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Assembly of bulb as encapsulation method for electroluminescent devices

Montagem de bulbo como método de encapsulamento para dispositivos eletroluminescentes

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ABSTRACT

A glass flask obtained of pickled food was developed as bulb with intern vacuum to tests of encapsulation method for electroluminescent devices. Two metal valves to vacuum or insert inert gas, one pressure gauge (with high or low pressures) and one printed circuit board with copper strips for electrical connections were adapted to the glass flask lid and sealed with epoxy. In the first investigation, intern vacuum was carried out and the possible variation of intern pressure was observed by elapsed time (for seven days). In the second investigation, four incandescent lamps (12 V and 10 W) were used without outer bulb to obtain the tungsten filaments that were polarized under vacuum atmosphere at different situations. After seven days, only an insignificant increase of intern pressure was observed. The tungsten filaments were polarized at least 40 times inside the bulb with intern pressure at 101325 Pa (or 76 cm.Hg), while outside the bulb (at room pressure) only two polarizations with significant degradation were obtained. A layer of tungsten oxide (WO_2) with greenish yellow color was formed on the surface of the tungsten filament which was obtained by microscopies and confirmed by EDXS measurement.

Keywords: Bulb, Lamp, Tungsten Filament, Vacuum, Degradation.

RESUMO

Um frasco de vidro obtido de alimento em conserva foi desenvolvido como bulbo com vácuo interno para testes de método para encapsulamento de dispositivos eletroluminescentes. Duas válvulas de metal para vácuo ou inserção de gás inerte, um manômentro de pressão (com alta e baixa pressão) e uma placa de circuito impresso foram adaptadas à tampa do frasco de vidro e seladas com epóxi. Na primeira averiguação, vácuo interno foi criado e possível variação da pressão interna foi observada pelo tempo decorrido (por sete dias). Na segunda averiguação, quatro lâmpadas incandescentes (12 V e 10 W) foram usadas sem o bulbo externo para obter os filamentos de tungstênio que foram polarizados sob atmosfera de vácuo em diferentes situações. Após sete dias, somente um aumento insignificante da pressão interna foi observado. Os filamentos de tungstênio foram polarizados pelo menos 40 vezes dentro do bulbo com pressão interna de 101325 Pa (ou 76 cm.Hg), enquanto fora do bulbo (em pressão ambiente) somente duas polarizações com significante degradação foram obtidas. Uma camada de óxido de tungstênio (WO2) com cor amarela esverdeada foi formada sobre a superfície do filamento de tungstênio que foi obtida por microscopias e confirmada por medições de EDXS.

Palavras-chave: Bulbo, Lâmpada, Filamentos de Tungstênio, Vácuo, Degradação.

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INTRODUCTION

Encapsulation is a technology of interconnecting electronic components that allows to decide and control the behavior of the operating method in the environment, respecting different specifications, such as: size, performance, reliability, cost, and lifetime. Markets of encapsulation involve some sectors, such as: food and feed, agriculture and environment, home and personal care, human and animal health, and chemistry[1]. This last market has been very important in the electronic device area, because it uses adhesives and sealants, paints and coatings, building and construction of materials[1]. The chemical industry has contributed with the evolution of this technology allowing some characteristics, such as: low cost, electromechanical compatibility, good thermal dissipation, minimization of mechanical stress, minimization of electromagnetic interference, and reduced size with the use of different materials.

It is possible to identify at least four factors with great importance, which directly affect the reliability of an encapsulation process, that are directly related with the considerable decrease of the lifetime in electronic devices as known by mechanical, electrical, environmental, and thermal effects[2]:

a. Mechanical effect: it can be generated by mechanical stress (successive motion).
b. Electrical effect: high frequency of electronic device operation causing noise as electromagnetic interference (with peaks of power) and mechanical tension caused by turn-on and turn-off.
c. Environment effect: encapsulation of electronic device as protection method avoiding external influences, such as: dirt; dust; moisture; radiation; ultraviolet and infrared rays; ionic contaminants and electromagnetic interference.
d. Thermal effect: thermal control to preserve the temperature required in the range limit safe avoiding mechanical stress in the encapsulation material with repetitive contraction or dilation by elapsed time.

In the case of thermal effect, it can cause some tensions in the materials contributing with emergence fails, such as thermoplastic deformations, due to uniform changes of temperature effect; microcracks, due to the abrupt changes of temperature; elastic tensions, due to thermal collision; fatigue and/or rupture stresses, due to material fragility[2]. These tensions are associated with some problems as fails in the active materials, occurrence of fails by thermal collision origin caused by thermal fatigue or other fail mechanisms, that has been known as electromigration, stress ruptures, chemical effects of metallization, particularly with aluminum, oxide rupture and electrostatic discharge. For example, commercial electroluminescent devices as light emitting diode (LED) of high intensity luminosity inside the lamps or luminaries, the elevated temperature generated in little intern physical space with low dissipation of heat cause failures in the electronic driver and/or active area of LEDs[3-5]. For these reasons, the thermal factor in electronic components and LEDs, both with low performance has influenced the normal lifespan below 25,000 h, as mentioned in the packing of LED lamps[4].

Methodologies with different arrangement of materials used as encapsulation and the better use of these materials to prolong the lifetime of electronic devices have been tested in laboratory[5-8]. In this case, glass has been very used as encapsulation method to avoid the degradation caused by the moisture and oxygen, principally in OLED (organic light emitting diode) devices[6,7]. Glass is a good material used as barrier to degradation very applied in the electronic and lighting areas, due to the its characteristics, such as low cost, transparency, different sizes and offers good mechanical resistance and recycling[8,9]. Degradation in electroluminescent devices affects directly the production of light emitting by decreasing current and luminance levels. Due to the fast degradation process, the materials developed at laboratories and used in the electroluminescent devices without an encapsulation method present low electrical and optical performances. This fact hinders the choice of the best material to be continuously improved, impeding progress towards new discoveries.

In the case of OLED devices, the degradation process causes dark spots on the active area (without light emission) with fast degradation, Methods to increase the lifetime of these devices, mainly for laboratory mounted devices are being studied[10,11].

In the incandescent lamps without outer glass bulb used as encapsulation, the fast oxidation process causes the rupture of tungsten filament or blocking the passage of the electrical current[12].

The goal of this work is the assembly of simple bulb obtained of glass flask with intern vacuum atmosphere tested as encapsulation method to polarization of tungsten filaments extracted of incandescent lamps. Figure 1 shows the commercial incandescent lamp model used during the experiments.

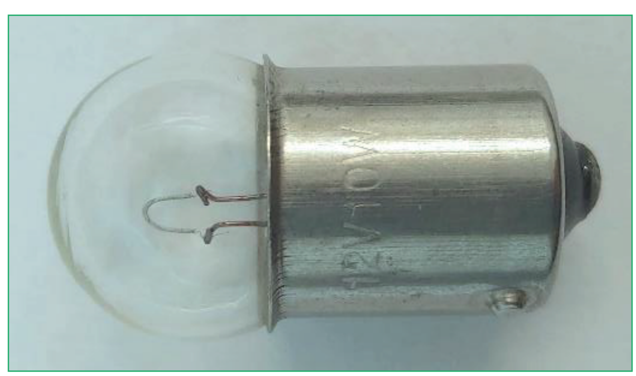

Figure 1: Model of commercial incandescent lamp with original bulb used for all experiments.

MATERIALS AND METHODS

The assembly of bulb with low cost used a glass flask obtained of pickled food with dimensions: 23.5 cm (height), 15.0 cm (diameter) and 10.0 cm (bottleneck diameter). This flask has a metal lid with intern rubber layer to improve the seal. Two metallic valves were adapted and sealed with epoxy (Araldite, Hobby model of time dry of 10 minutes) on the metal lid surface to insert the inert gas and purge the atmospheric air (another methodology to be investigated in the future); one pressure gauge with positive or negative atmosphere (negative pressure measured from 0 to 101325 Pa or 0 to 76 cm.Hg); one printed circuit board with copper stripes for electrical connections; clips (the same used to hold papers) that were welded with copper wires on the printed circuit board to the polarization of the lamps. To ensure a good sealing of bulb, a PTFE tape was placed around the bottleneck of the glass flask (Fig. 2).

Two experiments were performed to evaluate the glass flask as bulb:

1. First experiment: the possible inlet of atmospheric air into the bulb was analyzed. Vacuum was carried out inside the bulb to reach 101325 Pa (or 76 cm.Hg) using a mechanical pump. The analysis was observed by pointer of pressure gauge during 7 days;
1. Second experiment: four incandescent lamps (obtained of motorcycle linker with 12 V and 10 W) were used. The original bulbs were removed, and the filaments were analyzed at different conditions.

Figure 3 shows the commercial lamp with the outer bulb removed using cutter glass to maintain the integrity of the tungsten filaments.

Analysis of the first filament: the tungsten filament was polarized from 0 to 12 V three times outside the glass flask at atmospheric pressure (Patm);

Analysis of the second filament: the tungsten filament was polarized from 0 to 12 V once inside the glass flask with vacuum at 101325 Pa (or 76 cm.Hg);

Analysis of third filament: the tungsten filament was polarized from 0 to 4.5 V from 1 to 40 times inside the glass flask with vacuum at 101325 Pa (or 76 cm.Hg);

Analysis of fourth filament: (d1) the tungsten filament was polarized from 0 to 4.5 V inside the glass flask at different pressures: 13332 Pa (or 10 cm.Hg), 26664 Pa (or 20 cm.Hg), 53328 Pa (or 40 cm.Hg), 66661 Pa (or 50 cm.Hg) and 101325 Pa (or 76 cm.Hg); (d2) after polarized at 13332 Pa (or 10 cm.Hg (inside the flask glass) the tungsten filament was removed from the glass flask and polarized again at ambient pressure three times;

Analysis of fifth filament: the fifth filament was polarized at atmosphere pressure (P_{atm}).

All bulbs were removed with glass cutter to maintain the integrity of the tungsten filaments. Figure 4a shows the intact tungsten filament connected to metallic supports and Fig. 4b shows the image with the size of tungsten filament obtained by optical microscopy.

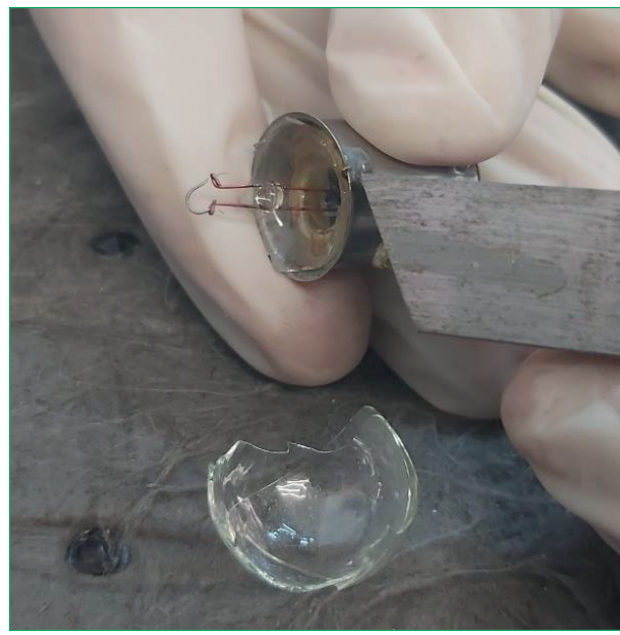

Figure 3: Commercial incandescent lamp with the outer bulb removed.

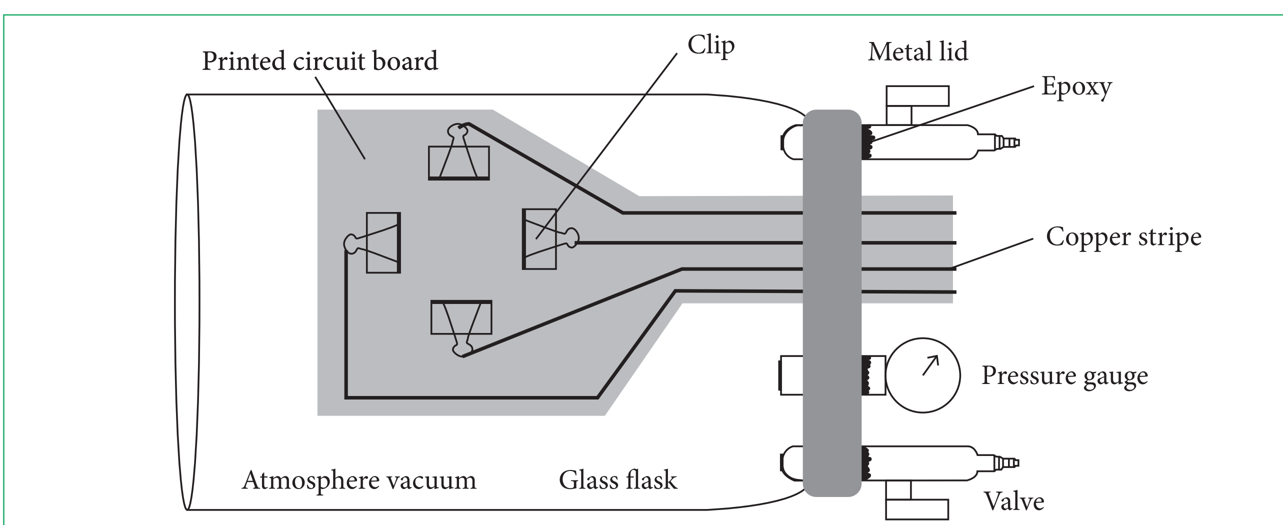

Figure 2: Glass flask used as bulb mounted with all components.

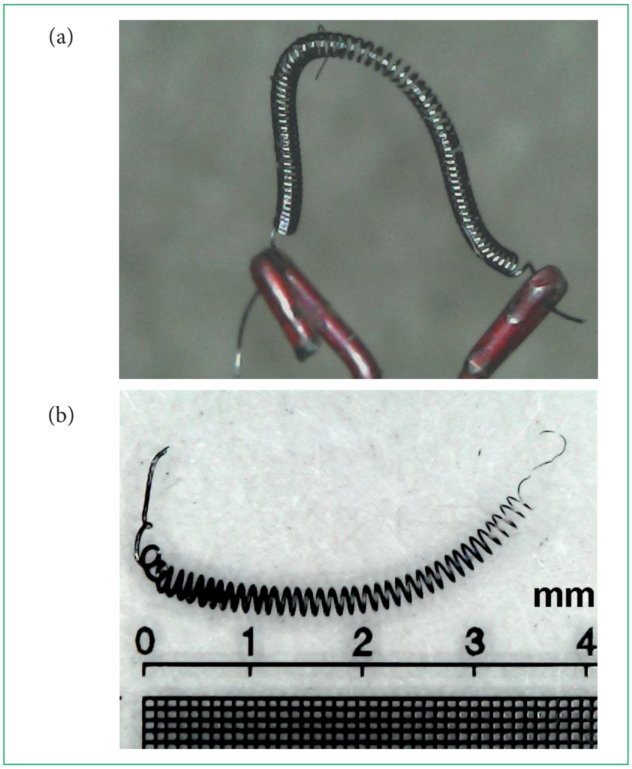

Figure 4: Intact tungsten filament connected by metallic supports (a) and size of tungsten filament (b).

The filaments were then inserted inside the glass flask under vacuum atmosphere. The objective of this experiment was the simulation of original lamps, but with internal vacuum, instead of argon or krypton, as frequently used in the manufacture of lamps[13]. The modified lamps were connected to the printed circuit board and vacuum was applied. A source meter manufactured by Keithley, model 2400 series was used to polarize the tungsten filaments connected by LabTracer software, version 2.0 using the following parameters: start voltage of 0 V, stop voltage of 4.5 or 12.0 V, step voltage to obtain 45 or 120 values, maximum current of 500 mA and acquisition time of 1.0 second for each step voltage.

Images of tungsten filaments were obtained by optical/digital microscopy and scattering electron microscopy (SEM); the energy-dispersive x-ray spectroscopy (EDXS) technique was used to identify the chemical elements formed on the surface.

RESULTS

First experiment

The first experiment revealed no significant inlet atmosphere air inside the glass flask, only an insignificant variation of intern pressure was observed for 7 days by the pressure gauge pointer. This behavior reveals a promissory method of encapsulation for electroluminescent devices, especially for laboratory mounted OLEDs. This period is sufficient to obtain complete electrical and optical analysis, causing insignificant degradation of the devices. It can demonstrate higher performance with reproducibility of results compared to any other encapsulation method used and developed at laboratory.

In another study, glass blades with epoxy were used on the active layer of OLEDs sealing the devices under inert atmosphere, but this procedure had been demonstrated low performance in devices polarization (increase of voltage and low electrical current), due to the significant degradation occurred with only one or two significant polarizations[14]. In this case, this process offers no good sealing of devices, because the epoxy layer used is very porous, compromising the direct performance or the epoxy accomplishes chemical attack in the active layer. Furthermore, this procedure is completely dependent on the inert gas inside the glove compartment chambers which are large and isolated from the environment necessary for the method's encapsulation assembly[15].

Second experiment

Analysis of first filament: Tungsten in the first polarization (Polarization 1) reached the highest voltage with ~ 3.9 V (set to 12 V) presenting maximum electrical current of ~ 320 mA (set to 500 mA) and, then the initial process of degradation is started. The second polarization (Polarization 2) shows the continuous degradation process to reach until the maximum voltage of ~ 3.4 V and electrical current of ~265 mA, then a fast and complete degradation process is obtained above 300 mA, decreasing the electrical current (Polarization 3). Fig. 5 shows the results for tungsten filament polarized outside the glass flask (P_{atm}), Polarization 1, 2 and 3.

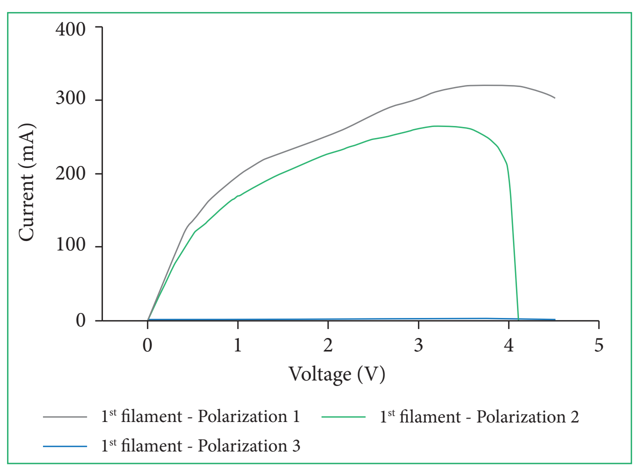

Figure 5: I-V results of first tungsten filament polarized outside the glass flask (P_{atm}).

Analysis of second filament: The tungsten filament polarized only once from 0 to 12 V had a similar electrical behavior. The vacuum atmosphere at 101325 Pa (or 76 cm.Hg) provided an elevation of voltage with ~ 4.9 V (set to 12 V) to obtain the electrical current of ~320 mA (set to 500 mA). After the device to reach these levels for both, the complete degradation process is observed after 6.5 V with abrupt fall of electrical current values. This behavior is evidenced in Fig. 6.

Analysis of third filament: Based on the result shown in Fig. 7, the tungsten filament was polarized by different times only to 4.5 V and at least 40 polarizations were obtained under vacuum at 101325 Pa (76 cm.Hg). These results show an evident influence caused in the voltage and electrical current levels by atmosphere created. The degradation process was very low and almost non-evident, providing a similar behavior for all polarizations.

Analysis of fourth filament: (d1) The tungsten filament inserted into the glass flask showed a similar electrical behavior for different pressures. Figure 8 shows the results for tungsten filament polarized at different pressures from 13332 to 101325 Pa (or from 10 to 76 cm.Hg); (d2) after polarization at 13332 Pa (or 10 cm.Hg), the tungsten filament was removed from the glass flask and polarized for only three times due to complete degradation. Figure 9 shows these results using the fourth filament.

Figure 10a and b shows the fifth filament polarized at room pressure (Patm) with or without incandescence, respectively. Figure 10a shows only the emissive punctual area (no incandescence on the complete area of filament). After polarization (Fig. 10b), a greenish yellow layer was obtained by WO_2 (tungsten oxide) formed[16]. This characteristic was not observed for the filament polarized inside the glass flask under pressure. The incandescence process was observed on the complete filament only when there was vacuum inside the glass flask. This electroluminescence phenomenon of punctual area on the filament can be related by the tungsten electrical resistivity. This hypothesis can be explained by chemical attack (caused by oxygen and moisture of ambient and elevation of temperature by polarization), increased electrical resistivity (caused by unbalanced charge carriers) near

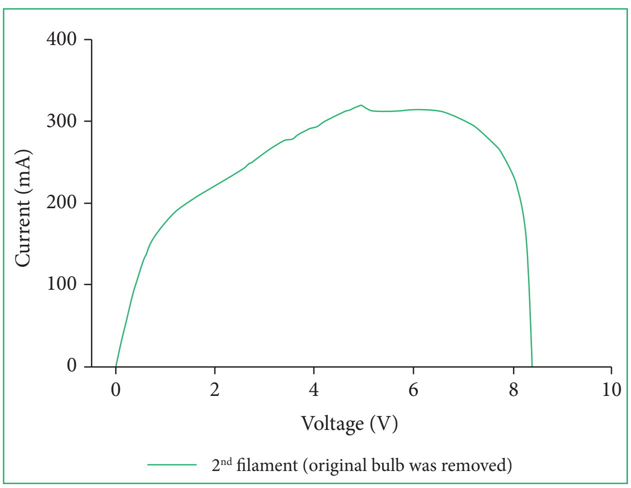

Figure 6: I-V result of second tungsten filament polarized inside the glass flask under vacuum at 101325 Pa.

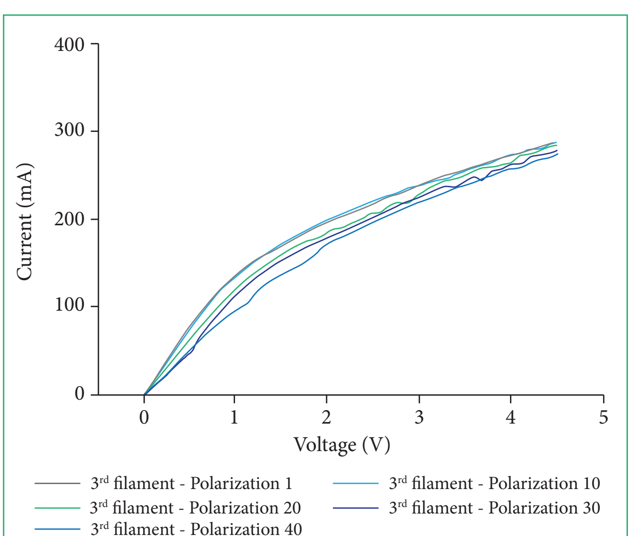

Figure 7: I-V results of third tungsten filament polarized at least forty polarizations inside the glass flask under vacuum at 101325 Pa.

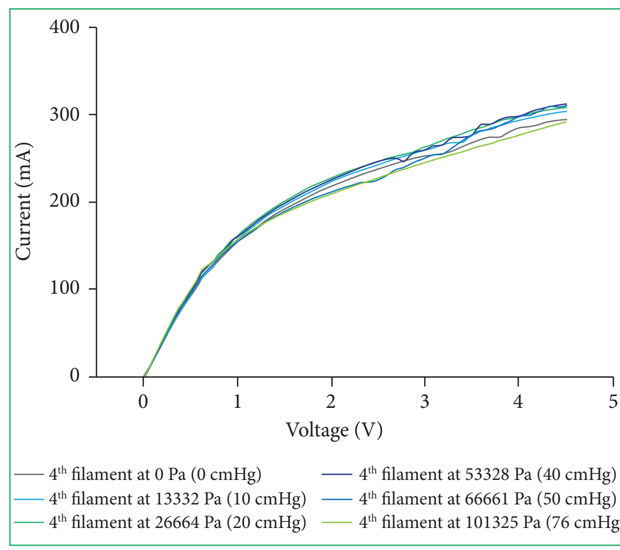

Figure 8: I-V results of the fourth tungsten filament polarized at different intern pressures from 13332 to 101325 Pa.

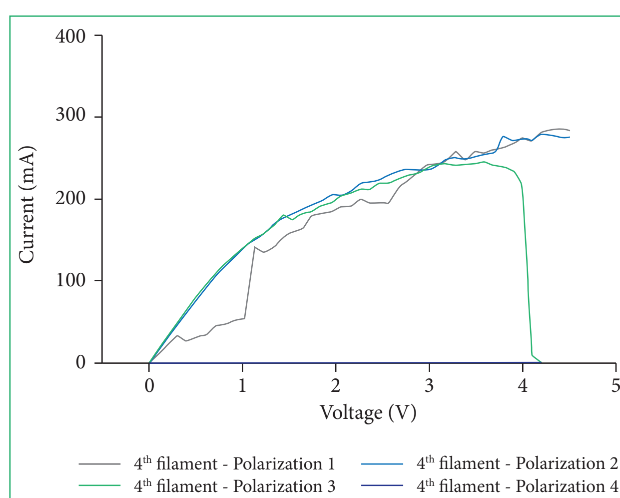

Figure 9: I-V results of fourth tungsten filament removed inside the flask and polarized by three times (P_{atm}).

of electrical contact region between the filament and electrodes. The little path created most located in the middle of the filament region has large concentrated charge carriers with low electrical resistance, promoting luminescence.

Figure 11a shows the image obtained by digital photography using microscopy. This image shows the yellowish green layer formed by the WO_2 (tungsten oxide) on surface of the broken tungsten filament. The tungsten oxide layer makes the wire more fragile and this aspect was observed not only in this experiment, but also in other analyses (results not reported here).

Figure 11b shows the image obtained by 250× magnitude revealing different aspects; the surface presents most roughness near of the disruption than the rest of the tungsten filament.

Figure 12 shows the results obtained by EDX of chemical elements on the tungsten filament. It revealed the presence of oxygen for the formation of the greenish-yellow layer of WO_2 in the fifth tungsten filament.

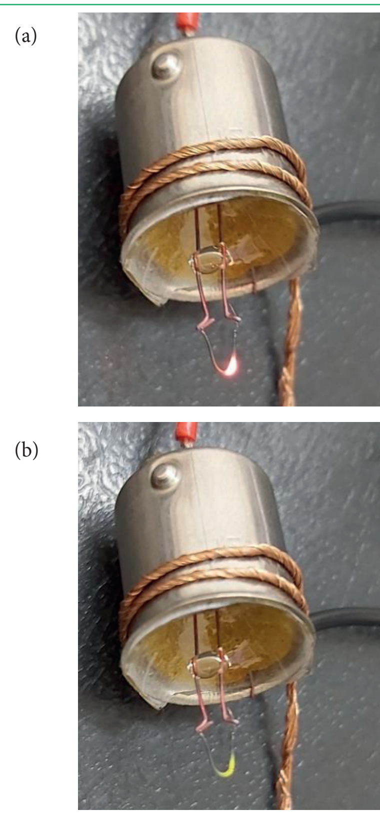

Figure 10: Fifth filament: (a) tungsten filament polarized outside the glass flask with punctual area emission of light and (b) tungsten filament after polarization outside the glass flask with WO_2 formed on the punctual area.

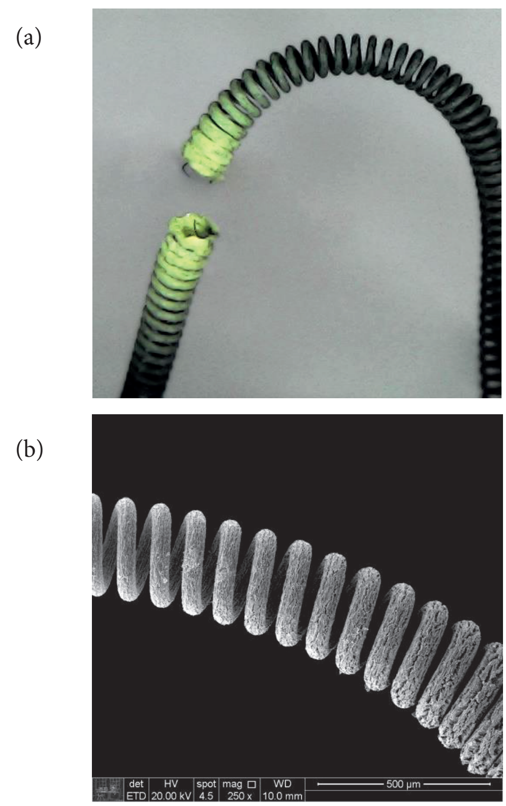

Figure 11: (a) Fifth tungsten filament broken after polarization outside the glass flask with WO2 layer formed and (b) WO_2 layer formed along the fifth tungsten filament after polarization outside the glass flask.

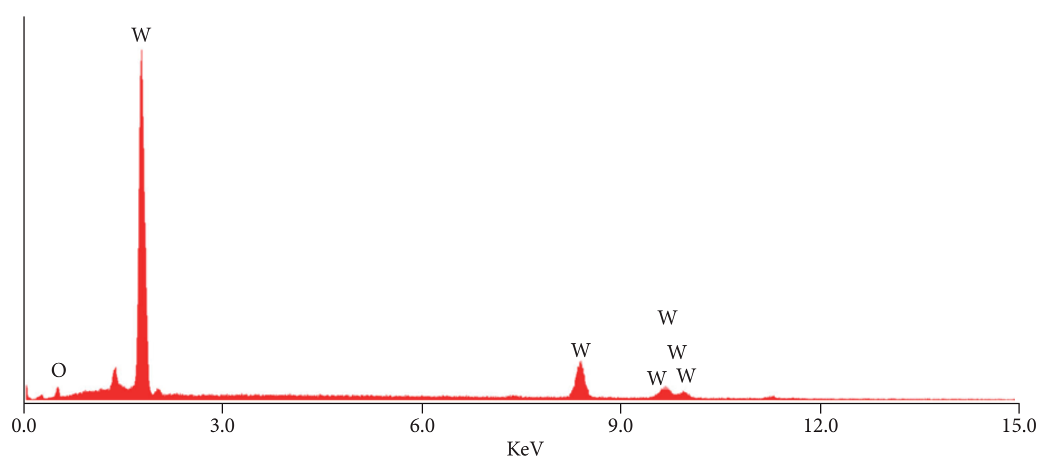

Figure 12: Result obtained by EDXS technique of the WO_2 greenish yellow layer formed on the tungsten filament.

CONCLUSIONS

A glass bulb has been assembled to create an internal vacuum atmosphere in order to increase the lifetime of the electroluminescent devices mounted in the laboratory. The bulb was assembled with a glass flask obtained from pickled food and some components. In the first experiment, inside the glass flask was created pressure with vacuum pump at 101325 Pa (or 76 cm.Hg) revealing good seal during seven days. Then, incandescent lamps (the same used in the motorcycle linker with electrical characteristics of 12 V and 10 W) were polarized without its outer bulb outside and inside the glass flask under vacuum atmosphere. The tungsten filaments were polarized from 0 to 4.5 V under vacuum from 13332 (or 10 cm.Hg) to 101325 Pa (or 76 cm.Hg) by several times preserving the luminescence on the complete extension of the tungsten filament. Another tungsten filament was also polarized outside the glass flask at same electrical conditions, but it revealed a poor performance, due to the oxidation formed by the WO_2 layer partially formed on the surface followed by rupture of metal wire.

The use of this glass flask with OLED devices using this same methodology can be promissory to obtain better performance.

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