KnE Energy & Physics
PhIO-2018
VII International Conference on Photonics and Information Optics
Volume 2018

Conference Paper

Research of Quantum Well Laser Diode's and Heterostructural P-I-N Photodiode's of Fiber-Optic Modules Radiation Hardness to Gamma-ray and Neutron Irradiation

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Abstract

The paper presents the measurements results of optical and electrical parameters of quantum well laser diodes and heteroepitaxial photodiodes under gamma-ray and neutron irradiation. The testing results of transceiver modules gamma irradiation tolerance are introduced. The most vulnerable elements of module are highlighted.

Keywords: laser diode, photodiode, radiation hardness, VCSEL, transceiver modules, fiber-optic communication

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Received: 28 January 2018
Accepted: 15 March 2018
Published: 25 April 2018

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the PhIO Conference Committee.

1. Introduction

Elements of precision equipment, such as laser diodes and photodiodes are widely used as controlled light sources in fiber-optic modules and communication lines. These devices are a potential alternative to the classical communication line on board the satellites [1] and therefore their radiation hardness assessment is required.

For these purposes, radiation tests of laser diodes of transmitting modules and photodiodes of receiving modules were carried out in order to estimate their total ionizing dose hardness from gamma-ray exposure and structural damage hardness from the neutron impact. These effects are most typical for the functioning electronic devices on board the satellites near the Earth's radiation belts.

2. Experiments

The test samples were irradiated using an electron accelerator in the bremsstrahlung mode. The reached level of total ionizing dose was approximately 0.5 Mrad. Figure 1

How to cite this article: R.K. Mozhaev and M.E. Cherniak, (2018), "Research of Quantum Well Laser Diode's and Heterostructural P-I-N Photodiode's of Fiber-Optic Modules Radiation Hardness to Gamma-ray and Neutron Irradiation" in *VII International Conference on Photonics and Information Optics*, KnE Energy & Physics, pages 393–399. DOI 10.18502/ken.v3i3.2053

shows the characteristics of transmitter (Fig. 1a) and receiver (Fig. 1b) sample. As can be seen from the figure this type of irradiation did not lead to significant changes in the characteristics

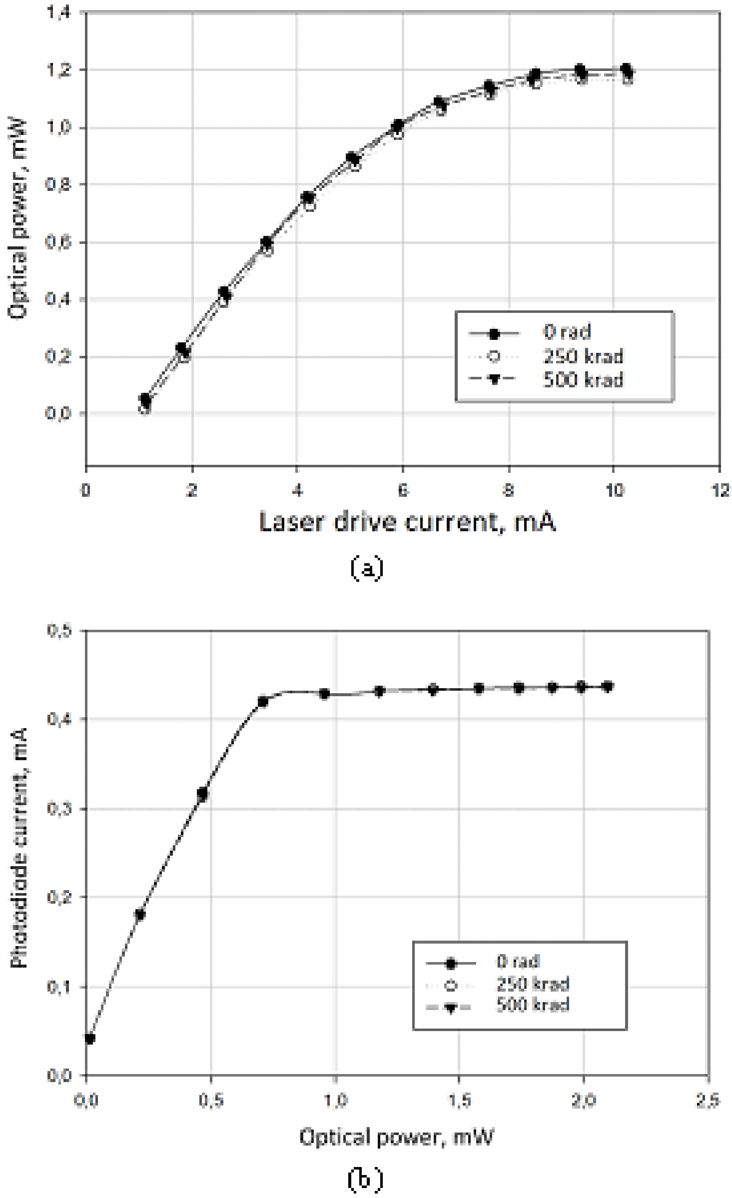

Figure 1: (a) Dependence of the output optical power of the laser diode on transmitter current at different total ionizing dose levels. (b) Dependence of the photocurrent of the laser diode on transmitter output power at different total ionizing dose levels

To simulate the effect of the protons of the radiation belts, the samples were irradiated on a pulsed fast neutron reactor with energy of 14 MeV. To eliminate annealing effects, the devices were irradiated in a passive mode. The results before and after the exposure are shown in Figure 2. The achieved level was 10^{14} n/cm^2.

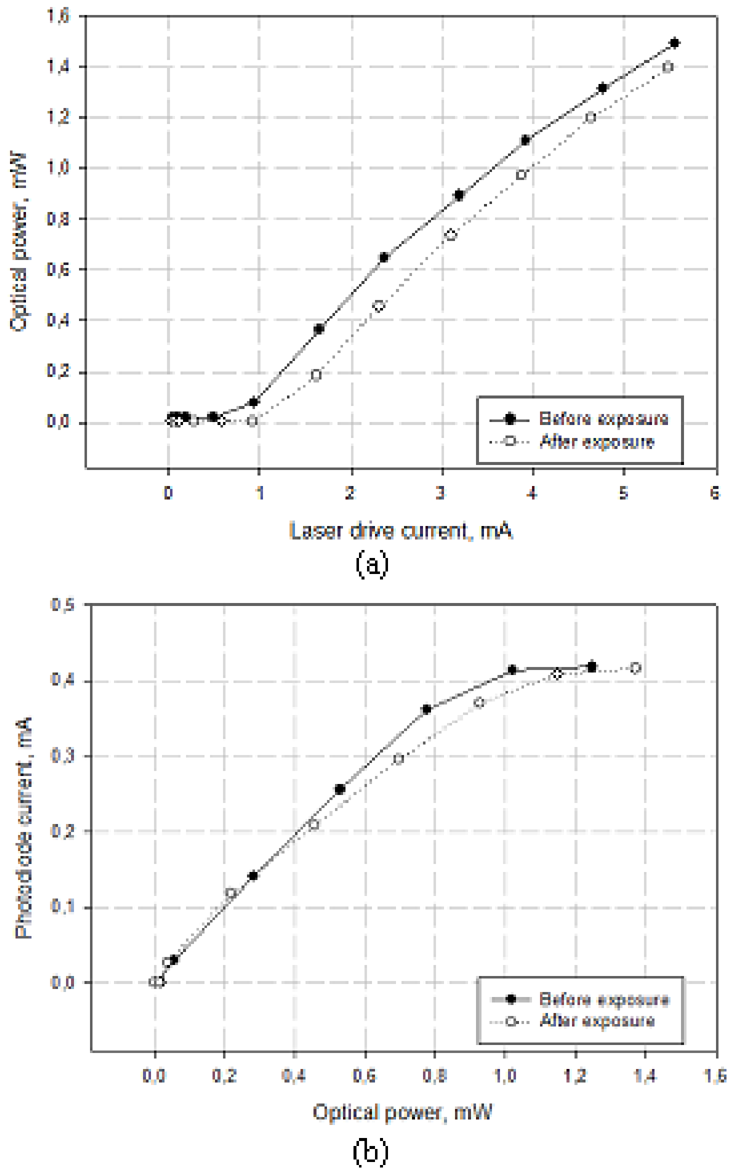

Figure 2: (a) Dependence of the output power of the laser diode on transmitters curent before and after 10^{14}n/cm2. (b) The graph of the receiver photocurrent versus the value of the input optical power of the reference source before and after reaching the level of 10^{14} n / cm2

3. Results and discussion

Optoelectronic devices are very sensitive to the displacement effects caused by neutrons [2]. When a neutron hits the solid lattice of the active region, the resulting recoil energy (elastic interaction) forms a Frenkel pair or a cascade of atoms displaced from the lattice sites [3-5]. The atoms displaced in this way become additional recombination centers, which leads to a decrease of minority carriers lifetime electrical resistance, and carrier mobility. The values of the damage constant K (and therefore of τ oK) are approximately 100 times greater for neutron irradiation damage than for

DOI 10.18502/ken.v3i3.2053

that caused by gamma irradiation. Since the nonradiative recombination sites compete with the radiative recombination process, neutron irradiation increases the threshold current at which lasing occurs [6].

In the relatively simple GaAs-based single-stripe lasers, the increase in threshold current started to become significant at fluence levels of 10^{13} to 10^{14} n/cm^{-2},and fluences up to about 10^{14} n/cm^{-2} did not cause catastrophic failure. Partial annealing of neutron damage can be achieved by operating in lasing mode after irradiation. Thermal annealing occurs at moderately elevated temperatures [7]. The carried out tests confirm it.

In order to minimize radiation effects, a laser diode should have a low threshold current and a very high maximum operating current [8].

Since VCSELs have several advantages in comparison to conventional edge-emitting laser diodes, including better output beam characteristics such as circular cross section and low divergence, low threshold currents, and high-temperature operation, they merit consideration for use in potential optoelectronic applications. In the future, however, they could become the dominant type of laser diodes [9-12]. Currently, VCSEL are increasingly used as lasing elements of the transceiver modules.

The tested devices are part of more complex setups, such as transceiver modules, which are usually the main part of fiber-optic systems. The modules, in addition to laser diodes and photodiodes, can include microcontrollers, memory blocks and other digital circuits. The modules under total ionizing dose tests included:

- VCSEL with fiber-optic pigtail;
- Photodiode with fiber-optic pigtail;
- transimpedance amplifier;
- amplifier-limiter;
- VCSEL driver

The operating mode of this device considers the conversation of electrical signal into an optical one, its transmission through an optical line, the conversion of a signal into electrical and comparison of the transmitted and received signals for errors during transmission. The fiber line segment of transmitter is connected to the receiver’s one.

During the test, the following parameters were monitored: the average optical power, laser drive current, receiver current and the number of errors per gamma-exposure session (at a data transmitting rate f = 1,0 Gbit/s)

Irradiations were carried out using an electron accelerator operating in bremsstrahlung mode. The average optical power was monitored using an optical power meter FHP2B04 during the transmission of pseudo-random signal. To control the optical power the irradiation was interrupted for no more than 5 minutes. The operation was monitored using a pseudo-random code generator/analyzer. The result of monitoring the loss of information during transmission is presented in Figure 3. The tests were carried out in two temperature modes: + 25 ° C and + 85 ° C. The average power level of the laser diode emission during signal transmission was 0.75 mW. Throughout the test exposure, the laser radiation power of the laser diode varied in an insignificant range (± 0.01 mW). The result of the tests was a malfunction of the devices with the subsequent catastrophic failure.

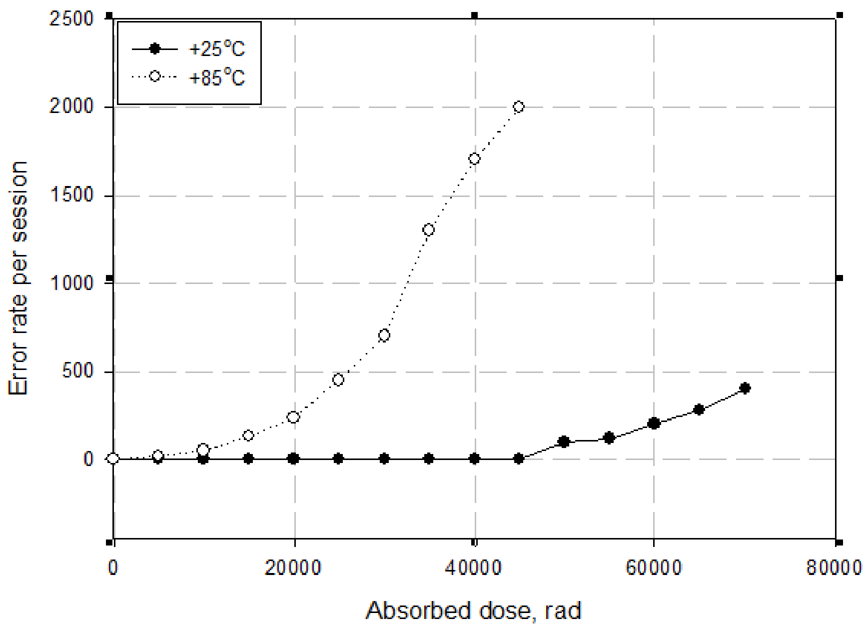

Figure 3: Dependence of error rate per session during data transmission on different values of absorbed dose.

The duration of one session was 400 s with an irradiation intensity of 13 rad/s. One error is considered to be 1 incorrect byte of transmitted information. The functional failure of the device irradiated at +25°C occurred upon reaching the absorbed dose level of 70 krad. The module irradiated at an elevated temperature (+85°C) occurred functional failure at level of 45 krad.

It is noteworthy that laser diodes and photodiodes in the modules, as shown by earlier tests, have a high level of resistance to gamma radiation. The effect of possible radiation-induced attenuation of fiber patches can be neglected because of their short length of the connecting section. Consequently, a malfunctioning of the product can be related to the degradation of parameters and the failure of other functional units of the module, such as ROM and microcontroller. Memory cells and microcontrollers of general purpose, in general, have relatively low radiation resistance with the level of absorbed dose, at which the device fails, about 5-50 krad. [13, 14].

4. Conclusions

The key components of transceiver module (laser diodes and photodiodes) showed a high level of resistance to gamma radiation. After exposure to neutrons, a shift of lasing threshold of the laser diode and a decrease in the output optical power level were observed. Another effect was a decrease of photosensitivity of the receiver after neutron irradiation. However, the whole product (transceiving module) showed a low level of radiation tolerance because of incorrect selection of electronic components.

Thus, developers and manufacturers of special-purpose transceiving modules should pay special attention to the selection of radiation-resistant digital and analogue schemes that are part of the modules because the radiation resistance of the product as a whole is determined by the least rad-hard element of this device.

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