Recent Proton and Co60 Radiation Test Data from a newly developed European Optocoupler source for space application


1. Optoelettronica Italia Srl, Via Vienna 8, 38121 Gardolo (TN), Italy, contact email: research@optoi.com
2. Fondazione Bruno Kessler, Via Sommarive 18, 38123 Povo (TN), Italy
3. AdvEOTec, 6-8 Rue de la Closerie, Lisses - ZAC Clos aux Pois, 91052 Evry Cedex, France
4. ESA – ESTEC, Keplerlaan 1, 2200 AG Noordwijk, The Netherlands

Abstract — The permanent degradation introduced in the main electrical parameters of a newly developed European optocoupler type is described, as a function of proton fluences and Co-60 total ionizing dose. Optoi’s devices assembled in Leadless Chip Carrier packages, coded OIER10 are being developed in the framework of an ECI project for ESA, aimed at the ESCC evaluation of Optoi optocouplers. The first analyses of the recent irradiation results show a good behavior of the parts under proton and gamma irradiation.

I. INTRODUCTION

Optocouplers are hybrid devices used in space electronics in order to provide electrical isolation between microelectronic circuit sectors; they are typically composed of two dice, separated by an optically transparent but electrically isolating medium. The signal is transferred by means of light generated by a Light Emitting Diode (LED) and absorbed by a photodetector receiver.

Optoi’s aerospace unit [1] is currently developing a new type of optocoupler within a project funded by the European Space Agency (ESA), in the framework of the European Component Initiative (ECI) [2]. Optoi’s development is centered on three typologies of package, i.e. TO-5, 4-pin and 6-pin Leadless Chip Carriers (LCC). This project including initial irradiation test results on different die typologies and the details of the evaluation test plan, was presented at ICSO conference in 2012 [3].

The irradiation test results described in this paper have been obtained with the LCC6 package type (Figure 1) designed and manufactured during the first phase of the activity. The next phase will be the submission of the OIER10 optocouplers to an ESCC evaluation plan throughout 2013. The activity is expected to be completed with the proposition of listing this optocoupler into the European Preferred Part List (EPPL) for space applications.

In the next sections, the permanent degradation of the OIER10 electrical parameters, mainly the Current Transfer Ratio (CTR), caused by proton and gamma ray irradiation, is reported. The analysis is based on a batch of about 150 identical parts. Preliminary analyses of the initial parameters as a function of the degradation of the CTR are reported.

II. EXPERIMENTAL PROCEDURE

A. Description of tested devices

About 150 parts were irradiated with different proton energies and two dose rates of Co-60 gamma-rays; the tested optocouplers are shown in Figure 2 according to their functional schematic. The tested devices host phototransistors developed and manufactured by Fondazione Bruno Kessler (FBK) in its MT-Lab section, on a fabrication lot of 22 4"-wafers, leading to an overall volume higher than 20 thousand parts. The phototransistors under test belong to two of these 22 wafers, and they have been selected randomly and not screened.

The majority of the parts were grounded (GND) during irradiation, which is the worst-case condition as shown in previous works [4-6]. Biasing during irradiation has been applied to one third of the batch with: \(I_f=3\text{mA}, V_{ce}=5\text{V}\).
Emitter: LED
Receiver: Phototransistor

[Diagram of Optoi’s OIER10]

Figure 2. Functional schematic of the tested optocouplers

B. Irradiation

Proton irradiations have been performed at the Kernfysisch Versneller Instituut (KVI) in Groningen [7] with proton beams at 25 MeV, 60 MeV and 185 MeV with five fluence steps.

The TID testing was performed at ESA / ESTEC (European Space Agency, European Space Research and Technology Center) with a Co-60 facility at 36 and 360 rad(Si)/h [8].

Details are shown in Table 1; the Co-60 irradiation were followed by a 24-hour anneal at room temperature and 168-hour anneal at 100°C, according to [9].

<table>
<thead>
<tr>
<th>Facility</th>
<th>Radiation</th>
<th>Energy</th>
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<tbody>
<tr>
<td>KVI</td>
<td>Proton</td>
<td>28, 60, 185 MeV</td>
</tr>
<tr>
<td>ESTEC</td>
<td>Co-60 γ-rays</td>
<td>1.17, 1.33 MeV</td>
</tr>
</tbody>
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| Dose rates | 36, 360 rad/h |

Table 1. Test facilities and exposure summary

C. Measurements

The primary parameter of interest in an optocoupler is the Current Transfer Ratio (CTR), which is the ratio of the output collector current \( I_c \) to the LED forward current \( I_f \) for a fixed \( V_{ce} \).

\[
CTR = \frac{I_c}{I_f}
\]

The CTR was measured over the entire LED forward current range, from 0.1 to 35 mA (proton irradiation) and from 0.1 to 20mA (TID testing). The collector-emitter voltage was set at 5, 15 and 37 V (proton irradiation) and at 5, 10V (TID testing).

Other measurements were also performed, investigating the phototransistor dark current, the phototransistor gain, the direct and reverse \( I(V) \) characteristics of the LED and other intrinsic parameters.

III. TEST RESULTS

A. Proton

The absolute value of the OIER10 CTR under 60MeV proton beam is plotted in Figure 3 for several samples, 5 grounded and 3 biased \( (I_f=3mA, V_{ce}=5V) \) during irradiation. The CTR is measured under nominal test conditions: \( I_f=1mA, V_{ce}=5V \).

Under this operating condition, the initial absolute value of the OIER10 CTR is around 5.

The CTR can be normalized to its initial (pre-irradiation) value. The CTR results from Figure 3 are normalized and averaged for each bias condition, and displayed in Figure 4.

The CTR relative value (in Figure 4) significantly degrades at large fluences, above 1E11 cm-2. It is also shown that both bias cases (grounded or biased during irradiation) provide close results, the worst-case being measured in the grounded case.

The normalized CTR degradation with proton beam energy equal to 60 MeV is illustrated in Figure 3 under nominal test conditions: \( I_f=1mA, V_{ce}=5V \) and considering the average of the obtained trends. Under this operating condition, the initial absolute value of CTR is around 5; the evolution of the absolute value of CTR during proton irradiation is shown in Figure 4. Samples irradiated have been exposed to an annealing of several days at room temperature followed by 168-hour at 100°C. A slight recovery on the CTR degradation is observed on the parts after annealing (Figure 5). In terms of performances, the initial absolute value of CTR of the OIER10 is lower than some other non-European equivalent parts. This value could be increased through a more efficient coupling between the phototransistor and the LED.

The obtained results of the OIER10 after proton testing have been compared with equivalent structures of non-European optocouplers used in space applications under similar nominal working conditions \( I_f=1mA, V_{ce}=5V \) (Figure 6). Details on the radiation behavior of these devices from Isolink (OLS449, OLH249) and Micropac (66226) can be found in a previously published study [10]. The normalized CTR decrease of the Opel devices is comparable to these other equivalent non-European parts. To our knowledge, only some parts from AVAGO (HCPL5501 and HCPL5507) with different device structure and different receptor types (photo Darlington photodiode or high gain photon detector) achieve significantly less degradation to proton irradiation [11].

The trend in the CTR degradation with increasing LED forward current is illustrated in Figure 7, for OEIR10. A comparison of the normalized CTR degradation on unbiased devices irradiated with different proton energies is shown in Figure 8. The NIEL values correspond to Silicon material (ECSS-E-10-12 [12]) and the Displacement Damage Dose (DDD) is calculated for all conditions (varying energies and fluences) with respect to the CTR drifts. The obtained trend is well aligned with the NIEL modeling, as shown in Figure 9.
Figure 4. Normalized averaged CTR degradation of OIER10 devices under 60MeV-proton irradiation, measured with $I_f=1mA$, $V_{ce}=5V$ on devices biased and unbiased during irradiation.

Figure 5. Normalized averaged CTR recovery after annealing for OEIR10 samples with 60MeV-proton irradiation for 2 different fluencies, measured with $I_f=1mA$, $V_{ce}=5V$ for devices grounded during irradiation.

Figure 6. Normalized averaged CTR degradation under 60MeV-proton irradiation as a function of fluence on equivalent types of optocouplers, grounded during irradiations. These measurements have been performed under the normal working condition of the parts with $I_f=1mA$, $V_{ce}=5V$.

Figure 7. Normalized averaged CTR degradation of OIER10 devices as a function of LED forward current with 60MeV-proton irradiation for different fluencies, for devices grounded during irradiations.

Figure 8. Comparison of normalized averaged CTR degradations on devices grounded during irradiation as a function of fluence at different energies with $I_f=1mA$, $V_{ce}=5V$.

Figure 9. Comparison between the obtained results versus DDD and the expected trend according to NIEL modeling.
Preliminary analyses have been carried out, in order to identify any potential correlation between the optocoupler degradation under DDD and the device intrinsic initial parameters.

No evident relation between the initial CTR value and its normalized value of degradation has been observed. However, we observe that for all proton energies and fluences, the OIER10 degradation seems to be correlated to the initial gain of the hosted phototransistors. This trend is depicted in Figure 10 and Figure 11 with different parts randomly selected from two different wafers after being exposed at two different fluences at an energy of 60 MeV (8E10p/cm², 3E11p/cm²). The OIER10 optocouplers with higher initial gain seem degrading slightly less than the ones with lower initial gain. This observation needs to be confirmed with a higher sample size from future radiation campaigns and by analyzing other intrinsic parameters. The goal of future analyses with better statistics would be to obtain a non-destructive screening methodology in order to select the optocouplers from a specific Lot that might be less sensible to DDD.

B. Gamma radiation

Tests under gamma rays have been conducted with dose rates of 36 and 360 rad(Si)/h, for reaching an overall ionizing dose equal to 79 krad(Si) and 169 krad(Si) respectively. 5 biased and 5 unbiased devices were irradiated per dose rate; biasing conditions during irradiation are the same as for proton irradiation, i.e. \( I_f = 3\, mA, \, V_{ce} = 5\, V \).

The testing at a dose rate of 360 rad(Si)/h has been conducted up to a total dose of 169 krad with 7 dose steps and intermediate measurements in order to check the progressive degradation of the devices (Figure 12). This “high dose” test was followed by a 24-hour annealing at room temperature and 168-hour annealing at 100°C, according to [9]. The trend in the CTR degradation as a function of LED forward current is illustrated in Figure 13 at different irradiation dose steps. The testing at lower dose rate of 36 rad(Si)/h followed the same procedure. The results reach the overall ionizing dose of 79 krad(Si) (Figure 14).

The degradations of the CTR between the components undergoing the testing at “high and low” dose rates are similar. No enhanced low dose rate effect (ELDRS) effect has been identified. The observed degradation is minor, only 6% at 79 krad and 13% at 170 krad.

The degradation results of the tested optocouplers under gamma irradiation have been compared (Figure 15) with non-European part tested to gamma reported in previous studies [10]. The OIER10 optocoupler shows good resistance to gamma TID with a low LED forward current. This behavior is also confirmed after comparison with more different optocoupler references recently tested [11].
Figure 14. Normalized averaged CTR (I=1mA, Vce=5V) of optocouplers exposed to Co-60 gamma rays with low dose rate and either biased or unbiased during irradiation, and following annealing.

Figure 15. Comparison of normalized CTR degradation as a function of total ionizing dose for different optocouplers on devices unbiased during irradiation.

CONCLUSION

An European manufacturer has developed a new source of optocouplers in a radiation hard technology. According to the background project strategy, the entire supply chain and related procurements is privileging European raw materials.

The OIER10 CTR degradation caused by Co-60 gamma TID irradiation is considerably reduced compared to non-European parts commonly used for space applications. The OIER10 are particularly robust against gamma irradiation. Under protons, the OIER10 CTR degradation is in the same range as for non-European optocouplers. Preliminary analyses of the CTR degradation due to proton irradiation as a function of the sample initial parameters show that a non-destructive screening methodology based on the initial gain of the phototransistor could be implemented for a specific manufactured Lot.

The component developed by Optoi in the framework of an ECI project for ESA is now ready to complete the ESCC evaluation testing. This activity is scheduled in the second half of 2013 with the goal to list the OIER10 reference into the EPPL.

ACKNOWLEDGMENT

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The entire work of design, simulation, manufacturing, testing, data elaboration has been conducted by Optoi and FBK's MT-Lab staff. In particular, MT-Lab supported the front-end aspects and the testing activities.

The back-end procedures and microelectronic assemblies of devices were directly managed by Optoi.

AdvEOTec contributed to the definition of the test plan and to the result elaboration, together with ESA.

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