Radiation Sensitivity of Light Emitting Diodes (LED), Laser Diodes (LD) and Photodiodes (PD)

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Abstract

Commercially available diodes were irradiated at a flash X-ray source, a ^{60}Co gamma ray source, and a 14 MeV neutron generator.

During irradiation at the ^{60}Co source the light output of the LEDs and LDs was measured continuously. From time to time we also observed their emission spectrum. With the PDs we measured the preamplifier output during ^{60}Co irradiation as well as dark current and noise before and after irradiation.

Determination of the sensitivity against neutrons was made off-line.

After pulsed irradiation of PDs we measured how long a certain type of preamplifier was overdriven by the induced photocurrent.

LEDs and LDs showed a maximum decrease of output power of only 0.5 dB up to a total gamma dose of 10^6 Gy or neutron fluences of $4 \cdot 10^{13}\,cm^{-2}$ (1 MeV), respectively. Pulsed X-ray irradiations with dose rates up to 10^8 Gy/s (pulse length 30 ns) yielded no effect.

Irradiations of PDs with ^{60}Co gammas up to a total dose of 10^6 Gy as well as irradiations with neutrons up to fluences of $\lesssim 4 \cdot 10^{13}\,cm^{-2}$ (1 MeV) lead to significant changes of the device parameters. The main effect is a strong increase of the dark current by factors of 2 up to 5000.

I. Introduction

In order to determine the radiation sensitivity of data transmission systems based on optical fibres instead of copper cables, some new components have to be taken into consideration: The fibres themselves, other passive opto-electronic components as couplers, multiplexers, and connectors, and finally the light emitting and receiving diodes that are subject of our present investigations.

To get a survey of the radiation hardness of present commercial optoelectronic devices for wavelengths of about 850, 1300 and 1550 nm, we irradiated a variety of LEDs, LDs and PDs of different manufacturers at a flash X-ray source, a ^{60}Co source, and a 14 MeV neutron generator.

Dose rates, total dose values and neutron fluences were choosen such that we get estimates of the survivability in military as well as in nuclear engineering and space environments.

Testing of the radiation hardness of semiconductor devices is often reported in the literature. An excellent overview of the theoretical aspects of radiation damage in optoelectronic devices (LEDs, LDs and PDs) can be found in [1].

Earlier investigations as well as theoretical considerations predict a decrease of the light output power of LEDs and LDs [2], [3]. Ionizing radiation leads to a reduction of the minority carrier lifetime due to an increase of the densitiy of non-radiative recombination centres. Therefore the number of radiative recombination centres is smaller and the LEDs and LDs emit with less intensity. With LDs one also observes an increase of the threshold current. LEDs and LDs used today in the telecommunication industry exhibit short minority carrier lifetimes as well as high current densities already before irradiation. Therefore they are quite radiation hard, as outlinded in [1].

Irradiation of PDs can drastically increase dark current as well as noise and thus raise the minimum detectable light power. The effects of neutrons on silicon photo diodes are well described by R. Korde et al. [4]. They found that the forward voltage drop and the series resistance increased. They also present a simple model to predict neutron induced changes of the PD shunt resistance and dark the current. Changes of the PD parameters in AlGaAs structures are presented in [5].

In contrast to many of the results reported in the literature where the test objects are either specially developed radiation hard devices or not in use anymore, most of our tested devices are still used in large quantities by the telecommunication industry.

II. Experimental

With LEDs and LDs we measured continuously the light output during and after successive gamma irradiations at the ^{60}Co source. A first irradiation with a dose rate of 3 Gy*/min up to a dose of 100 Gy was followed by an irradiation with about 100 Gy/min up to the same total dose. The third irradiation was again carried out with the dose rate 100 Gy/min, but up to total dose values between some 10^5 Gy and 10^6 Gy. From time to time the emission spectrum of the LEDs and LDs was examined by means of an optical spectrum analyzer. Fig. 1 shows a block diagram of the experimental set-up.

For pulsed irradiations of the emitting diodes, the light output was converted into a voltage signal by means of a fast preamplifier (ANTEL AFM-S/-D for $\lambda < 1000$ nm/ > 1000 nm, respectively). The preamplifier output was recorded by a transient digitizer. Dose rates were between 10^6 and 10^8 Gy*/s.

* See Appendix

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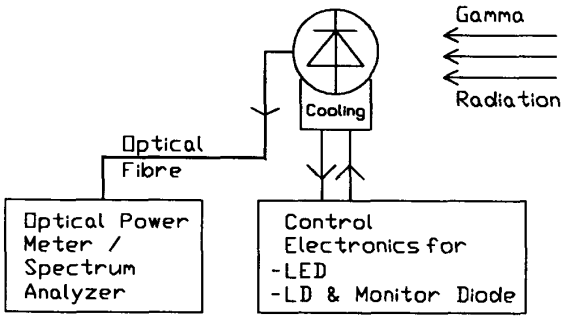


Fig.1. Experimental set-up for continuous gamma irradiation of LEDs and LDs

Irradiations of the photo diodes (PIN as well as APD) at the ^{60}Co source and flash-X-ray source were performed in the same way, with respect to dose and dose rate values. The incoming light was modulated and their photo current was converted into a modulated voltage signal by means of a separate preamplifier that was shielded against the respective radiation so that it obtained less than 1/1000 of the diode's dose. Before and after irradiations at the ^{60}Co source up to high dose values, noise and dark current measurements were performed. Fig. 2 shows a block diagram of the PD test equipment.

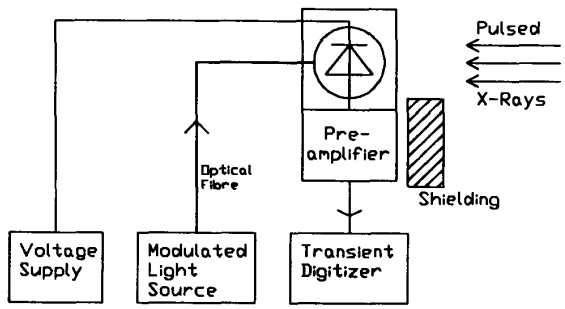


Fig. 2. Experimental set-up for pulsed irradiation of photo diodes

The neutron sensitivity of all devices was determined off-line. Characteristic data (light output and spectral distribution with emitting diodes; photo current at given light input, as well as noise and dark current with photo diodes) were measured before and after irradiation up to fluences between $5 \cdot 10^{11}$ and $4 \cdot 10^{13}$ cm^{-2} (1 MeV).

Table I gives an overview of the tested devices. Table II lists measured quantities as well as applied radiation doses, dose rates, and neutron fluences.

Table I
Overview of the tested devices

Type	Material	Manufacturer	Wavelength
LEDs			
1 A 177 A	InGaAsP	ABB-HAFO	1300 nm
1 A 148 A	GaAlAs	"	860 nm
1 A 208	GaAlAs	"	810 nm
HMP-2101	GaAlAs	Honeywell	850 nm
HFE-4003	GaAlAs	"	850 nm
IRE-832-200	GaAlAs	Laser Diode Inc.	813 nm
LDs			
ML 9701 A	InGaAsP	Mitsubishi	1550 nm
CQF 63 D	InGaAsP	Philips	1300 nm
CQL 20	InGaAsP	Philips	780 nm
PDs			
HMP-2004	Si	Honeywell	750 nm
HFD-3002	Si	"	860 nm
C 30 997	Si	RCA	860 nm
SFH 202 A	Si	Siemens	860 nm
ETX 75	InGaAs	Epitaxx	1300 nm
NDL 1202	Si	NEC	860 nm

Table II
Overview of the measured quantities, applied dose and dose rates, and neutron fluences.

Device	Measured Quantity	Dose rate [Gy/s]	Dose [Gy]
	Continuous γ-Irradiation (^{60}Co)		
LED	- output power	0.05/2	10^2, $2 \cdot 10^6$
	- wavelength (peak/FWHM)	"	"
LD	- output power	0.05/2	10^2, $5 \cdot 10^5$
	- wavelength	"	"
	- forward current	"	"
	- monitor diode current	"	"
PD	- dark current	0.05/0.2/2	10^2, 10^4, 10^6
	- photo current	"	"
	- noise	"	"
	- annealing	"	"
	Pulsed X-Ray Irradiation		
LED, LD	- preamp. output voltage vs. time	$10^6/10^7/10^8$	0.03, 0.3, 3
PD	- preamp. dead time	"	"
	Neutron Irradiation (up to $3.5 \cdot 10^{13}$ cm^{-2} (1 MeV))		
LED	- output power		
	- wavelength (peak/FWHM)		
LD	- output power		
	- wavelength (peak/FWHM)		
	- monitor diode current		
PD	- dark current		
	- photo current		
	- noise		

III. RESULTS

In this paper we only present some typical results which are representative for the selected devices. A detailed presentation of our investigations is given in [6].

A. Continuous γ Irradiation (^{60}Co)

Fig. 3 shows the decrease of the output power of two LEDs and a LD as a function of gamma dose. The LD was used in the current stabilization mode. With power stabilized LDs we observed a relatively strong increase of the output power that was caused by a damage of the integrated monitor diode. The LD output power had to be increased in order to produce a constant photo current of the damaged monitor diode.

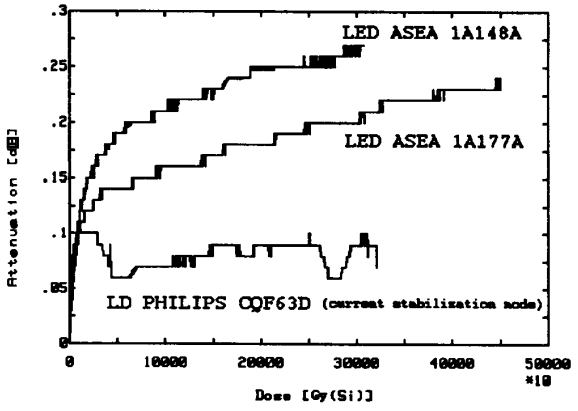


Fig. 3. Decrease of the light output (designated as "Attenuation") with increasing gamma dose; $\dot{D}_\gamma$ = 1.9 Gy/s, T = 22°C.

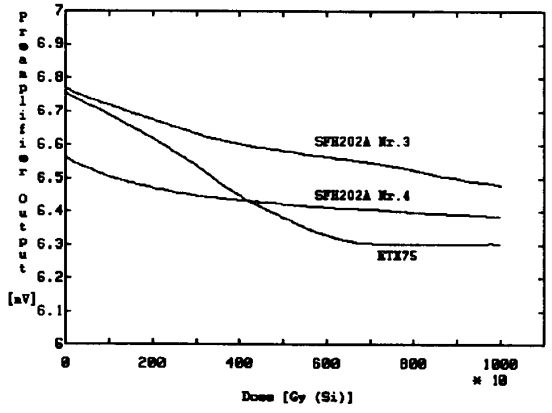


Fig. 4. Decrease of the photo current with increasing gamma dose; $\dot{D}_\gamma$ = 0.2 Gy/s, T = 22°C.
PIN diode Siemens SFH 202 A
(Si; λ = 865 nm, P = 5.6 μW, two different pieces)
PIN diode Epitaxx ETX 75
(InGaAs; λ = 1309 nm, P = 22 μW)

In Fig. 4 the decrease of the photo current with increasing gamma dose of two different types of PIN diodes is compared.

We also measured the increase of the dark current and of the noise level after gamma irradiation. Fig. 5 and Fig. 6 show some typical results.

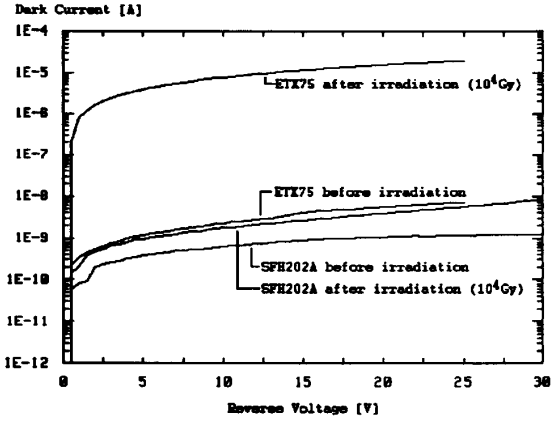


Fig. 5. Increase of the dark curent of PIN diodes after gamma irradiation; $\dot{D}_\gamma$ = 0.2 Gy/s, D_γ = 10^4 Gy T = 22°C.
PIN diode Siemens SFH 202 A
PIN diode Expitaxx ETX 75

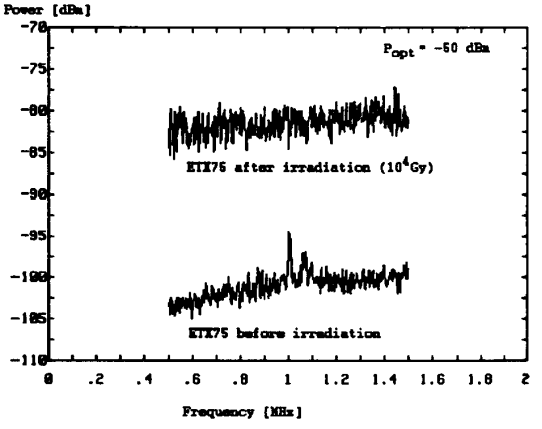


Fig. 6. Increase of the noise level after gamma irradiation.
PIN diode Epitaxx ETX 75.
$\dot{D}_\gamma$ = 0.2 Gy/s, D = 10^4 Gy, T = 22°C,
P_{opt} =- 50 dBm modulated with 1 MHz.

Table III (LEDs and LDs) and Table IV (PDs) summarize the results of the continuous γ irradiations.

Table III
Results of continuous γ irradiation of LEDs and LDs

Type	Dose rate [Gy/s]	Dose [Gy]	Change of output power (dB)	Wavelength shift [nm]
1 A 208	2.2	$2.9 \cdot 10^5$	-0.28	+0.23
HFE-4003	2.2	$5 \cdot 10^5$	-0.23	+0.2
1 A 177 A	1.9	$4.5 \cdot 0^5$	-0.23	+0.6
ML 9701	1.9	$3 \cdot 10^5$	1.1[b]	-0.1
CQF 63 D	1.9	$3.2 \cdot 10^5$	-0.1[a]	-3.4
QCF 63 D	1.9	$3.2 \cdot 10^5$	3.0[b]	-3.4

a: Current stabilization; b: Power stabilization

Table IV
Results of continuous γ irradiation of PDs

Type	Dose [Gy]	Increase of dark current
HMP 2004	10^6	x 8.9
HFD 3002-2	$4.4 \cdot 10^5$	x 5
HFD 3002-3	$2.6 \cdot 10^5$	x 5000 (!)
C 30997	$2.9 \cdot 10^6$	x 42
SFH 202 A-3	10^4	x 3.8
SFH 202 A-4	10^4	x 1.8
ETX 75	10^4	x 3330 (!)
NDL 1202	10^4	x 25

B. Pulsed X-Ray Irradiation

Pulsed irradiations of emitting diodes with up to 10^8 Gy/s yielded no effect that could be ascribed to the radiation itself.

Fig. 7 shows the effect of pulsed radiation on one of the tested photo diodes.

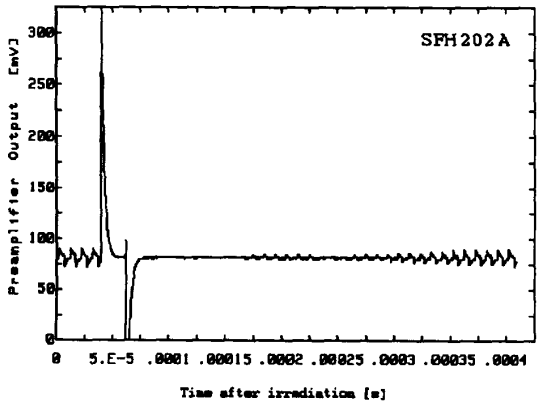


Fig. 7. Interruption of data transmission after pulsed irradiation of the PIN diode Siemens SFH 202 A (Si; active area = 1 mm^2)
$D_\gamma = 10^8$ Gy/s, D = 3 Gy, λ_p = 867 nm, P = 1 µW
Preamplifier: ANT 61 4125 000 00 STR

The radiation induced photo current overdrives the following preamplifier for more than 300 µs. The dead time is dependent on the recovery characteristics of the employed preamplifier as well as on the size of the photo diode. With an active area of about 0.004 mm^2 instead of about 1 mm^2 (Epitaxx ETX 75 instead of Siemens SFH 202 A), we only saw a dead time of < 10 µs.

Table V summarizes the results of pulsed irradiations of PDs.

Table V
Results of pulsed X-ray irradiation of PDs

Type	Dose rate [Gy/s]	Dose [Gy]	Dead time [µs]	Active area
LED				
		no influence		
LD				
SFH202 A-9	$10^6/10^7/10^8$/	0.03/0.3/3	40/300/300	1x1 mm^2
SFH202 A-10	"	"	41/300/320	"
ETX 75	"	"	9/10/10	0.0044 mm^2
NDL 1202	"	"	30/70/2000	0.045 mm^2

C. Neutron Irradiation

Fig. 8 shows the influence of a neutron fluence of about $1.6 \cdot 10^{13}$ cm^{-2} (1MeV) on the output power of three different laser diodes. The decrease seems to be negligible within the whole investigated forward current range.

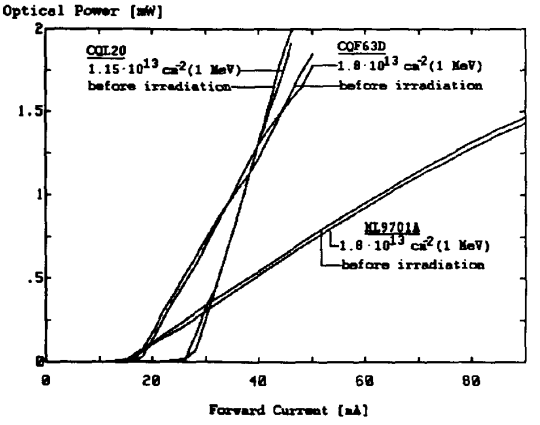


Fig. 8. Decrease of light output of three different laser diodes after neutron irradiation.
Mitsubishi ML 9701 A (λ = 1550 nm),
Philips CQ63 D (λ = 1312 nm),
Philips CQL 20 (λ = 787 nm).

Changes of the emission spectrum of LEDs and LDs caused by high neutron fluences ($\lesssim 4 \cdot 10^{13}$ cm^{-2}, 1 MeV) seem to be negligible. We only observed changes in peak wavelength of about 3 nm in both directions. Changes of the half width were of equal size.

Fig. 9 demonstrates the strong increase of the dark current after irradiation of a photodiode with neutrons.

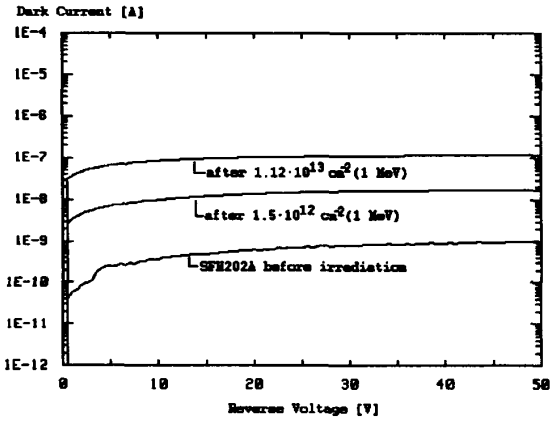


Fig. 9. Increase of the dark current of the PIN diode Siemens SFH 202 A after neutron irradiation

Table VI summarizes observed changes of the output power of LEDs and LDs after exposure to fast neutrons.

Table VI
Neutron irradiation of LEDs and LDs

Type	Fluence [cm^{-2}(1 MeV)]	Change of output power [dB]
1 A 208 R	$3.5 \cdot 10^{13}$	-0.24
1 A 208 Q	"	-0.2
HMP 2101	$1.8 \cdot 10^{13}$	-0.09
IRE-832-200	$3.5 \cdot 10^{13}$	-0.9
HFE-4003	$1.8 \cdot 10^{13}$	-0.3
1 A 148 A	$3.5 \cdot 10^{13}$	-0.5
1 A 177 A	$1.15 \cdot 10^{13}$	-0.09

A survey of the increase of the dark current of PDs after neutron exposure is found in Table VII.

Table VII
Neutron irradiation of PDs

Type	Dark current [nA] before irradiation	Dark current [nA] after 5×10^{11} cm^{-2}	Dark current [nA] after 5×10^{12} cm^{-2}
HFD 3002	0.16	2.28	36.7
C 30997	17.0	17.7	48.7
SFH 202 A	0.62	13.7	102.8
ETX 75	0.64	13.0	104.7
NDL 1202	1.13	10.6	43.2

IV. Conclusions

LEDs as well as LDs show no significant reduction of light output up to total gamma dose values of $\lesssim 5 \cdot 10^5$ Gy and neutron fluences $\lesssim 10^{12}$ cm^{-2} (1 MeV). The reason is that all the tested devices are designed for high power and high speed, as necessary in data transmission lines, so that they operate with high current densities and short minority carrier lifetimes.

Photo diodes are more sensitive to radiation. Mainly the strong increase of dark current and noise (especially after neutron irradiation) are the limiting factors in device performance. LDs with integrated monitor diode should therefore be used in the current stabilization mode.

To reduce the influence of short intensive ionizing radiation pulses on PDs, their active volume should be as small as possible. The diodes should possibly be turned off during irradiation in order to prevent "burn out".

V. Appendix

Dose values at the ^{60}Co irradiation facility are given in Gy(Air). Dose in the respective diode material can be calculated by multiplication with 0.99(Si), 0.90(InGaAs, 0.90(GaAlAs), and 0.91(InGaAsP), respectively.

Dose values at the flash X-ray facility are given in Gy(LiF). Dose in the respective diode material can approximately be calculated by multiplication with 1.08(Si, 1.24(InGaAs), 1.07(GaAlAs), and 1.22(InGaAsP, respectively.

VI. References

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