework of the hydrodynamic approach. The following **results** were obtained. Experimental studies of behavior of semiconductor components of electrical radio units exposed to strong pulsed electromagnetic fields have been carried out. The nature of changes in the performance of semiconductor components has been studied. It has been shown that the impact of pulsed electromagnetic radiation is accompanied by currents in the conductive elements of the units. We define here a certain type of reversible failures of semiconductor radio units. Failures of this type occur due to interaction between the external radiation induced currents and own fields of radio equipment components. Such failures occurs in presence of transition radiation (when the current is directed along the normal to the boundary of the unit). We argue that such interactions lead to energy losses in induced currents due to excitation of natural oscillations in the units, i.e. the units enters an oscillation generation mode, which is characterized by a change in the current-voltage characteristics of radio devices. With the results of comparative analysis of the experimental and calculated data obtained in this work, it is possible to use the proposed physical model of reversible failures and calculated derived relationships to determine criteria of occurrence and quantitative characteristics of reversible failures in semiconductor diodes exposed to pulsed electromagnetic radiation (occurrence of S-shaped sections of direct current). **Conclusion.** The results obtained can be used to assess electromagnetic compatibility of active electronic devices (millimeter/submillimeter amplifiers, generators and transducers of electromagnetic oscillations) exposed to external pulsed electromagnetic fields. A comparative analysis of quantitative estimates of reversible failures of semiconductor devices depending on the spatial configuration of the affecting field (the induced current is normal to the structure boundary) allows us to solve the problem of optimizing the degree of distortion in the operating characteristics of these devices.

Keywords: electromagnetic radiation; semiconductor structures; surface oscillations; charged particles; decrement of oscillations.

Introduction

The whole variety of failures that occur in electronic equipment resulting from the impact of external factors is divided into categories: reversible and irreversible [1-3]. Irreversible failures lead to complete cease of equipment functioning. They occur when the changes in equipment internal parameters of the go beyond the permissible limits (when exposed to external electromagnetic radiation (EMI), irreversible failures usually occur due to thermal breakdown of components). Reversible failures are characterized by a temporary interrupt in functioning leading to a distortion in the output characteristics.

Available theoretical and experimental results of studies of the EMR impact on electrical radio equipment (ERE) mainly relate to irreversible failures [2]. At the same time, there are still many open questions as to what degree interaction between induced EMR currents and natural electromagnetic oscillations occurring directly in ERE components, may affect the performance of the ERE.

Meanwhile, interactions of this kind actually determine the degree of deviation of the output characteristics from the normal values and the possibility of recovery of component normal functioning, i.e. reversibility criteria for the failures.

Here we propose and verify a physical model of reversible failure occurrence in semiconductor diodes (from impact of electromagnetic-radiation-induced currents on current-voltage characteristics of the devices). This model is based on the mechanism converting the energy of currents induced by external EMR into the energy of natural electromagnetic oscillations of solid-state components of radio equipment (transition radiation effect). We also describe our experimental studies of the impact the pulsed electromagnetic radiation has on the current-voltage characteristics of direct current sections of diodes. The results of the comparative analysis of the experimental and calculated data obtained in this work make it possible to use the proposed physical model of reversible failures and the calculated ratios obtained on its basis to determine the criteria for occurrence of reversible failures as well as their quantitative characteristics.

Task solution

Problem formulation. In [5], a model is proposed for converting the energy of currents induced by external EMR into the energy of natural electromagnetic oscillations of solid-state components of the ERE, which leads to the occurrence of reversible failures in the latter (temporary alterations in their performance).

The possibility of this energy conversion is determined by the effect of transition radiation. This effect takes place when the induced current (the direction vector of the affecting EMR electric field strength) is perpendicular to the boundaries of the semiconductor device (in particular, diode) and manifests itself in the following [4].

When a charge moves in a material medium, the produced electromagnetic field is determined not only by the magnitude of the charge and its speed, but also by the dielectric properties of the medium. If these properties change when a charge with a constant speed crosses the interface between the media (semiconductor structure), the field created by the charge changes, the field partially separates from the particle and the separated portion can be radiated into space. The resulting radiation received the name of transition radiation. As a result, the electromagnetic-radiation-induced particle flux passage through a semiconductor structure leads to continuous process that converts the energy of the charges into the energy of natural oscillations of the field. The structure switches to oscillation generation.

Thus, the electronic system loses some of its energy, i.e. an increase in current is accompanied by drop in voltage, which leads to negative resistance sections in the current-voltage curve. This mode (of generation and instable oscillation) is characteristic for exponential increase in the amplitude of the natural oscillations of the structure ($\approx \exp(+\gamma\, t)$), where γ is the instability increment.

The results of beam instability studies (determination of instability increment) obtained in [5] let us to estimate the radiation energy of natural oscillations and to obtain the calculated relationships between the parameters of the impacting pulsed field, the semiconductor device parameters and the degree of deviation of device I-V curve within the direct current section.

The radiation power ΔP_{rad} of natural oscillations of a semiconductor device exposed to an external field (in the presence of induced current) can be defined as particle flux translational motion energy loss (kinetic energy) during the passage of a particle flux through the surface wave field localization region.

$$\Delta P_{rad} = \Delta W_{\text{кин}} / \Delta t, \tag{1}$$

where $\Delta W_{kin} = (mv^2/2)\cdot(n_{ob}V)$; $mv^2/2$ is the kinetic energy of a particle of the beam induced by an external impulse; n_{ob}, v, e, m are respectively concentration, drift velocity, charge and mass of the beam electrons, V is the volume occupied by the induced current (the volume of the solid-state structure). In the beam instability mode, the drift velocity $v \approx v_0 \exp(+\gamma\, t)$, therefore:

$$\Delta P_{rad} \approx m{v_0}^2 \gamma\, (n_{ob}V) \tag{2}$$

where $\gamma \approx \left(\omega_b^2 / \omega_1^2\right)\cdot\tau^{-1}$ is the increment of the beam instability of the surface oscillations of a structure within the semiconductor device having natural frequency ω_1 (a surface polariton) [6]; $\omega_b = \sqrt{4\pi e^2 n_{ob}/m}$ is the plasma frequency of the electrons of the flux induced by the external electromagnetic radiation; τ is the time the charge drifts through the oscillation localization region.

Thus, the energy ΔW_{rad} radiated during Δt_{rad} – the time of exposure to an external EMR voltage pulse – is determined by the following equation:

$$\begin{aligned} \Delta W_{rad} &= \Delta P_{rad} \Delta t_{rad} = \\ &= m{v_0}^2\, \gamma \left(\omega_b^2 / \omega_1^2\right)\cdot \tau^{-1} (n_{ob}V)\Delta t_{rad}. \end{aligned} \tag{3}$$

The parameters determining the value of ΔW_{rad} can be estimated using the existing experimental relations between the characteristics of the currents induced in the structures under study [7–10] (i.e. concentration n_b, drift velocity v_0 and Langmuir frequency ω_b of the induced current electrons) and the parameters of the external pulsed electric field (amplitude E_0 and duration Δt_{imp}). Own frequencies ω_1 are determined by the parameters of the structure of the semiconductor device under study (carrier concentration, dielectric permittivity and dimensions). For high frequency and pulsed semiconductor diodes studied here, the frequencies ω_1 falls within the submillimeter range.

With relation (3), it is possible to estimate the energy losses the currents induced by external EMR experience due excitation natural oscillations of metal-semiconductor-dielectric structures constituting semiconductor diodes. It is obvious that the generation mode in semiconductor devices leads to the occurrence of S-shaped direct current sections with negative differential resistance on the I-V curves for the device [11] because negative resistance characterizes the amount of energy the solid-state electronic system losses with radiation - (Fig. 1, section A–B) i.e.

$$dR = \frac{dU}{dI} < 0;\ dU < 0;\ dI > 0\,.$$

Thus, due to the exposure to external electromagnetic radiation, an increase in the forward current is accompanied by a decrease in the voltage on the diode. The presence of a negative resistance region on the I-V curve characterizes the possibility that a kind of reversible failure occurred (temporary change in current-voltage characteristics) resulted from the transformation of the induced current energy into oscillation energy, which is radiated into the environment.

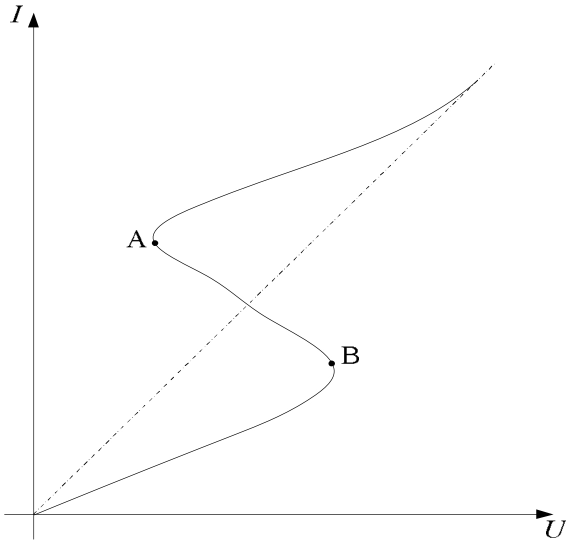

Fig. 1. I-V curve of the diode (direct current) (A–B is a distortion of the current-voltage characteristic due to exposure to EMR)

As a result, the energy loss of the induced current during the exposure to a voltage pulse Δt_{imp} in the experiment can be estimated by the following equation:

$$\Delta W_{rad} = \Delta P_{rad}\,\Delta t_{rad} = I_{rad}\,U_{rad}\,\Delta t_{rad} \qquad (4)$$

where I_{rad} is the magnitude of the direct current of the diode in the section A–B (Fig. 1); U_{rad} is the voltage in the section A–B (Fig.1) during the exposure to external EMR.

Objective:

1. Experimental assessment of the degree of distortion of the current-voltage characteristics of semiconductor diodes exposed to external electromagnetic radiation.
2. Determination of the presence of negative resistance direct current sections, depending on the parameters of the diode and external EMR.
3. A comparative analysis of the calculated data obtained on the basis of the physical model and experimentally obtained data (Figure 1.)

The object of the study is the current-voltage characteristics of the following semiconductor devices exposed to pulsed electromagnetic radiation: a 2D922B planar silicon diode diode with Schottky barrier and a KD409A silicon epitaxial diode. These units are used in high-speed impulse devices for converting alternating voltage. Electrical characteristics and parameters of the diodes are provided in Table 1.

The scheme of the experiment and its results. Experimental studies of pulsed electromagnetic field impact on function of semiconductor devices have been carried out using Reference Standard of Ukraine for pulsed electric and magnetic fields (REMP Standard) developed at Molniya Research and Design Institute, NTU “KhPI” [6].

The experimental equipment consisted of a high-voltage pulsed power supply (HVPPS) being discharged to a field-forming system (FS) in the form of a symmetric closed stripline (SL) (Fig. 2).

Table 1 – **The Electrical Parameters of the Diodes and the Requirements to the REMP Parameters**

Characteristics			**2D922B**	**KD409A**
Electrical parameters	Direct reverse current, mcA	T_1=25°C	0,5 (U_{rev}=10V)	same at $Urev$=24B
		T_2=100°C	10 ($Urev$=10V)	
	Total capacity, pf		1,0(U_{rev}=0)	2,0(U_{rev}=15V)
	Inductance, nH		1,0	4,0
Performance Limitations	Constant reverse voltage, V		10	24
	Direct forward current, mA	T_1=35°C	10	15
		T_2=100°C		25
	Pulsed forward current, mA $t_u \leq$ 10mcs, $Q \geq$ 10	T_1=25°C	20	500
		T_2=100°C		250
	Ambient temperature, °C		-60° C to +100° C	

Parameter	Magnitude
1 Electric field strength, kV/m	from 10^{-3} to 200
2. Magnetic field strength, A/m	from 0,1 to 530
3. The duration of the pulse, ns, max.	1
4. Pulse duration at 0.5, mcs, max.	100
5. Working volume dimensions (length×width×heght), mm, min.:	500×500×150

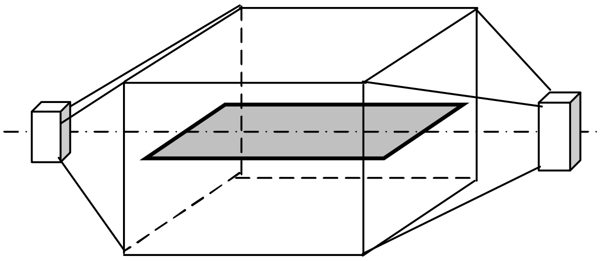

Fig. 2. Symmetric closed SL

The HVPPS generates discrete high voltage pulses with temporal parameters provided in Table 1, the amplitudes of these pulses to ensure generation of necessary levels of E and H fields taking into account FS transformation.

The main requirement to FS is to generate E and H fields with uniform structure, certain directions of field vectors and amplitudes that can be easily calculated from geometrical sizes of FS. Guidelines of the stripline type are the most suitable to this requirement.

A flat TEM-type electromagnetic wave propagates along the SL and has a definite direction of the vectors of E and H fields in any transverse section of the SL (Fig. 3). The SL dimensions determine the dimensions of the working volume where the test object is located (the connection circuit of a semiconductor diode). In this case, the dimensions of the SL are chosen in such a way that the wave impedance of the SL be 50 Ω.

During the experimental studies of EMR impact on the performance of semiconductor diodes, we used an SL-24 strip line with a height of 24 cm working with nanosecond pulses, since the mechanisms of external electromagnetic field influence studied here are implemented in this time range.

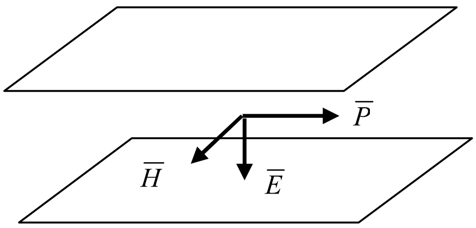

Fig. 3. The SL electromagnetic field vector directions.

In the experiments, one of the indicated diodes was sequentially connected to a direct current source and resistances, one of which (R_1) allowed the current of the diode (I) to be changed, and the other ($R_2 = 50\Omega$) provided matching mode with a cable connection to an oscilloscope (recorder) (Fig. 4).

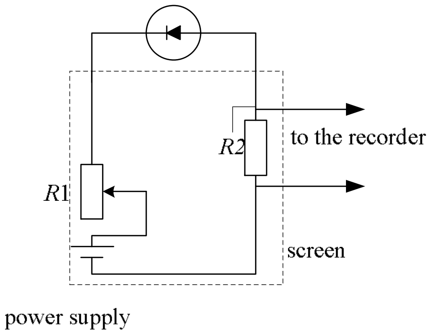

Fig. 4. The scheme of the experiment

The circuit, with the exception of the diode, was placed in a shielded volume and was taken out of the field-formation system (FFS). The object being exposed to a pulsed electromagnetic field (diode) was itself located between the plates of the stripline (Fig. 5). Fig. 5 shows the variants of the arrangement of the diode relative to the acting external field.

In the course of the experiment, we studied the influence of a pulsed electromagnetic field on current-voltage characteristic of the diode when the intensity vector of the external electric field is directed parallel to the direct current of the diode (this case corresponds to Cherenkov radiation mechanism), Fig. 6.

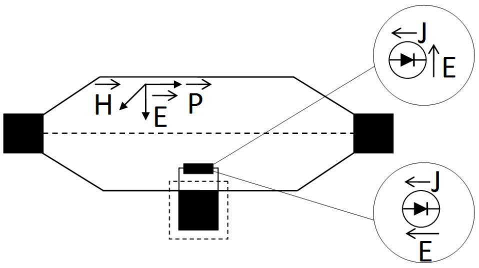

Fig. 5. Variants of the test object location within the field formation system

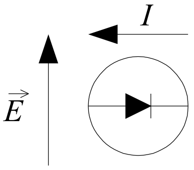

Fig. 6. The vector directions of the direct current diode and the external field under transition radiation

The direct forward current of diode I increased from 5 to 30 mA. The temporal parameters of a field strength pulse generated in the SL system:

- front duration - 0.5 ns;
- field strength pulse duration (Δt_{imp}) - 500 ns.

During the experiment, we studied the effect of a pulsed electromagnetic field with field strength amplitudes $E = 10, 20 \text{ and } 30\ kV/m$ on the level of the resulting voltage pulse (U) at the test object (diode).

Each step of increase in the current of the diode with an interval $\Delta I = 5mA$ was accompanied by the impact of an EMR pulse in the field formation system.

The evolution of the amplitude of the voltage pulse (U) at the diodes depending on the step-by-step change in the forward current (I) with simultaneous exposure to an external EMR was recorded with an oscilloscope.

Thus, we obtained the ratios of the voltage pulse U amplitude to the level of direct current at diode I for each of the indicated levels of the applied EMR ($E = =10, 20 \text{ and } 30\ kV/m$) and determined the shapes of the corresponding sections of the I-V curve.

The ratios of the voltage pulse amplitudes to the levels of direct current at the diodes are provided in Table 2. The data obtained shows that with increase in the current a decrease in the amplitude of the voltage pulse is observed, which corresponds to the I-V curve section with negative resistance of oscillation generation region (section A–B in Fig. 1).

The indicated diode types were chosen for the experimental studies because the working range of their parameters (current and voltage within the direct bias section) with electric field strength pulse duration in order of several hundred ns and the pulse amplitude about 10–30 kV/m determines the range of the radiation energy of natural electromagnetic oscillations of the semiconductor structures of the device components to be 10^{-7}–10^{-9} J. The radiation energy determined on the basis of the proposed physical model of reversible failures of semiconductor devices falls within the same range.

Table 2 – **Evolution of the voltage pulse amplitude U (mV) of KD409A epitaxial silicon diode and 2D922B silicon planar direct current diode with Schottky barrier as a function of I (mA)**

KD409A	Voltage pulse amplitude U(m B)		
Direct current diode I(mA)	E=10 kV/m	E=20 kV/m	E=30 kV/m
5	950	1450	1650
10	930	1430	1620
15	910	1400	1600
20	840	1390	1580
25	800	1350	1450
30	740	1290	1410
2D922B	Voltage pulse amplitude U(m V)		
Direct current diode I(mA)	E=10 kV/m	E=20 kV/m	E=30 kV/m
5	1550	2950	3200
10	1520	2910	3150
15	1490	2870	3090
20	1450	2800	2950
25	1440	2760	2940
30	1410	2700	2820

The analysis of the current-voltage characteristics obtained experimentally indicates the presence of sections with negative differential resistance similar to the calculated direct current section of the physical model of reversible semiconductor device failures (section A–B in Fig. 1) because under the experimental conditions the increase in direct current was accompanied by a decrease in the total (including the external influence) voltage at the diode.

In this case, the deviation character of the current-voltage characteristic obtained during the experiment did not depend on the pulse amplitude of the impacting voltage.

This mode of growth of radiation energy of electromagnetic oscillations of semiconductor devices due to the energy of induced currents is, in our opinion, determined by the mechanisms of beam instabilities.

Analysis

Let us present a comparative analysis of the values of radiation energy of natural oscillations of semiconductor diodes 2D922B and KD409A obtained experimentally and quantitative estimates of the magnitude of the radiation energy obtained by calculation based on the physical model of reversible failures of semiconductor devices proposed here.

It was found experimentally that an increase in the forward current of diode 2D922B within the range $\Delta I \approx 5 - 30 mA$ (the amplitude of the impulse of the acting voltage falls within $E_0 \approx 10 - 30\ kV/m$) leads to a drop in the amplitude of the voltage pulse at the diode within $\Delta U \approx 1550 - 2800 mV$. This means that a section with negative resistance appear on the I-V curve of the diode (section A–B in Fig. 1.)

When the pulse duration $\Delta t_{imp} \approx 500 ns$, the range of radiation energy determined using equation (4) $\Delta W_{rad} \approx 0,6 \cdot 10^{-9} - 1,2 \cdot 10^{-8} J$.

For KD409A diode, with similar parameters of the acting pulse and in the same direct current ranges, the drop in the voltage amplitude at the diode is within $\Delta U \approx 950 - 1400 mV$, and the radiation energy is $\Delta W_{rad} \approx 0,3 \cdot 10^{-9} - 0,8 \cdot 10^{-8} J$.

Let us determine now the energy losses of charged particle fluxes induced by external pulsed radiation, occurring due to the excitation of natural oscillations of solid-state structures, using the physical model of reversible failures proposed here (equation (3)).

The parameter levels that determine ΔW_{rad} can be estimated using the existing experimental dependencies relating the induced current magnitude in silicon structures constituting the objects under study (diodes) [7] to the levels of external electric field strengths E_0 (i.e., the concentration of electrons of the induced current (Langmuir frequency of electrons of the induced current $\omega_b^2 = 4\pi e^2 n_b / m$) and drift speed v_0)).

When changing the parameters of the acting pulse, similar to that used in the experiment ($E_0 \approx 10 - 30\ kV/m$, $\Delta t_{imp} \approx 500 ns$) for the studied silicon diodes 2D922B and KD409A the values of the parameters falls within the following ranges:

$$n_b \approx 10^{10} - 10^{12} cm^{-3},\ v_0 \approx 10^6 - 10^7 \frac{cm}{s},$$

$$\omega_b \approx 10^9 s^{-1}.$$

The natural frequencies (surface polaritons) of the ω_1 structures constituting the diodes are determined from the magnitudes of the Langmuir oscillations $\omega_0 = \sqrt{4\pi e^2 n_0 / m}$, i.e. electron concentration n_0 in semiconductor component constituting the diodes:

$$\omega_1 \approx \omega_0 \approx 10^{10} - 10^{11} s^{-1} \text{ [7].}$$

While the value of ΔW_{rad} is $10^{-7} - 10^{-9} J$ according to (3).

The comparative analysis of the experimental and calculated data shows that the transition radiation energy for the studied semiconductor devices (diodes) is determined by one order of magnitude $\Delta W_{rad} \approx 10^{-7} - 10^{-9} J$ with a general tendency of increase in the radiation energy depending on the physical parameters of the component materials and characteristics (amplitude increase) of the applied voltage pulse.

Conclusions

1. We have justified the experimental procedure for studying a physical model proposed in [5] and describing the occurrence of reversible failures (the effects the current induced by electromagnetic radiation has on current-voltage characteristics of semiconductor devices). We have also determine the ranges of external electromagnetic radiation parameter values at which this physical model can be applied (electric field strength amplitude $E < 100\ kV/m$ and pulse duration $\Delta t_{imp} \approx 10^2 - 10^3 ns$).

2. The experimental studies were performed to determine the impact pulsed electromagnetic radiation (with electric field strength amplitude $E \equiv 10 - 30\ kV/m$ and pulse duration $\Delta t_{imp} \approx 500 ns$) has on the current-voltage characteristics of direct current sections of diodes (namely 2D922B silicon planar diode with a Schottky barrier and KD409A silicon epitaxial diode). They revealed the presence of negative differential resistance sections in the curve, characterizing the mode of generation of natural oscillations in these devices (increase in direct current accompanying the voltage drops)

The results of a comparative analysis of the experimental and the calculated data obtained here make it possible to use the proposed physical model of reversible failures and the calculated relationships derived from it to determine the criteria for the occurrence of reversible failures in semiconductor diodes exposed to pulsed electromagnetic radiation (the occurrence of S-shaped sections of direct current curve) and quantitative characteristics of such failures.

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Електромагнітна сумісність напівпровідникових приладів в умовах перехідного випромінювання

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Анотація. **Предметом** вивчення є аналіз процесів і фізична модель виникнення оборотних відмов напівпровідникових діодів (впливу наведених електромагнітним випромінюванням (ЕМВ) струмів на вольт-амперні характеристики приладів). Дана модель базується на механізмі перетворення енергії наведених зовнішнім ЕМІ струмів в енергію власних електромагнітних коливань твердотільних комплектуючих радіовиробів (ефекті перехідного випромінювання). **Мета** - обґрунтування постановки експериментальних досліджень на базі запропонованої фізичної моделі оборотних відмов (появи областей вольт-амперних характеристик напівпровідникових діодів з негативним опором). Визначено області параметрів зовнішнього електромагнітного випромінювання і напівпровідникових приладів при яких реалізується дана фізична модель. Проведено експериментальні дослідження впливу імпульсного електромагнітного випромінювання на вольт - амперні характеристики ділянок прямого струму діодів. Вони показали наявність ділянок з негативним диференціальним опором, що характеризують режим генерації власних коливань (збільшення прямого струму при падінні напруги). **Завдання**: експериментальні дослідження взаємодії наведених зовнішнім EMI струмів з електростатичними коливаннями напівпровідникової структури, заснована на реалізації перетворення енергії рухомих зарядів (наведених струмів) в енергію електромагнітних коливань в умовах перехідного випромінювання, коли потік частинок рухається по нормалі до межі напівпровідникової структури. Використовувані методи: аналітичні методи рішення рівнянь Максвелла і рівнянь середовища в рамках гідродинамічного підходу. Отримані наступні **результати**: Проведено експериментальні дослідження функціонування напівпровідникових комплектуючих електрорадіовиробів в умовах впливу сильних імпульсних електромагнітних полів. Вивчено характер змін працездатності напівпровідникових комплектуючих елементної бази технічних засобів. Показано, що вплив імпульсного електромагнітного випромінювання супроводжується виникненням струмів в провідних елементах виробів. Визначено один з типів оборотних відмов напівпровідникової елементної бази електрорадіовиробів, заснований на взаємодії струмів, наведених зовнішнім випромінюванням, з власними полями структур, комплектуючих виріб. Подібні відмови реалізуються в умовах перехідного випромінювання (струм спрямований по нормалі до межі структури). Показано, що дана взаємодія проводить до енергетичних втрат наведених струмів на збудження власних коливань структури, тобто появі режиму генерації коливань, який характеризується зміною вольт - амперних характеристик радіовиробів. Результати порівняльного аналізу, отриманих в даній роботі експериментальних і розрахункових даних, дозволяють використовувати запропоновану фізичну модель оборотних відмов і отримані на її основі розрахункові співвідношення для визначення критеріїв виникнення і кількісних характеристик оборотних відмов напівпровідникових діодів в умовах впливу імпульсного електромагнітного випромінювання. (Появі S-подібних ділянок прямого струму). **Висновки**. Результати, отримані в роботі, можуть бути використані при оцінці електромагнітної сумісності активних радіоелектронних приладів (підсилювачів, генераторів і перетворювачів електромагнітних коливань міліметрового та субміліметрового діапазонів) в умовах впливу зовнішніх імпульсних електромагнітних полів. Проведений в роботі порівняльний аналіз кількісних оцінок оборотних відмов напівпровідникових приладів в залежності від просторової конфігурації впливає поля (наведений струм нормальний кордоні структури) дозволяє вирішувати задачі оптимізації ступеня спотворення робочих характеристик даних приладів.

Ключові слова: електромагнітне випромінювання; напівпровідникові структури; поверхневі коливання; заряджені частинки; декремент коливань.

Электромагнитная совместимость полупроводниковых приборов в условиях переходного излучения

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Аннотация. Предметом изучения является анализ процессов и физическая модель возникновения обратимых отказов полупроводниковых диодов (влияния наведенных электромагнитным излучением (ЭМИ) токов на вольт-амперные характеристики приборов). Данная модель базируется на механизме преобразования энергии наведенных внешним ЭМИ токов в энергию собственных электромагнитных колебаний твердотельных комплектующих радиоизделий (эффекте переходного излучения). **Цель** - обоснование постановки экспериментальных исследований на базе предложенной физической модели обратимых отказов (появления областей вольт-амперных характеристик полупроводниковых диодов с отрицательным сопротивлением). Определены области параметров внешнего электромагнитного излучения и полупроводниковых приборов при которых реализуется данная физическая модель. Проведены экспериментальные исследования влияния импульсного электромагнитного излучения на вольт – амперные характеристики участков прямого тока диодов. Они показали наличие участков с отрицательным дифференциальным сопротивлением, характеризующие режим генерации собственных колебаний (увеличение прямого тока при падении напряжения). **Задача**: экспериментальные исследования взаимодействия наведенных внешним ЭМИ токов с электростатическими колебаниями полупроводниковой структуры, основанная на реализации преобразования энергии движущихся зарядов (наведенных токов) в энергию электромагнитных колебаний в условиях переходного излучения, когда поток частиц движется по нормали к границе полупроводниковой структуры. Используемые **методы**: аналитические методы решения уравнений Максвелла и уравнений среды в рамках гидродинамического подхода. Получены следующие **результаты**: Проведены экспериментальные исследования функционирования полупроводниковых комплектующих электрорадиоизделий в условиях воздействия сильных импульсных электромагнитных полей. Изучен характер изменений работоспособности полупроводниковых комплектующих элементной базы технических средств. Показано, что влияние импульсного электромагнитного излучения сопровождается возникновением токов в проводящих элементах изделий. Определен один из типов обратимых отказов полупроводниковой элементной базы электрорадиоизделий, основанный на взаимодействии токов, наведенных внешним излучением, с собственными полями структур, комплектующих изделие. Подобные отказы реализуются в условиях переходного излучения (ток направлен по нормали к границе структуры). Показано, что данное взаимодействие проводит к энергетическим потерям наведенных токов на возбуждение собственных колебаний структуры, т.е. появлению режима генерации колебаний, который характеризуется изменением вольт – амперных характеристик радиоизделий. Результаты сравнительного анализа, полученных в настоящей работе экспериментальных и расчетных данных, позволяют использовать предложенную физическую модель обратимых отказов и полученные на её основе расчетные соотношения для определения критериев возникновения и количественных характеристик обратимых отказов полупроводниковых диодов в условиях воздействия импульсного электромагнитного излучения. (появлению S –образных участков прямого тока). **Выводы.** Результаты, полученные в работе, могут быть использованы при оценке электромагнитной совместимости активных радиоэлектронных приборов (усилителей, генераторов и преобразователей электромагнитных колебаний миллиметрового и субмиллиметрового диапазонов) в условиях воздействия внешних импульсных электромагнитных полей. Проведенный в работе сравнительный анализ количественных оценок обратимых отказов полупроводниковых приборов в зависимости от пространственной конфигурации воздействующего поля (наведенный ток нормален границе структуры) позволяет решать задачи оптимизации степени искажения рабочих характеристик данных приборов.

Ключевые слова: электромагнитное излучение; полупроводниковые структуры; поверхностные колебания; заряженные частицы; декремент колебаний.