# Radiation effects in optical communication devices

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**Optical fibre technology is seriously considered for communication and monitoring applications in space and around nuclear fission reactors as well as future thermonuclear fusion reactors. Space and nuclear environments are characterised, in particular, by the presence of ionising radiation fields. The influence of radiation on photonic devices therefore needs to be investigated. Our previous experiments showed that particular types of optical fibres and optical emitters such as VCSELs exhibit a limited sensitivity to ionising radiation. In this paper, we complete the picture by addressing the ionising radiation sensitivity of photodiodes. We also describe our recent results on radiation damage in WDM components including optical fibre Bragg gratings and couplers.**

## Introduction

Since several years now, photonic technology is seriously considered for communication and monitoring applications in spaceborne systems and nuclear environments. A major problem which arises when dealing with photonics in these environments is the presence of ionising radiation fields. Space radiation includes mainly protons, electrons and heavy ions, whereas gamma and neutron radiation are a major concern around nuclear fuel cycle facilities such as power and reprocessing plants.[1]

It is well known that any electronic or photonic component may suffer from exposure to nuclear radiation.[1] The resulting system malfunctions might have dramatic consequences on safety and cost. Therefore, it is essential to investigate the reliability of optical communication devices upon irradiation. In this paper, we summarise recent results obtained on different fibre-optic link devices, including a commercial-off-the-shelf (COTS) optical fibre, vertical-cavity surface-emitting laser diodes (VCSELs), LEDs, multimode photodiodes and WDM components. We estimate the total radiation-induced optical loss in an elementary multimode fibre link at a typical gamma dose-rate/total dose condition. The unit of radiation dose used throughout the text is Gy ("Gray"), where 1 Gy corresponds to an absorbed energy of 1 Joule per kilogram of material.

## Multimode optical fibre

It is well known that the effect of ionising radiation on optical fibres is an increase of the attenuation, caused by the creation of so-called colour centres, with corresponding absorption bands at particular wavelengths. Generally speaking, pure silica fibres or fibres with a low Ge doping and no other dopants show the lowest radiation induced losses.[2] Fig. 1 shows the influence of the dose-rate on the radiation induced loss measured at 850 nm and room temperature in a COTS 100 µm-core multimode fibre. The straight lines in Fig. 1 are curves fitted to the experimental data according to a power-law model.[3] At a total dose of 1 MGy and a dose-rate around 2 kGy/h, the radiation induced loss at 850 nm in a 100 m length multimode Spectran TCG fibre would be less than 2.5 dB.

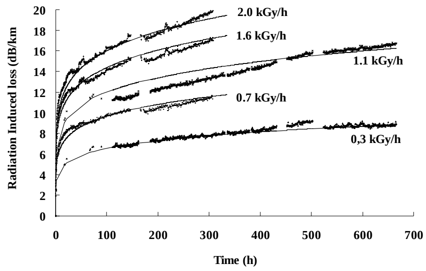
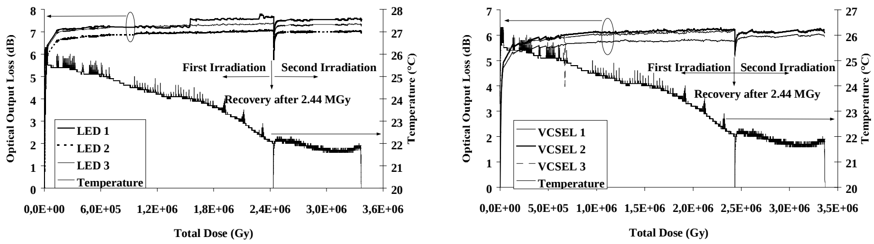



Figure 1: Radiation induced loss at 850 nm in Spectran TCG multimode fibre at different dose-rates

## Multimode emitters

Photonic devices in which the active elements are semiconductors are frequently sensitive to radiation because the absorption or generation of light in a solid medium is influenced by the defect structure of that medium. In LEDs the various recombination mechanisms determine the light output efficiency. Radiation induced damage centres can interfere with this process. In our experiments, 850 nm VCSELs and LEDs showed maximum losses of 6-7 dB at doses on the order of 1 MGy (dose-rate 2.7 kGy/h), as depicted in figure 2. The rapid increase of the loss is probably due to the lens in the component package.[4]

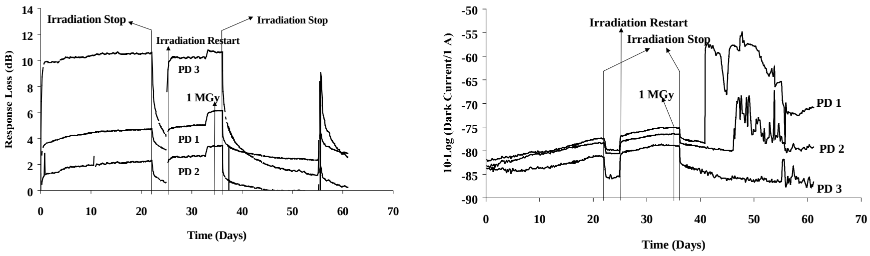



(a) (b)

Figure 2 : Radiation induced optical output loss of ST-packaged COTS multimode emitters (a) Honeywell HFE4050 LEDs at a 46 mA forward current and (b) Mitel 1A444 VCSELs at a 12 mA forward current

## Multimode photodiodes

Photodiodes still remain the weakest elements in the fibre-optic link.[4] Detection of light relies on the collection of minority carriers generated by light, only within the active area. In fact, γ-radiation/matter interaction has a bulk effect, including the generation of electron/hole pairs in the whole semiconductor volume. Hence, the radiation can create additional charge carriers increasing the dark current of photodetectors. Generally, for both pin and avalanche diodes, radiation increases the dark current as well as the noise, thus decreasing the minimum detectable light power. Moreover, bulk and surface radiation damage can again interfere with these collection processes. We measured the decreased responsivity and increased dark current of COTS multimode PIN photodiodes during irradiation at 1.3 kGy/h, as shown in Fig. 3.




(a) (b)

Figure 3 : Radiation response of Honeywell HFD3013 Si PIN photodiodes
(a) Responsivity Loss and (b) Dark current (logarithmic expression)

## WDM components

Bragg gratings and couplers are essential components in WDM optical fibre communication systems. For Bragg gratings, radiation can influence the refractive index of the fibre, which results in a possible shift of the Bragg wavelength $\lambda_B$. The gratings used to study the effect of γ-radiation were written with the phase mask technique in : photosensitive 10 mol.% Ge-doped fibre (G1), 2.5 mol.% hydrogen-loaded telecommunication Ge-doped fibre (S1 and K1) and N-doped fibre (N1). The parameters of FBGs were monitored under gamma radiation at 3 kGy/h up to a total dose of 1.5 MGy, using an experimental set-up described in [5]. The behaviour of FBGs written in hydrogen-loaded Ge-doped and in N-doped fibre differ from that of FBGs written in a 10 mol.% Ge-doped fibre without hydrogen loading. The radiation-induced shift of the Bragg peak saturated at a higher level for FBGs written in hydrogen-loaded Ge-doped fibre. By contrast, the Bragg peak shift showed no saturation for the FBG written in N-doped fibre even at the maximal accumulated dose (Fig. 4). The amplitude and the width of the Bragg peak changed during irradiation for gratings written in hydrogen-loaded Ge-doped fibres and in N-doped fibre, while it did not change for gratings written in unloaded Ge-doped fibre. Changes of the grating strength during γ-irradiation are attributed to different kinetics in radiation-induced changes of refractive index at minima and maxima of UV fringe pattern. The higher γ-radiation sensitivity of gratings written in the hydrogen loaded fibres is thought to be due to radiolytic ruptures of OH-bonds.[5]

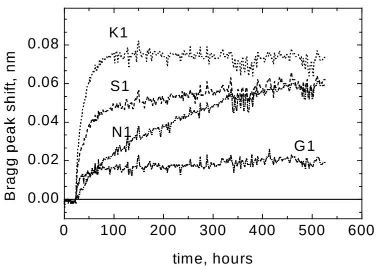



Figure 4 : Shift of the Bragg peak under γ-radiation for different gratings

Little information is available in literature about the radiation response of optical fibre couplers. We therefore checked the radiation response of broadband 1310/1550 nm couplers and narrowband WDM couplers. In the first case (Fig. 5) we observe an increased loss and decreased isolation at levels which do not critically compromise the functionality of the broadband coupler. The narrowband WDM couplers (Fig. 6), however, exhibit a drift of the wavelength isolation channels of approximately 0.5 pm/kGy, for reasons which are not clear at this time.[6]

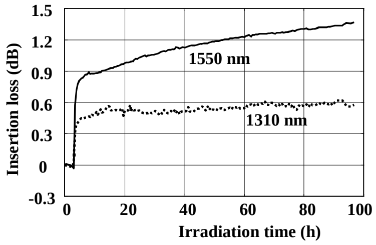



Figure 5 : Broadband coupler insertion loss during irradiation at 25 kGy/h and 38 °C

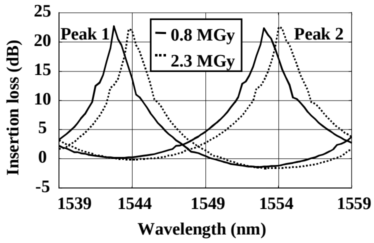



Figure 6 : Narrowband coupler insertion loss at two total doses during irradiation at 25 kGy/h and 38 °C

## Conclusion

Our recent work has shown the potential for application of an elementary optical fibre link after irradiation up to the MGy level. Using the observed losses at 1 MGy for the COTS multimode emitters, optical fibre and photodiode, and neglecting the variations in dose-rates (ranging from 1.4 kGy/h to 2.7 kGy/h) between the different experiments, a 100 m multimode fibre communication channel would show a radiation induced optical loss of approximately 15 dB, which needs to be taken into account in the system power budget.

Additional reliability studies are still necessary before final fibre-optic solutions for high total dose radiation environments will be available. The complex internal structure of modern devices compromises the interpretation of data extracted from radiation experiments. The presence of defects in heterojunctions or thin layers of material and the variations between such components can cause devices in a larger batch of samples to respond differently after radiation compared to typical devices. Our future work will therefore include more advanced investigations on the radiation response of VCSELs and photodiodes as well as the development of radiation-hardened optical emitter and receiver circuitry.

## References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