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

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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 and a LED structure.

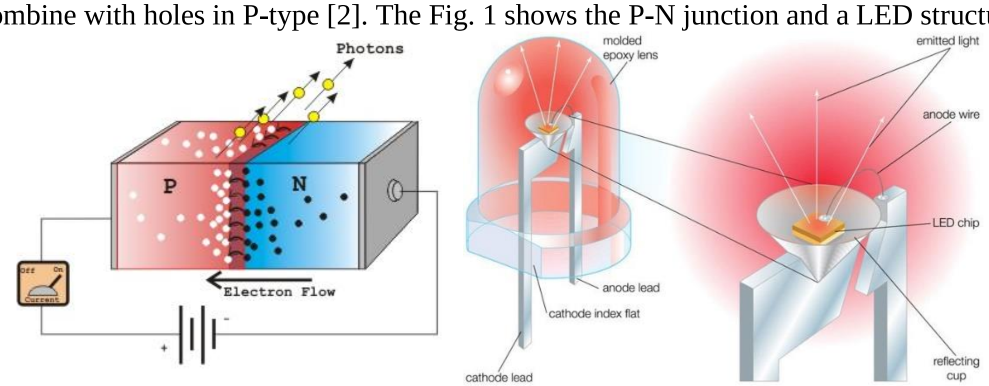

Figure 1: Left side with P-N junction of LED. Right side with LED structure.

For the analysis, LEDs were submitted under electrical overstress (EOS), which describes a situation where an electronic component operates above its electrical rated values [3]. 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 [4].

2. Methodology

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 - 100kV), a CCD X-ray detector (16MP), which holds a sample maximum size of 75 mm diameter and 70 mm height [5]. 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) [6]. A group containing several LEDs was analyzed, however, due to the similar behavior, was chosen a LED that emits light in the red wavelength to demonstrate the results.

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.

3. Results and Discussion

Based on the projections made before EOS, the image at Fig. 2 was built to a better observation. It was possible to notice its entire internal structure, including the P-N junction in interior.

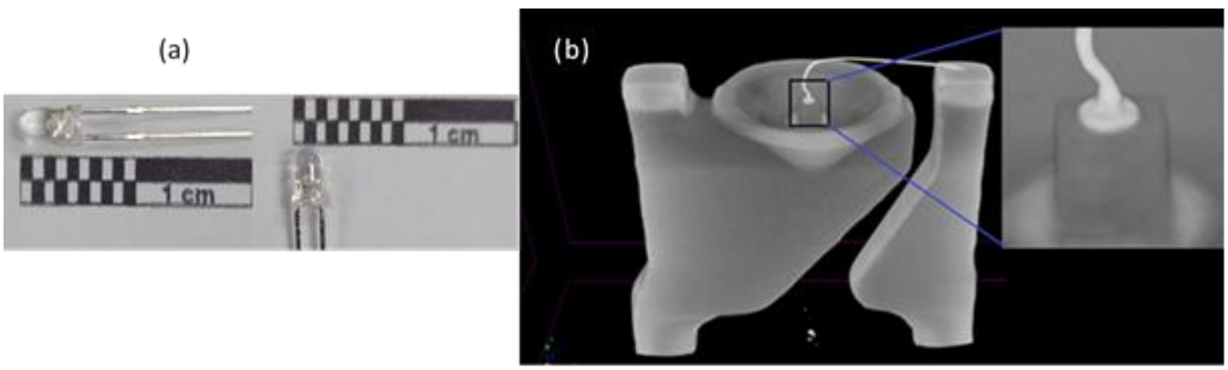

Figure 2: (a) the micro led analyzed in this work. (b) 3D red LED internal reconstruction before EOS.

The image in Fig. 3 contains the 3D LED reconstruction and evaluates the internal damage at wire bond suffered with the electrical overload.

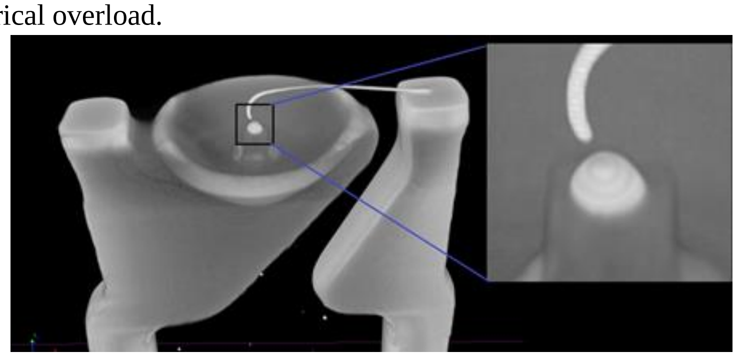

Figure 3 : 3D reconstruction of the LED structure after EOS.

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. 4 represents a measure of grayscale contrast, which by use of the first derivative, it was possible to determine the thickness of wire bond P-N junction to LED cathode.

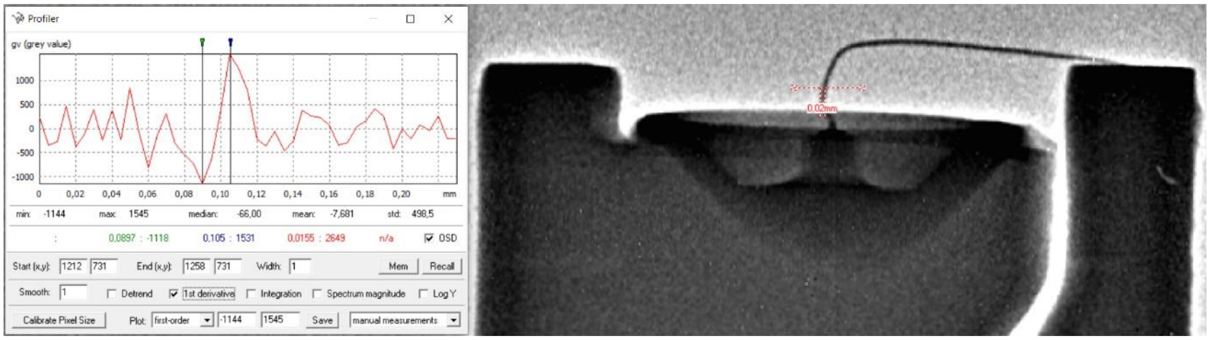

Figure 4 : Interior of LED with greyscale contrast and first derivative at wire region selected.

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 LED was corrupted and not corrupted by electrical overstress). Visually and metrically was possible to notice there was no difference. The Fig. 5 and Fig. 6 shows it.

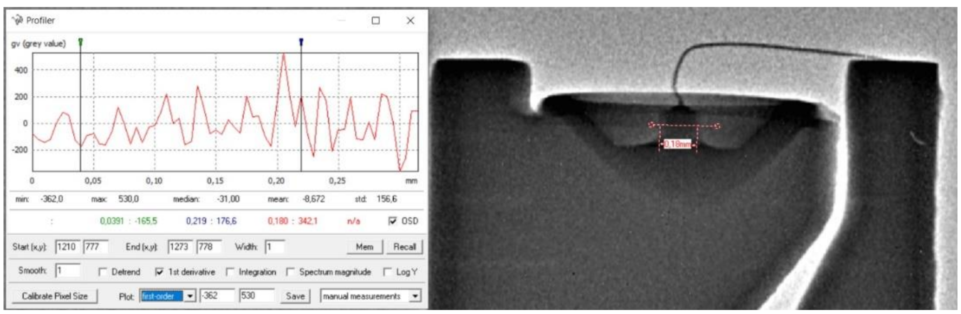

Figure 5 : Uncorrupted wire bond with greyscale of sample and dimension of P-N junction.

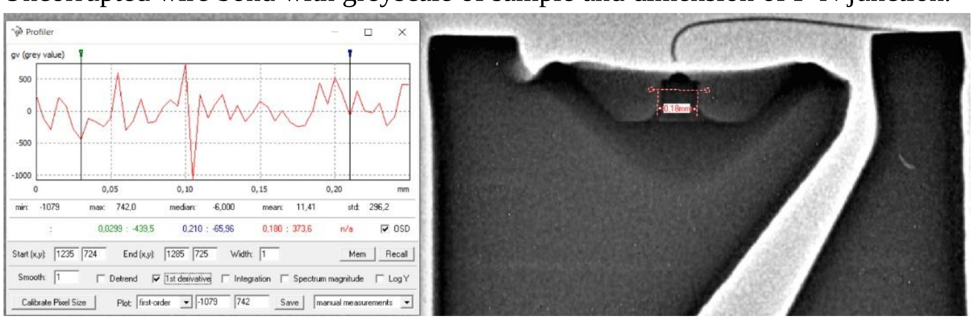

Figure 6 : Corrupted wire bond with greyscale of sample and dimension of P-N junction.

Image filters were applied to intensify the desired region, and it obtained the width of the P-N junction with 180 µm in both cases. From image processing and filters, it 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.

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 [7], substances that have potential to cause human health and ecological toxicity effects [8].

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 [9]. 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. Conclusions

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. The Micro-CT data also allows you to quickly locate possible areas of interest in the microscopic investigations. 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).

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