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Semiconductors (LEDs) quality control based in high-resolution 3D X-ray microscope

Costa D.S.S.[1], Machado A. S.[3], Oliveira D. F.[3], Assis J.T.[2], Lopes R.T.[3], Anjos M.J.[1]

[1]*Instituto de Física – Universidade do Estado do Rio de Janeiro. R. São Francisco Xavier, 524 – 20550-900, Rio de Janeiro, RJ, Brasil.*

costa.diogo@posgraduacao.uerj.br; marcelin@uerj.br.

[2]*Instituto Politécnico-IPRJ, Universidade do Estado do Rio de Janeiro, Nova Friburgo RJ Brasil*

joaquim@iprj.uerj.br

[3]*Laboratório de Instrumentação Nuclear/COPPE Universidade Federal do Rio de Janeiro Rio de Janeiro, RJ Brasil*

alessandra.machado@coppe.ufrj.br, davifoliveira@coppe.ufrj.br, rlopes@coppe.ufrj.br

ABSTRACT

Electronic devices are getting smaller each time and the technology, increasingly complex. Commonly found problems such as reflow soldering and open solder connections, are mostly difficult to detect by conventional means like X-ray images or physical cut on the transverse section. Along with the challenge of finding these flaws, there are also some problems that may arise on the exposure of them using destructive analysis techniques, such as the transversal cut and chemical decapsulation. Both techniques may induce damage not relevant to where that flaw is located or remove evidence of a flaw or a damaged place. The high-resolution 3D x-ray computerized microtomography provides a powerful alternative solution and non-invasive to issues that involve the analysis of semiconductor devices. This research contemplates the study of semiconductor's integrity (LED's) based of X-ray computerized microtomography. The SkyScan 1272 Bruker commercial equipment was used for analysis of the P-N junction in a set with 10 LEDs, under non polarized conditions and upon electrical overstress effects on its contact terminals. The P-N junction had their dimensions analyzed on the three spatial directions (x, y and z) and studied on the effects that occur when a LED is damaged. The study methodology of integrity regarding computerized microtomography have shown consist outcomes that allowed the understanding of what occurs on the LED's structure and investigates matters that allows decisions to be made regarding its quality, and so, accomplishing the goals designated on this research.

Keywords: **Computed microtomography, Semiconductor integrity, LED microtomography.**

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1. INTRODUCTION

All products offer or should offer high quality to their users. For a company be able to sustain itself and remains competitive in the market, it is important to have rules and procedures that guarantee this attribute. On the other hand, with more and more competitors emerging, quality is a key factor for companies to get ahead. This work contemplates a quality study in semiconductor components, specifically LEDs (Light emitting diode) using X-ray Micro Computed Tomography (Micro-CT).

LEDs are semiconductor devices able to emit ultraviolent, infrared or visible light. They are named diode because of way they work. Diodes are components where an electrical current can flow only in one direction. They contain N-type and P-type forms of silicon in interior. When these two types are next to each other, it is formed a P-N junction [1]. A LED produces light photons when excited electrons from N-type combine with holes in P-type [2]. The Fig. 1 shows the P-N junction in a semiconductor LED structure and Fig. 2 illustrates the LED structure (a) and its symbol definition in electronics circuits (b).

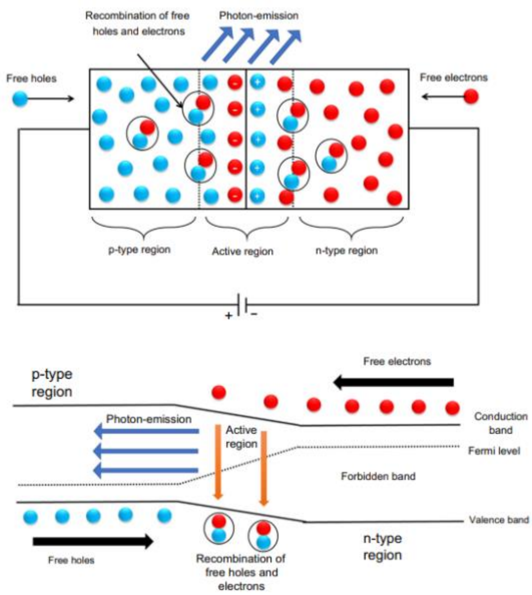

Figure 1: LED *working principle, with details for the semiconductor P-N junction, depletion region and how the electron flow process occurs.*
Source: Nair et al. [3]

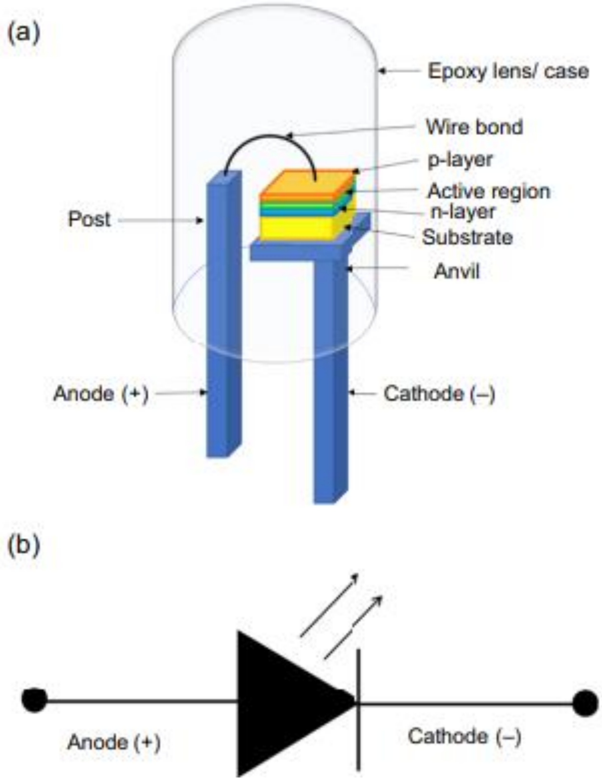

Figure 2: *Figure (a) shows a LED internal structure. Figure (b) is the LED symbol definition in electronic circuits.*
Source: Nair et al. [3]

For the analysis, LEDs were submitted electrical overstress (EOS), which describes a situation where an electronic component operates above its electrical rated values [4]. Before and after the EOS, it was used X-ray micro-computed tomography (micro-CT) technique, that is a non-destructive imaging tool. By mean of micro-CT, that consists of two-dimensional (2D) trans-axial projections generated by the target rotation, which is transformed to a three-dimensional (3D) representation with a digital process, it was possible to perform the object analysis, verifying its internal densities differences [5].

2. MATERIALS AND METHODS

2.1. SkyScan 1272 Bruker equipment and softwares

The equipment used in this project is a desktop SKYSCAN 1272 high-resolution 3D X-ray microscope based on micro-CT, with an X-ray source (10 W, 20 kV – 100 kV), a CCD X-ray detector (16MP), which holds a sample maximum size of 75 mm diameter and 70 mm height [6]. The utilized software's are: SKYSCAN 1272, NRECON, DATAVIEWER, CTVOX, CTAN, CTVOL (Bruker proprietary embedded at SKYSCAN 1272 system equipment) and ISee! Professional (Developed by Vision in X – Industrial Imaging) [7].

2.2. Samples

A group containing several LEDs was analyzed (ten LEDs), however, due to the images similarity, was chosen a LED that emits light in the red wavelength to illustrate the results. Fig. 3 shows the set used as samples for analysis.

Figure 3: *LED colors from top to bottom and left to right: blue, red, green, yellow, pink, orange, cool white, warm white, RGB fast flash and RGB slow flash.*
Source: The author

2.3. Experimental parameters and methodology

The procedure was made in two steps: micro-CT scanning before and after EOS. In both cases, the experimental parameters were: X-ray tube power supply with 90 kV and 111 µA, Al 0.5 mm + Cu 0.038 mm detector filter, 2452 x 1640 pixels image size (5 µm pixel size), projection rotation step of 0.5º, 5 frames per step, 360º rotation stage and measurement total time of 1h 49 min. To submit the EOS, a power supply was provided until the LED stopped to work (in this sample was 11 V and 0,10 A). From these procedures, visual and metrical comparisons were made of its internal structure to observe the damage that an electrical overstress generates.

Before performing the reconstructions, it is interesting to make certain adjustments to the alignment of the images, so the final computational working process is reduced, thus optimizing the final analyses. Dataviewer is a software that allows the user to make adjustments to any of the three projections (transverse, coronal and sagittal). From the views of the three sections (Fig. 4), positioning can be done to ensure the best possible alignment.

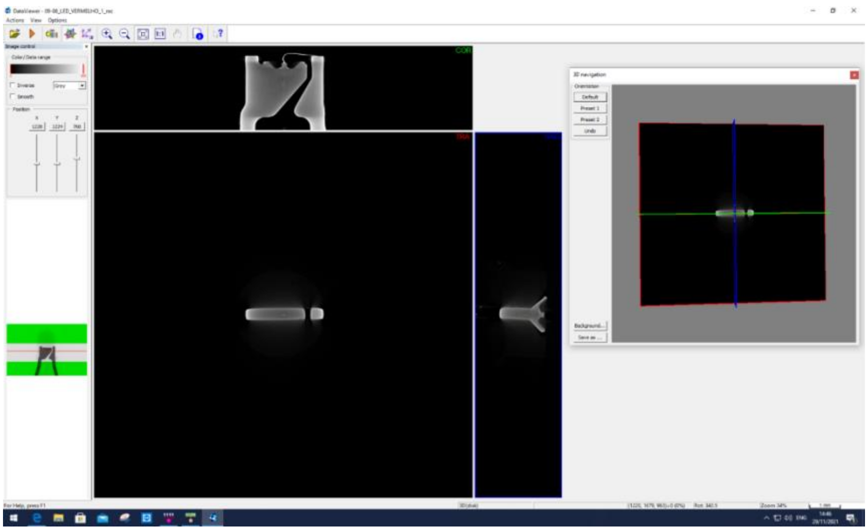

Figure 4: *DataViewer software screen that demonstrates one measured sample transverse, coronal and sagittal slices.*

Source: The author

3. RESULTS AND DISCUSSION

All samples have similar dimensional characteristics, therefore, due to this, one was taken to show dimensional characteristics (Fig. 5).

Figure 5: Utilized sample.
Source: The author

Based on the projections made before EOS, and to exemplify the reconstruction processes applied to the red LED, the image at Fig. 6 was built to a better observation. It was possible to notice its entire internal structure, including the P-N junction in interior.

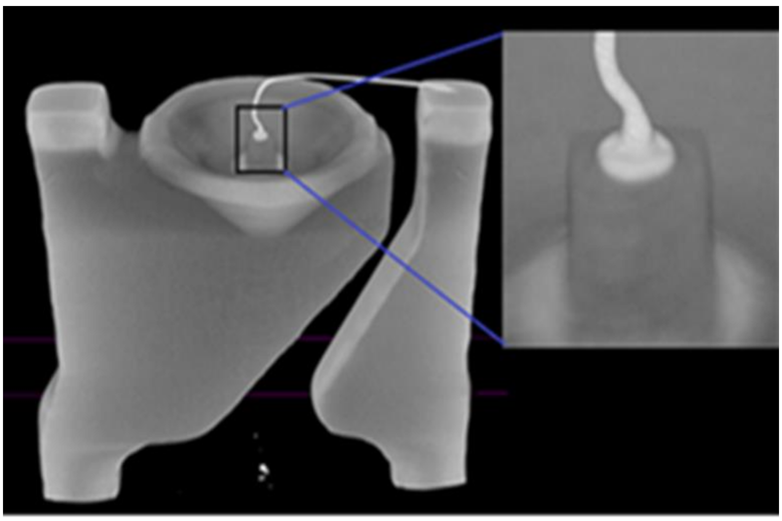

Figure 6: *3D red LED internal reconstruction before EOS.*
Source: The author

From the same LED, performing the same reconstruction processes, now under the effects of EOS, the rupture of the wire bond may be observed (Figure 7).

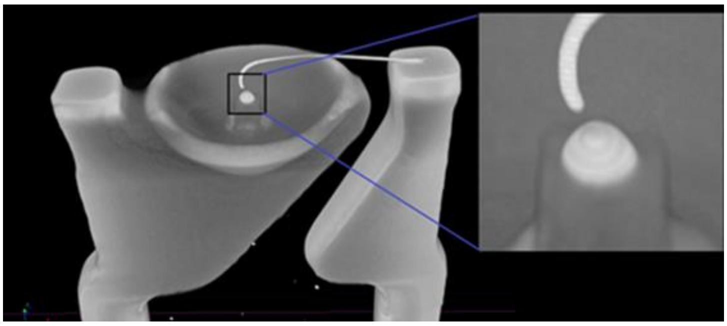

Figure 7: *3D reconstruction of the LED structure after EOS.*
Source: The author

During the radiographic projections process, the metric size of pixels was registered in the generated image files. Using these images information, it was possible to determine measurements of internal region. The Fig. 8 represents a measure of grayscale contrast, which by use of the first derivative, it was possible to determine the thickness of internal Red LED cathode contact.

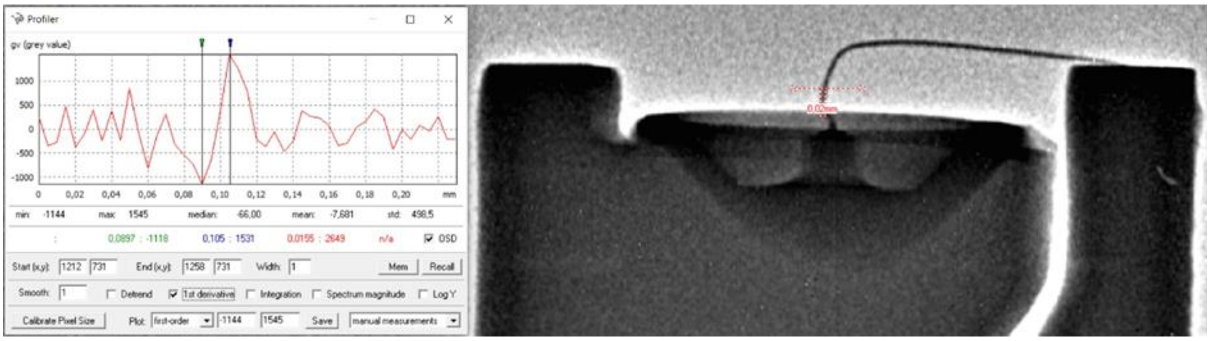

Figure 8: *Interior of LED with greyscale contrast and first derivative at wire region selected*.
Source: The author

With the pixel metric size and the greyscale shown, it was possible to obtain the diameter of the wire bond: 15.5 µm.

The P-N junction was analyzed in both cases (when the set of LEDs were corrupted and not corrupted by electrical overstress). Visually and metrically was possible to notice there was no difference. The Fig. 9 and Fig. 10 shows the measurement process applied in a Red LED.

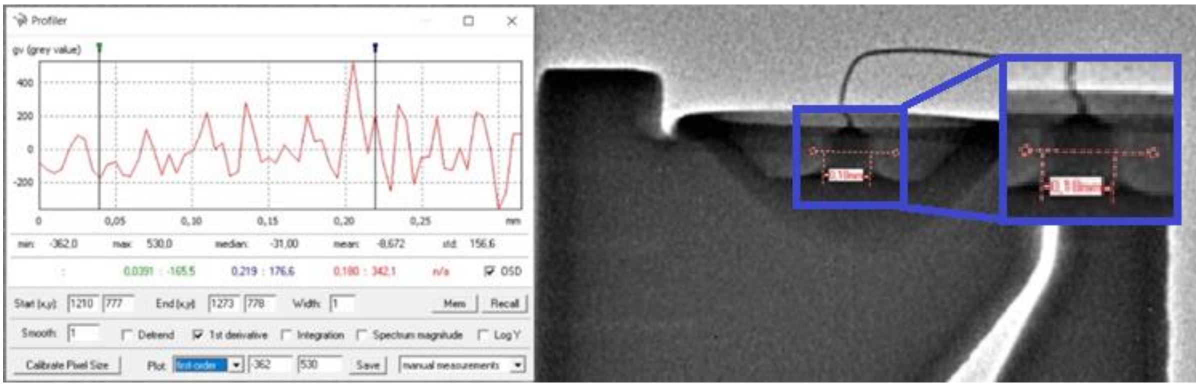

Figure 9: *Uncorrupted wire bond with greyscale of sample and dimension of P-N junction.*
Source: The author

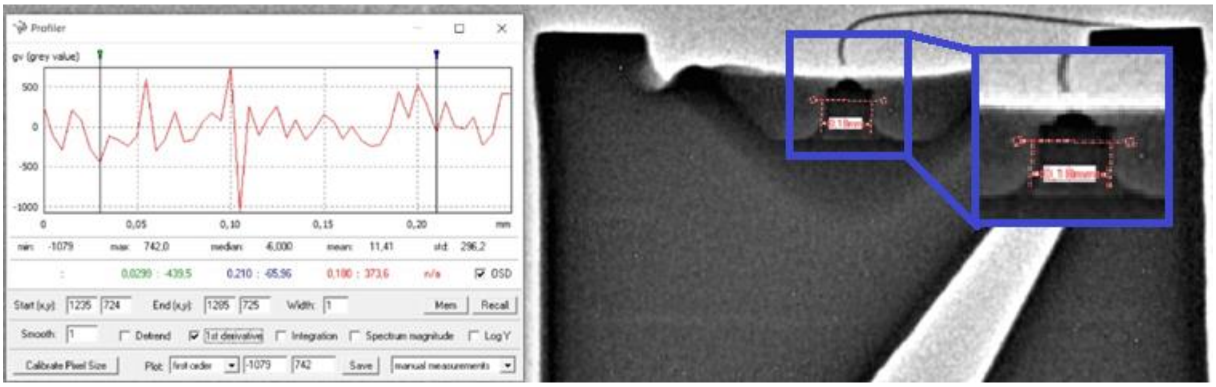

Figure 10: *Corrupted wire bond with greyscale of sample and dimension of P-N junction.*
Source: The author

Table 1 shows the average values obtained for the x, y and z measurements of the P-N junctions in the analyzed LED's set. There were two LED's (both RGB) with more than one P-N junction (four for each one), which were analyzed individually each of them. Values outside the parentheses represent the mean of the measurements, while the ones inside represent the standard deviation.

Image filters were applied to intensify the desired region (P-N junction). From image processing and filters, visually was noticed that when a LED was under EOS, the wire bond is destroyed, but other regions remain unchanged. One observed fact is that the wire bond breaks near the P-N junction.

Table 1: Table of mean values and standard deviation (in the X, Y and Z directions of the P-N junctions.

	direction x		direction y		direction z	
LED type	**Before EOS**	**After EOS**	**Before EOS**	**After EOS**	**Before EOS**	**After EOS**
Blue	0.127 (0.005)	0.125 (0.005)	0.222 (0.003)	0.222 (0.002)	0.091 (0.00008)	0.108 (0.002)
Red	0.171 (0.007)	0.172 (0.004)	0.178 (0.001)	0.177 (0.002)	0.157 (0.002)	0.178 (0.003)
Greem	0.276 (0.0008)	0.275 (0.0008)	0.152 (0.036)	0.154 (0.004)	0.109 (0.001)	0.122 (0.002)
Yellow	0.099 (0.002)	0.100 (0.002)	0.104 (0.002)	0.100 (0.0005)	0.131 (0.0004)	0.135 (0.002)
Pink	0.179 (0.002)	0.179 (0.010)	0.269 (0.002)	0.270 (0.003)	0.114 (0.002)	0.140 (0.002)
Orange	0.129 (0.001)	0.129 (0.001)	0.153 (0.003)	0.154 (0.003)	0.169 (0.002)	0.169 (0.002)
Cool White	0.215 (0.0004)	0.214 (0.0005)	0.145 (0.002)	0.145 (0.002)	0.103 (0.002)	0.104 (0.0005)
Warm white	0.389 (0.002)	0.389 (0.002)	0.217 (0.001)	0.217 (0.0007)	0.120 (0.001)	0.126 (0.002)
RGB fast flash - 1	0.172 (0.002)	0.173 (0.001)	0.182 (0.001)	0.182 (0.001)	0.110 (0.0005)	0.109 (0.001)
RGB fast flash - 2	0.331 (0.003)	0.332 (0.002)	0.155 (0.001)	0.155 (0.0006)	0.080 (0.0001)	0.080 (0.00007)
RGB fast flash - 3	0.125 (0.002)	0.126 (0.005)	0.158 (0.001)	0.156 (0.0006)	0.134 (0.001)	0.155 (0.0007)
RGB fast flash - 4	0.411 (0.001)	0.413 (0.0007)	0.478 (0.001)	0.475 (0.0007)	0.275 (0.0007)	0.276 (0.0005)
RGB slow flash - 1	0.132 (0.003)	0.131 (0.003)	0.140 (0.001)	0.140 (0.0005)	0.157 (0.0008)	0.157 (0.001)
RGB slow flash - 2	0.136 (0.002)	0.135 (0.002)	0.194 (0.001)	0.194 (0.001)	0.089 (0.0001)	0.090 (0.0002)
RGB slow flash - 3	0.121 (0.0006)	0.121 (0.0005)	0.194 (0.0007)	0.195 (0.002)	0.096 (0.0001)	0.096 (0.00007)
RGB slow flash - 4	0.394 (0.002)	0.395 (0.002)	0.538 (0.0006)	0.538 (0.0009)	0.281 (0.006)	0.281 (0.009)

Some of the height measurements at the PN junction (z axis) do not match due to the fact that, upon electrical overstress, the wire bond inside is overheated and melts, where material accumulates on the P-N junction surface. This accumulation is distributed over the entire surface, giving the impression that the joint is higher.

During the superheating of the region, it can be noticed that only this height increases (and not all the samples), so the effects due to thermal expansion at the P-N junction can be neglected.

Figures 11-13 comparatively show the mean values of the LED’s P-N junction dimensions in a bar graph. It performs a visual comparison between size averages measurements at the three directions (x, y and z) with the situations before and after electrical overstress. The measurements indicated on the vertical axis of this graph are in millimeters.

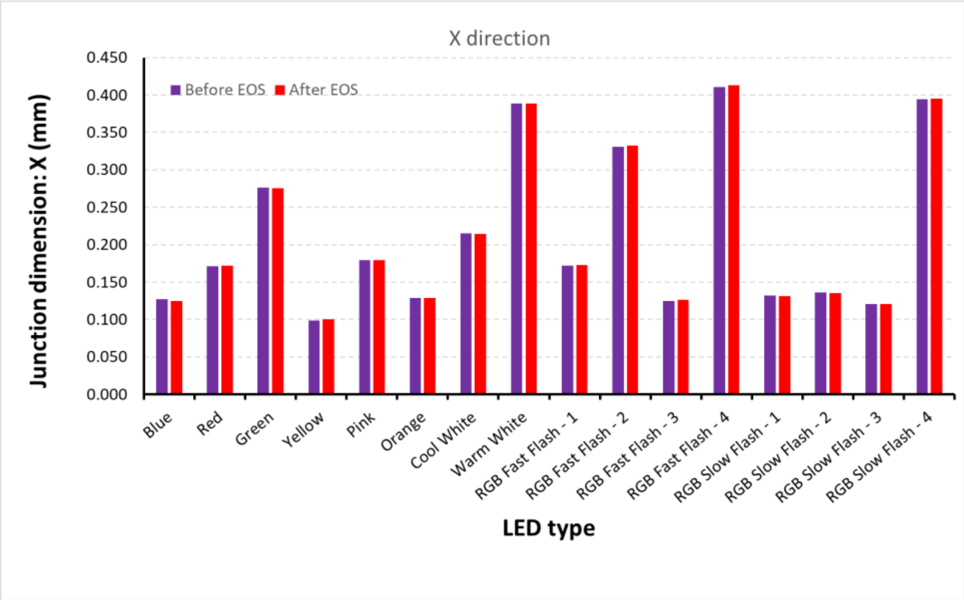

Figure 11: *Measurements averages Comparison at X direction.*
Source: The author

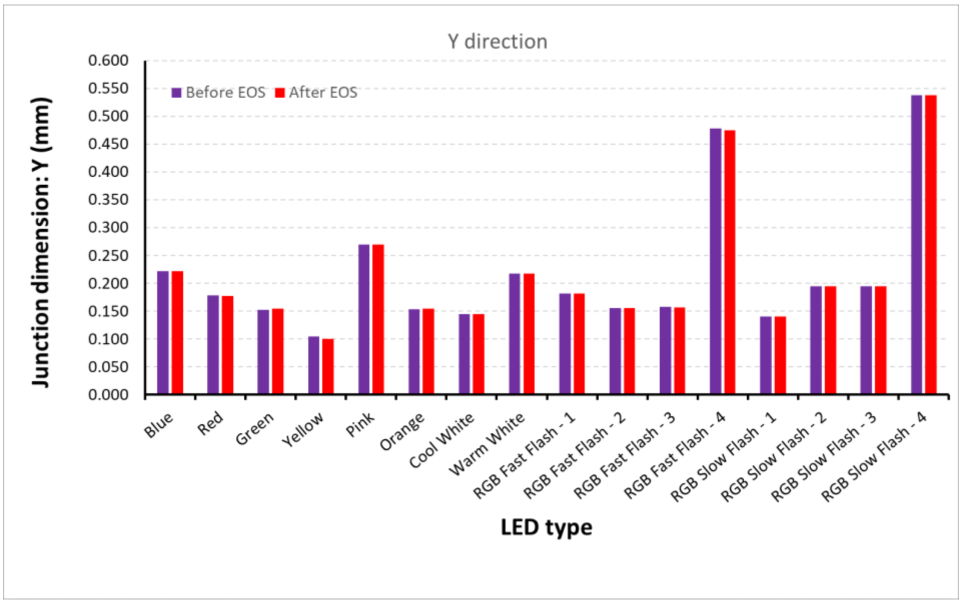

Figure 12: *Measurements averages Comparison at Y direction.*
Source: The author

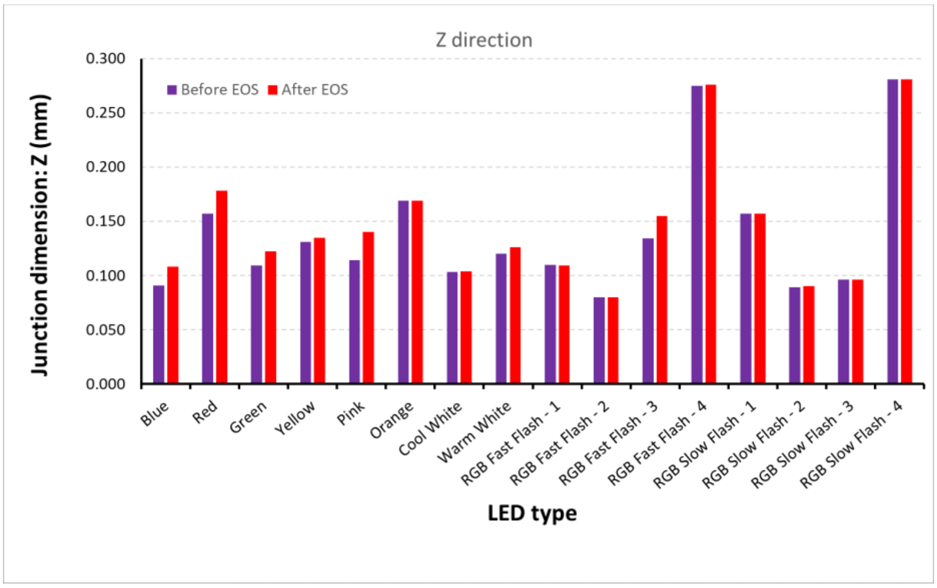

Figure 13: *Measurements averages Comparison at Z direction.*
Source: The author

A LED can be considered useless when it reduces its luminosity intensity due to the lifetime or is damaged by an electrical overstress. As evidenced during the study, when it was electrical overstressed, the wire bond behaved like a fuse. The quality parameter searched it was evidence what happens with all parts, mainly with the P-N junction. The metallic material in its P-N junction and the contact terminals kept preserved, which could enable its recycling. The wire rupture was due the fact that, during the EOS, the P-N junction was overheated, and the wire bond suffered an expansion effect, so it broke close the higher temperature zone (P-N junction). A way to extend its lifetime, with a physical protection from energy peaks (beyond the electrical circuits protection), is attach a heat sink in the region below it. This can transfer the energy to outside and minimize the effects at wire. If the intention is a fuse behavior, an interesting attitude is to reuse it. The potential environmental impact that electronics can cause is gigantic, as LEDs can contain arsenic, gallium, indium, and/or antimony [8], substances that have potential to cause human health and ecological toxicity effects [9].

One of the big problems today is what to do with discarded LEDs and any other electronical semiconductor component. Their metallic constituents inside could be used for other functions, or even rebuild to produce light again. The impacts by now seem to be small, although, this can be enlarged with time and the higher electronical consumer. They are built with rare earth metals, and this can increase pressure in the world natural resources if they keep being discarded carelessly [10]. A company that can guarantee a superior durability will contrast, but it should also be thought about what to do when the device is not working anymore.

4. CONCLUSION

Non-destructible analysis in the electronic device industry has advanced in the past due to the importance of electronic devices in the development of science and technology worldwide. The volume information obtained by micro-CT can be extended in depth to targeted cross-sectional analysis. micro-CT is one of the few techniques that allows, in a non-destructive way, the verification of optical properties associated with microstructure and even submicrometric structural details. Optical defects or inhomogeneities can be definitively and traceable linked to structural or electrical defects of electronic devices such as those studied in this work (LEDs).

One of the big problems today is what to do with discarded LEDs and any other electronic semiconductor components. The potential environmental impact that electronics can cause is enormous, as LEDs contain arsenic, gallium, indium and/or antimony (substances that have the potential to cause ecological toxicity and human health effects). When a LED is not working anymore, its internal metallic constituents could be directed to other functions, or even reconstructed to produce light again.

The analyzes of the LED's were made before and after the electrical overstress effects and their internal structures were observed. The wire jump in all the set was broke, acting as a safety fuse under an electrons excess flow. In all the electrical overstress situations, the wire jumps broke close to the semiconductor P-N junction region. It was noticed that the resin in the encapsulation suffers effects due the sudden temperature variation, being damaged also in the region near the junction. With this information, it is possible to assume that the P-N junction overheats when the LED is electrically overstressed. This overheating effect could dilate the junction and damage it.

By mean of computed microtomography, a three-dimensional analysis of P-N junction was made. In some cases, this region presented a significantly height increasing (z direction compared before and after electrical overstress). The other dimensions (x and y axis) had no significant dimensional variation. With the process to damage the LED, the wire jump spread over the surface of P-N junction. Therefore, the junction was not damaged. Through observations with micro-CT, only the wire jump is corrupted with electrical overstress process due the overheating effects. One way to extend the LED lifetime is include temperature protections, such as heat sink in the lower region of this semiconductor.

The knowledge of the microarchitecture of these materials is extremely important to better understand their performance. The ability to probe a material in any direction and angle, revealing complex hidden structures within the object, is invaluable for failure analysis as well as electronic device product development. The micro-CT data also allows quickly locate possible areas of interest in the microscopic investigations.

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