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TP–PHYSICS INTEGRATION
TPD - DIAGNOSTICS

TW4-TPDC-IRRCER
IRRADIATION EFFECTS IN CERAMICS FOR HEATING AND CURRENT DRIVE, AND DIAGNOSTIC SYSTEMS

***Deliverable:* Ionizing and neutron-irradiation effects on optoelectronic components (semiconductor lasers and embedded detector)**

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1. Introduction

The present report is related to:

- the evaluation of ***gamma-ray, electron beam and neutron*** effects on four types of laser diodes emitting at 635 nm, 650 nm, 670 nm and 850 nm.
- the additional study of the degradation of the operating characteristics of two laser diodes ***emitting at communication wavelengths*** (1310 nm and 1550 nm),

in order to evaluate their possible use in robotic and sensing system at ITER.

2. Results

2.1 The setups and the software programmes used

The setups used for the measurement of electrical, optical and optoelectronic characteristics of the investigated laser diodes are the same used in the previous investigations and already reported in 2004. In addition to the existing capabilities, a complex set-up for the evaluation of the emitted spectrum and the peak wavelength for laser diodes operating at communication wavelengths and emitting in free space (no optical fibre is attached to the laser diode case) was developed. This set-up includes a high numerical aperture collimating optical system and an optical spectrum analyzer (OSA). The challenge was the antagonist conditions we faced: a very divergent laser beam and a small core diameter (62.5 μm) optical fibre coupled to the OSA's input. The maximum beam divergence is 40 ^{O}. A small diameter optical fibre is required in order to keep a reasonable spectral resolution for the OSA (in this case 0.05 nm). All these operating conditions imply that a very small fraction emitted optical power can be coupled to the instrument input. The OSA's sensitivity is from – 60 dBm to + 20 dBm in the spectral interval 600 nm to 1000 nm, and from – 90 dBm to + 20 dBm in the spectral range from 1000nm to 1650 nm. Another problem is the wavelength range (1300 nm – 1600 nm) over which the optical radiation is emitted. This spectral restriction is associated with the difficulty to find adequate collimating optics. For these measurements, the OSA was operated in the single sweep mode and data were collected for different working conditions of the laser diode (driving current and case temperature), having as parameter the total irradiation dose.

2.2 Results concerning laser diodes irradiation

During the reporting period, the irradiation effects on four types of semiconductor lasers operating at λ = 635 nm, 650 nm, 670 nm, and 850 nm were studied. Samples of the main results are illustrated below, separately for gamma-ray, electron beam and neutron irradiations. Only the extreme diode case temperature and total irradiation doses are considered for the simplicity of the representation. Data are available for ***all*** the irradiation steps. For electron beam irradiation the total irradiation dose was 1.04 MGy. In the case of gamma-ray irradiation the total irradiation dose was 1.5 MGy, while the maximum fluence for the neutron irradiation was 10^{14} n/cm^2. All the irradiations were done at room temperature. The measurements were performed in the Laser Metrology and Standardization Laboratory, off-line, for various operating conditions (driving current and laser diode case temperature). [1] – [3]

We have also studied the changes induced by irradiation on two quantum well semiconductor lasers operating at 1300 nm and 1550 nm, for higher total doses/ fluences previously reported. Detailed data on the irradiation induced changes on the operating parameters of various laser diodes under different irradiation conditions can be found in the 2005 Final Report of the task, where data are presented in over 110 graphs.

The present report includes some characteristics as an example.

2.2.1 The laser diode emitting at 635 nm (quantum well structure - AlGaInP)

Gamma-ray irradiation

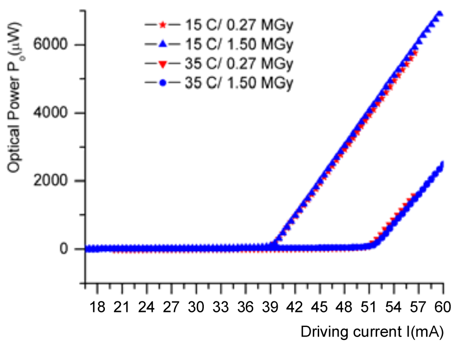


Figure 1. The optical power vs. the driving current characteristics for the two total doses (gamma irradiation), at two case temperatures.

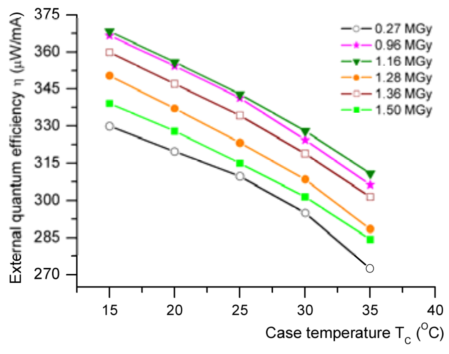


Figure 2. The external quantum efficiency vs. the case temperature characteristics for six total doses (gamma irradiation).

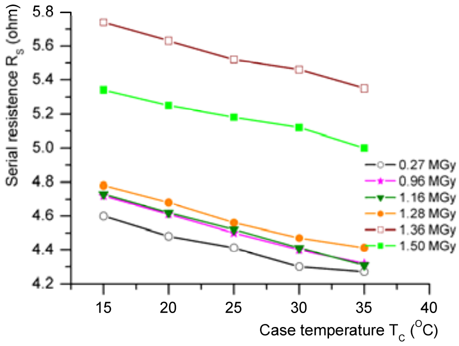


Figure 3. The serial resistance vs. case temperature characteristics for six total doses (gamma irradiation).

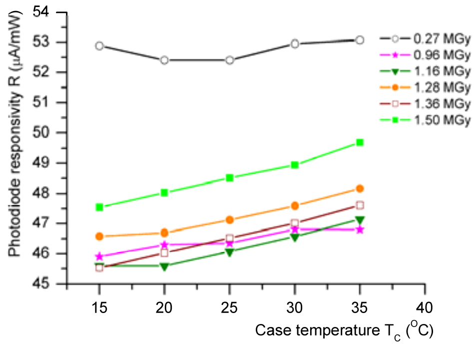


Figure 4. The photodiode responsivity vs. case temperature characteristics for six total doses (gamma irradiation).

2.2.2 The laser diode emitting at 650 nm (quantum well structure - InGaAlP)

<u>Gamma-ray irradiation</u>

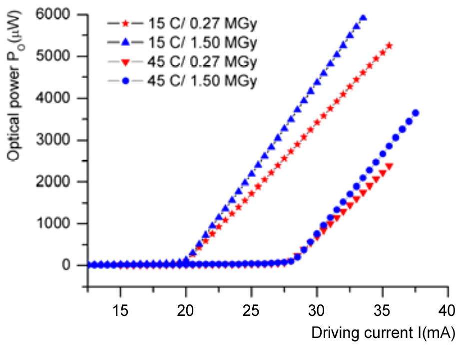


Figure 5. The optical power vs. the driving current characteristics for the two total doses (gamma irradiation), at two case temperatures.

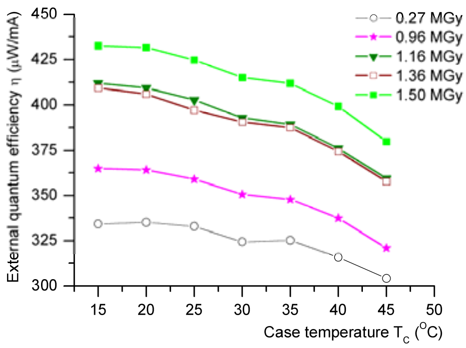


Figure 6. The external quantum efficiency vs. the case temperature characteristics for five total doses (gamma irradiation).

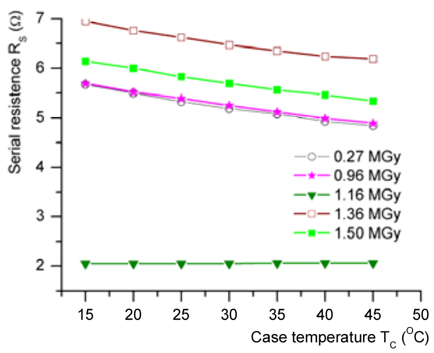


Figure 7. The serial resistance vs. case temperature characteristics for five total doses (gamma irradiation).

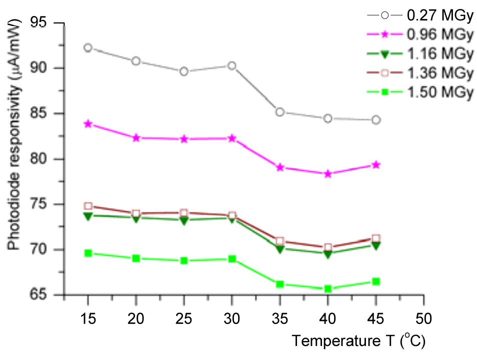
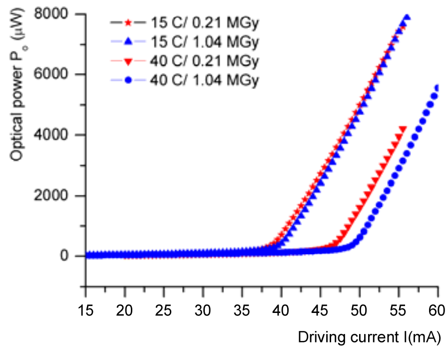


Figure 8. The photodiode responsivity vs. case temperature characteristics for five total doses (gamma irradiation).

2.2.3 The laser diode emitting at 670 nm (quantum well structure - AlGaInP)

Electron irradiation



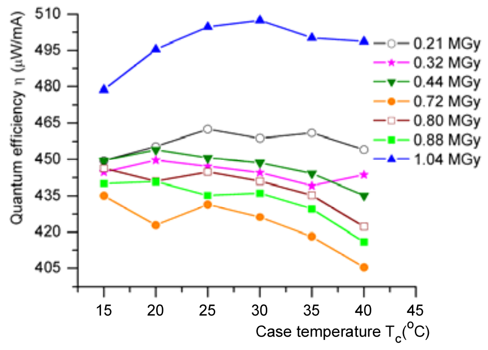
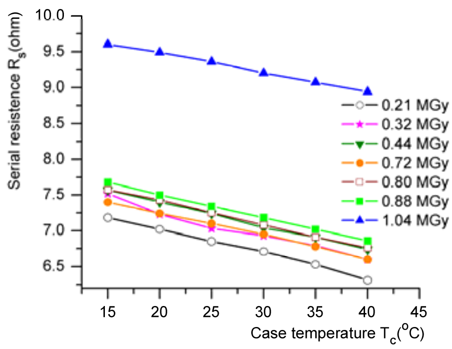


Figure 9. The optical power vs. the driving current characteristics for the two total doses (gamma irradiation), at two case temperatures.



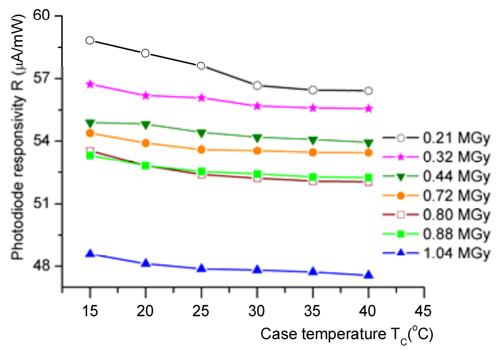
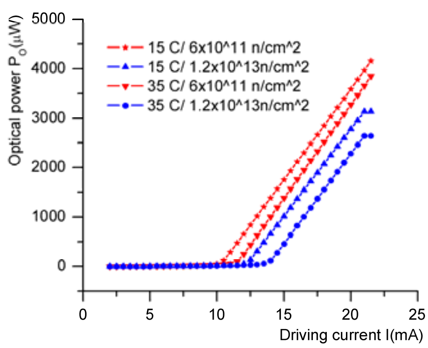


Figure 10. The serial resistance vs. case temperature characteristics for seven total doses (electron beam irradiation).

Figure 11. The photodiode responsivity vs. case temperature characteristics for seven total doses (electron beam irradiation).

2.2.4 The laser diode emitting at 850 nm (double hetero junction - AlGaAs)

Neutron irradiation



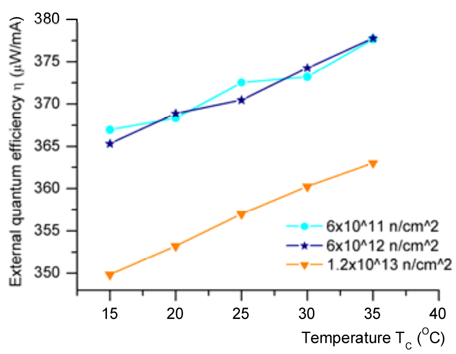


Figure 12. The optical power vs. the driving current characteristics for two neutron fluences, at two case temperatures.

Figure 13. The external quantum efficiency vs. the case temperature characteristics for three neutron fluences.

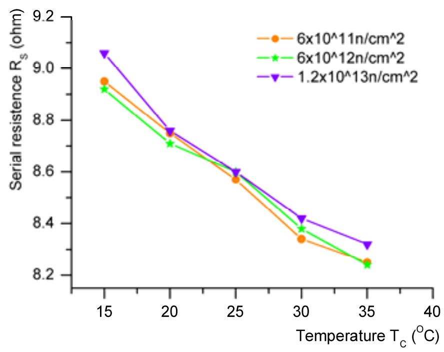


Figure 14. The serial resistance vs. case temperature characteristics for three neutron fluences.

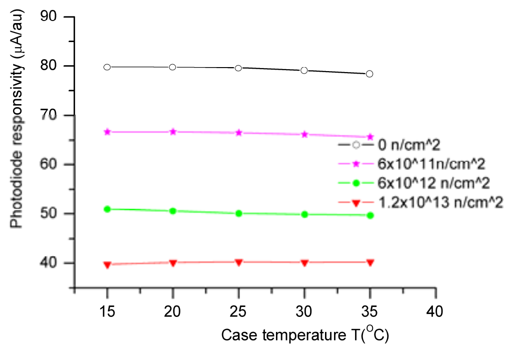


Figure 15. The photodiode responsivity vs. case temperature characteristics for the non-irradiated laser diode and three neutron fluences.

2.2.5 Investigations on the emitted radiation spectral characteristics

Continuing our previous work we performed some investigations concerning the emitted radiation spectral characteristics such as: peak wavelength and its temporal stability, centroid wavelength, full-half-bandwidth. These evaluations were done using a multi-channel optical fibre spectrometer, a laser diode diver and a temperature controller.

As an example of the temporal variation of the longitudinal mode structure for the four laser diodes we discuss about, in Figures 16 - 18 is indicated the variation of the intensity for three wavelengths. From the recorded data the change in the peak emission wavelength and in the laser diode's full-half-bandwidth can be deduced, as they are modified in time and with the laser driving conditions.

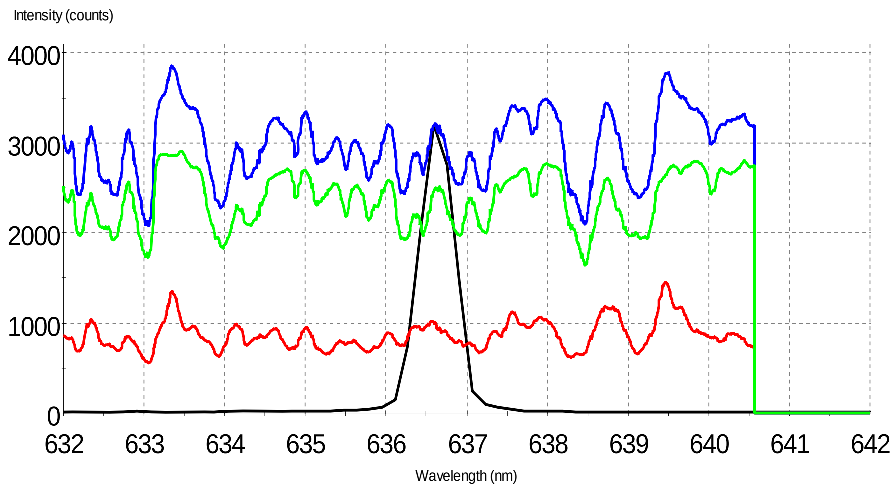


Figure 16. The change in the relative intensity of three wavelengths for laser diode emitting at 635 nm, for the total radiation dose of 1.5 MGy gamma radiation, at case temperature of T_c = 15 ^OC and the driving current of I = 60 mA. The monitored wavelengths were: λ_1 (red) = 636.2 nm; λ_2 (blue) = 636.6 nm; λ_3 (green) = 636.9 nm.

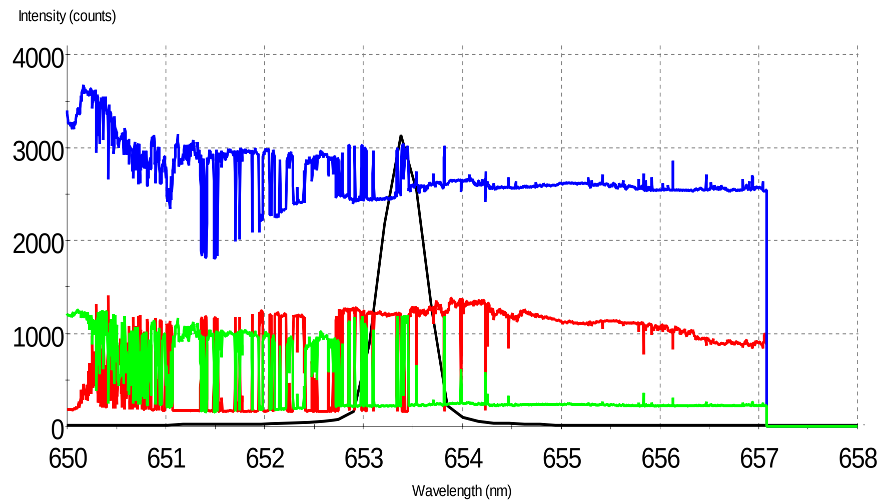


Figure 17. The change in the relative intensity of three wavelengths for laser diode emitting at 650 nm, for the total radiation dose of 1.5 MGy gamma radiation, at case temperature of T_c = 45 ^{O}C and the driving current of I = 35 mA. The monitored wavelengths were: λ_1 (red) = 653.2 nm; λ_2 (blue) = 653.6 nm; λ_3 (green) = 653.9 nm.

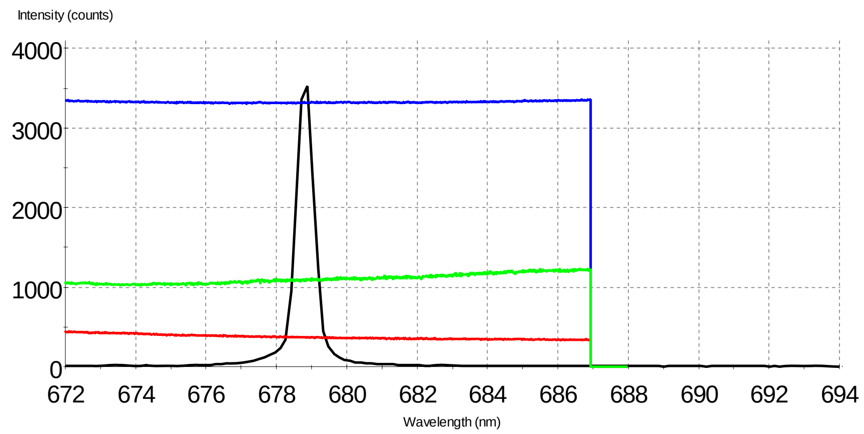


Figure 18. The change in the relative intensity of three wavelengths for laser diode emitting at 670 nm, for the total radiation dose of 1.5 MGy gamma radiation, at case temperature of T_c = 40 ^{O}C and the driving current of I = 55 mA. The monitored wavelengths were: λ_1 (red) = 678.4 nm; λ_2 (blue) = 678.8 nm; λ_3 (green) = 679.2 nm.

In our case, the lasers were operated at the upper limit of their driving current, for the case temperature at its lower and upper limits. The recording time was about 20 min in each case. For the spectrometer, the value for the box car parameter was equal to 1, the integration time was 500 ms for all the laser diodes. The average was performed over one acquisition in all measurements.

2.2.6 Semiconductor lasers operating at communication wavelengths

For the two laser diodes, emitting at 1300 nm and 1550 nm we developed a set-up for the evaluation of the peak emission wavelength and the spectral distribution of the emitted radiation using an optical spectrum analyzer. Some results are given below for two non-irradiated laser diodes. The characteristics are function of the driving current and the case temperature.

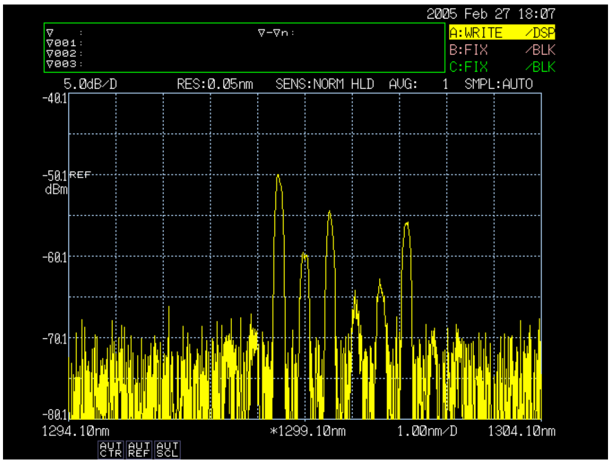


Figure 19. Non-irradiated laser diode emitting at λ = 1300 nm, for the case temperature T_c = $10^{O}C$ and the driving current I = 30 mA

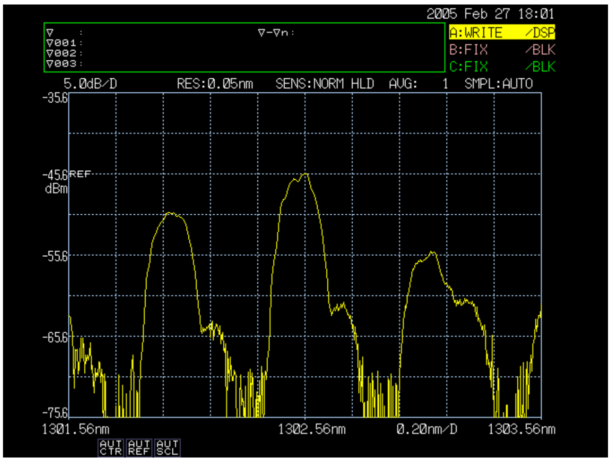


Figure 20. Non-irradiated laser diode emitting at λ = 1300 nm, for the case temperature T_c = $10^{O}C$ and the driving current I = 70 mA

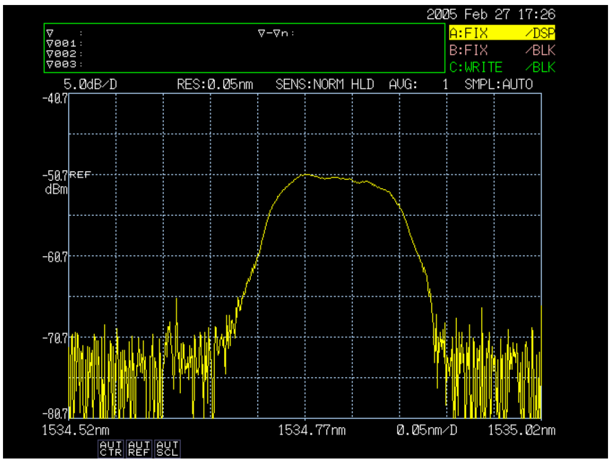


Figure 21. Non-irradiated laser diode emitting at λ = 1550 nm, for the case temperature T_c = $10^{O}C$ and the driving current I = 30 mA

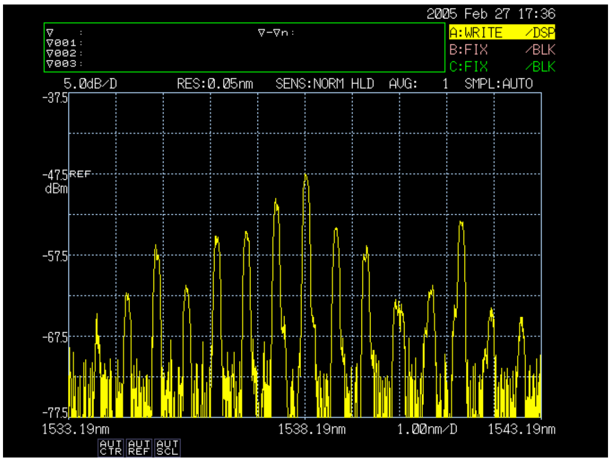


Figure 22. Non-irradiated laser diode emitting at λ = 1550 nm, for the case temperature T_c = 10^{O}C and the driving current I = 70 mA

3. Conclusions

The main results of the investigation are:

A. for quantum well laser diodes:

I. diode emitting at λ = 635 nm:

gamma irradiation

1) no major changes of the threshold current was observed (for all values of the case temperature and at the total irradiation dose of 1.5 MGy);
2) an increase of the external quantum efficiency by 2.4 % (at the case temperature of 15 ^{O}C and at the total irradiation dose of 1.5 MGy);
3) an increase of the serial resistance by 16.3 % (at the case temperature of 15 ^{O}C and at the total irradiation dose of 1.5 MGy);
4) a decrease of the embedded photodiode responsivity by 10 % (for all the values of the case temperature and at the total irradiation dose of 1.5 MGy);
5) the emitted radiation wavelength remains unchanged above the threshold current values.

neutron irradiation

1) an increase of the threshold current by 6.2 % (at the case temperature of 15 ^{O}C) followed by a drastic degradation of the optical power vs. the driving current characteristics at the case temperature of 35 ^{O}C and the fluence of 1.2 x 10^{13} n/cm^2;
2) a very small degradation of the external quantum efficiency, for all the values of the case temperature;
3) a decrease of the embedded photodiode responsivity by 17.5 % (at the case temperature of 15 ^{O}C and at the fluence of 1.2 x 10^{13} n/cm^2);
4) an increase of the serial resistance by 13 % (at the case temperature of 15 ^{O}C for the fluence of 1.2 x 10^{13} n/cm^2);

5) a decrease of the emitted radiation centroid wavelength by almost 10 nm, at the fluence of 1.2×10^{13} n/cm^2, for the driving current below the threshold value;
6) the emitted radiation wavelength remains unchanged above the threshold current values.

Instabilities of the emitted optical power can be seen at the higher case temperature (35 ^{O}C) for gamma irradiation (total dose of 1.5 MGy). For neutron irradiation these instabilities are lower at the fluence of 6×10^{13} n/cm^2, as compared to the case of gamma irradiation.

II. diode emitting at λ = 650 nm:

gamma irradiation

7) no major changes of the threshold current was observed (for all values of the case temperature and at the total irradiation dose of 1.5 MGy);
8) an increase of the external quantum efficiency by 29.4 % (at the case temperature of 15 ^{O}C and at the total irradiation dose of 1.5 MGy);
9) an increase of the serial resistance by 8.8 % (at the case temperature of 15 ^{O}C and at the total irradiation dose of 1.5 MGy);
10) a decrease of the embedded photodiode responsivity by 24 % (for all the values of the case temperature and at the total irradiation dose of 1.5 MGy);
11) the emitted radiation wavelength remains unchanged above the threshold current values.

neutron irradiation

1) an increase of the threshold current by 2.6 % for all values of the case temperature at the fluence of 1.2×10^{13} n/cm^2;
2) the external quantum efficiency remains almost unchanged over the entire case temperature range and for all the fluences;
3) the embedded photodiode responsivity remains quite unchanged over the whole range of the case temperature;
4) an increase of the serial resistance by 2.4 % (for all values of the case temperature and at the fluence of 1.2×10^{13} n/cm^2);
5) a decrease of the emitted radiation centroid wavelength by almost 12 nm, at the fluence of 1.2×10^{13} n/cm^2, for the driving current below the threshold value;
6) the emitted radiation wavelength remains unchanged above the threshold current values.

Instabilities of the emitted optical power can be seen at the higher case temperature (35 ^{O}C) for gamma irradiation (total dose of 1.5 MGy).

III. diode emitting at λ = 670 nm:

gamma irradiation

1) no major changes of the threshold current was observed (for all values of the case temperature and at the total irradiation dose of 1.5 MGy);
2) an increase of the external quantum efficiency by 9.5 % (at the case temperature of 15 ^{O}C and at the total irradiation dose of 1.5 MGy);

3) an increase of the serial resistance by 3.7 % (at the case temperature of 15 ^{O}C and at the total irradiation dose of 1.5 MGy);
4) a decrease of the embedded photodiode responsivity by 16.9 % (for all the values of the case temperature and at the total irradiation dose of 1.5 MGy);
5) the emitted radiation wavelength remains unchanged above the threshold current values.

neutron irradiation

1) an increase of the threshold current by 2 % (for all values of the case temperature of 15 ^{O}C and at the fluence of 1.2 x 10^{13} n/cm^2);
2) a decrease of the external quantum efficiency by 2 % (at the case temperature of 20 ^{O}C and at the fluence of 1.2 x 10^{13} n/cm^2);
3) a decrease of the embedded photodiode responsivity by 23 % (for all the values of the case temperature and at the fluence of 1.2 x 10^{13} n/cm^2);
4) an increase of the serial resistance by 5 % (over the all the values of the case temperature and at the fluence of 1.2 x 10^{13} n/cm^2);
5) the emitted radiation wavelength remains unchanged both below and above the threshold current values.

electron beam irradiation

1) an increase of the threshold current was observed by 3.8 – 6.5 % (for all values of the case temperature and at the total irradiation dose of 1.04 MGy);
2) an increase of the external quantum efficiency by 6.6 % (at the case temperature of 15 ^{O}C and at the total irradiation dose of 1.04 MGy);
3) a decrease of the embedded photodiode responsivity by 16.4 % (for all values of the case temperature and at the total irradiation dose of 1.04 MGy);
4) an increase of the serial resistance by 33.3 % (for all the case temperatures at the total irradiation dose of 1.04 MGy);
5) the emitted radiation wavelength remains unchanged above the threshold current values for the case temperature of 15 ^{O}C, and a decrease of 1 nm can be noticed at the total irradiation dose of 1.04 MGy for the case temperature of 40 ^{O}C.

For this laser diode, the optical power instabilities after irradiation are insignificant for all types of irradiation (gamma, neutron and electron beam irradiation).

B. for heterojunction laser diodes:

I. diode emitting at λ = 850 nm:

gamma irradiation

1) a decrease of the threshold current was observed by 5 % (for all values of the case temperature and at the total irradiation dose of 1.5 MGy);
2) an increase of the external quantum efficiency by 13.9 % (at the case temperature of 15 ^{O}C and at the total irradiation dose of 1.5 MGy);
3) an increase of the serial resistance by 13.4 % (for all the case temperatures at the total irradiation dose of 1.5 MGy);

4) a decrease of the embedded photodiode responsivity by 23.6 % (at the case temperature of 15 ^{O}C and at the total irradiation dose of 1.5 MGy);
5) the emitted radiation wavelength remains unchanged above the threshold current values for the case temperature of 15 ^{O}C, and a decrease of 0.8 nm can be noticed at the total irradiation dose of 1.5 MGy for the case temperature of 35 ^{O}C.

neutron irradiation

1) an increase of the threshold current by 32.2 % (for all the values of the case temperature and at the fluence of 1.2 x 10^{13} n/cm^2);
2) a decrease of the external quantum efficiency by 4.6 % (at the case temperature of 15 ^{O}C and the fluence of 1.2 x 10^{13} n/cm^2);
3) a decrease of the embedded photodiode responsivity by 50 % (for all the values of the case temperature and at the fluence of 1.2 x 10^{13} n/cm^2);
4) the serial resistance remains unchanged over the entire case temperature range;
5) the emitted radiation wavelength remains unchanged above the threshold current values and exhibits a decrease of about 4 nm in the threshold current region.

For this laser diode, multimode emission occurs, but the emitted optical power remains constant after both gamma and neutron irradiations.

For the case of operating the laser diodes under extreme conditions for 20 minutes, no major changes of the parameters were observed, as compared to the modifications induced by the irradiation. No major changes of the transversal mode structure of the emitted beam were observed upon irradiation, as compared to the effects produced by the change of the case temperature.

References

[1] **Sporea D.**, "*Reliability testing of laser diodes under irradiation"*, presented at the TEST 2005 Conference, Nurenberg, Germany, May 2005.

[2] **Sporea D, Vata I.**, **Sporea R.**, "*Hetero-junction Laser Diodes under Neutron Irradiation"*, presented at the 13th International Conference on Nuclear Engineering, Beijing, China, May 2005.

[3] **Sporea D,**, **Sporea R**., **Oproiu C., Vata I.**, "*Comparative study of gamma-ray, neutron and electron beam irradiated index-guided laser diodes"*, presented at the RADECS 2005, Cap d'Agde, France September 2005.