Letter

Gas Evolution in Glass-sealed LED Filament Lamps

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ABSTRACT

It is well-known that the presence of Volatile Organic Compounds (VOCs) within sealed LED bulbs can induce lumen output degradation during the device life. We studied the evolution of the luminous flux and of the gaseous contaminants on LED filament lamps purchased on the market: the increase of large organic molecules concentrations was observed after aging in some samples. As a matter of fact, the lamp with higher increase in larger molecules contamination showed also higher rate of luminous flux degradation.

KEYWORDS: VOCs, Volatile Organic Compounds, LED, filament, aging, degradation

1. Introduction

One of the main features associated with the LEDs is to be point-source. This fact, associated with the small weight, the low voltages, their intrinsic robustness make the LEDs a very flexible tool, able to satisfy the more exotic requests on terms of lamp design, making virtually possible all shapes and conformations. In fact LEDs are successfully employed for obtaining flexible stripes, rigid bars, lighting planes (TV back illumination), 3-D installations, etc.1)

However the old-fashion incandescent A-series bulb shape (e.g., A19) is still in the hearts, as well as in the houses, of many customers and the traditional shape of these lamps is still paradigmatic of an illuminating device. To emulate the light spectrum coming out from incandescent lamps has been an object of a very broad discussion and there are many papers debating on the colour perception and correct colour metrics to evaluate LEDs performances. Save for technical matters such as light distribution angles, most discussions on the shape of the LEDs bulb focus on marketing related matters and customer convenience. As a matter of fact almost all producers offer LEDs retrofits that resemble incandescent-like products to meet the needs of nostalgic buyers and users who want to retain their existing lamp fixture.

Currently, there are basically two kinds of LED lamps with A-19 (or A 60 for European) bulb formats: in one embodiment the bulb lamp contains LEDs mounted on printed circuit board in thermal contact with a metallic heat sink and a plastic bulb-like envelope that provides mechanical protection and, in some case, light beam re-shaping. The polymeric dome can partially isolate the interior of the lamp from the external atmosphere but, because of the design and the permeation properties of the plastic material, there is an exchange of gases from outside to inside. In the second configuration, object of this study, the LEDs are assembled in a glass bulb filled with helium or with thermally conductive gas mixtures; the LED emitters are mounted on PCBs or linearly mounted on sapphire or glass bars covered by silicone embedded with phosphors. This second design closely resembles an incandescent light lamp where tungsten filaments are substituted by LEDs structures or LEDs filaments.

Apart from esthetical considerations, glass-sealed LED bulbs offer important advantages: they use simple configurations, cheap materials with small investment for plant production, etc. As a key feature they do not require a bulky heat sink, being the heat dissipation carried by the gas filling. Typically helium at pressures slightly below 1Bar is used. The choice of He as filling gas is motivated by its high thermal conductivity compared to other gases, its low viscosity and its inerterness. However the fact that He does not take part in ordinary chemical reactions does not mean that the environment inside the lamp jacket is immune from chemical reactions.

In fact, as shown in this paper, we have identified an evolution of gaseous species, specifically, organic gases, which are believed to play a role in the gradual degradation of the lamp optical performances.

2. Experiments

In this study we analysed three types of lamps coming from two different producers (the set of lamps 1 and the set of lamps 2 are from the same producer). The lamps are standard off-the-shelf products purchased on
Figure 1 Luminous flux curves obtained for the analysed lamps.

Figure 2 Spectra from mass spectrometer measurement on the three lamps after 1300h aging (solid lines) and after 0h (dotted lines).

The market and analysed in terms of electrical, optical as well as gas properties.

Optical measurements are performed within an integrated sphere (1m diameter) equipped with spectro-radiometer HAAS-2000 from EverFine. Calibration check is performed before and after the test with a calibrated halogen lamp (DC power supply). The reproducibility, as checked by measurements on control lamps, is better than 1% of luminous flux and ±15K of colour temperature. Electrical measurements are cross-checked with PF2010A and HB-6B units, also from Everfine.

In Figure 1 are reported the luminous flux data recorded at different aging time for the three lamps. The aging is performed at room temperature with continuous operation using line current. It is checked also that the power consumption is stable within 1% for all measurements.

The gas analysis is performed through a calibrated quadrupole mass spectrometer Balzers Prisma QMS200 from Pfeiffer. The lamp is mechanically connected with the vacuum bench, the free space is evacuated to pressures below $10^{-7}$ Torr, and then the glass wall is broken in order to expand the filling gas into the analysis volume. This procedure is well established for traditional fluorescent and high intensity discharge (HID) lamps. The test is destructive, thus it can be performed once per lamp and the comparison of the results can be done on different lamps coming from the same lot. It is important to note that gas analysis is performed at room temperature, then just the molecules in gas phase are traced. Results of the mass spectrometer analyses carried out on 0h lamps and 1300h aged lamps are reported in Figure 2. Filling gas is helium for all the lamps.

3. Discussion

As shown in Figure 1, the luminous flux behaviour is not constant along the time: in fact, with the exception of the short term trend for lamp 1, the lumen output of the lamps tends to decrease as a function of the operation time. It is worth underlining that while the flux degradation during aging is quite limited for lamp 1 and 2, the luminous output degradation is quite important for lamp 3 (more than 13% after 1300h).

At the same time, our measurements (Figure 2) indicate that a non-negligible change in gas composition occurs between an initial lamp and an aged lamp. Specifically, we identified an increase in the final concentration of hydrogen, methane and other more complex molecules after aging.

The increment of hydrogen and methane is well recognised in all lamps measured with the variation of more than one order of magnitude with respect to measurements performed on initial 0h lamps. In particular, lamp 1 experiences a net increase of 3000 ppm (v/v) and 770 ppm respectively. Lamp 2 undergoes a variation of 1510 ppm (H₂) and 190 ppm (CH₄), while lamp 3 has a change of 720 ppm (H₂) and 100 ppm (CH₄). It is speculated that these contaminants originate from decomposition of larger molecules organic compounds (coming from solvents, lubricants, methyl-silicones, etc.). In other words, the heavier and less stable VOCs molecules would break down into smaller molecules when irradiated by blue light at moderately high temperatures.

Peak 73 a.m.u. is likely attributed to tetra-methyl-silane and the whole group of peaks 73, 74 and 75 is probably due to molecule containing tri-methyl-silane pendant. Similarly, the group of peaks adjacent to 59 a.m.u. 
is compatible with organic derivative of the silicone such as iso-propyl-dimethyl-silane, however a relatively good matching is found also for alcohol such as 2-pentanol. Concerning the series of peaks in between 41 and 47 a.m.u., there are several representatives from amine (e.g., dimethyl and isopropyl-amine) and nitrile (e.g., butanitrile) families that show, at least, a partial match with. At the moment is not possible to address a precise assignment but on the basis of these observations it would be possible the presence of nitrogen-containing compounds. In all the lamps the small amounts of O2 present at 0h tend to decrease with the aging.

Generally speaking, lumen flux degradation is a phenomenon that involves many factors. Among others, there is a well-known mechanism reported for LEDs operating in sealed environment that refers to the accumulation of carbonaceous species in the silicone encapsulant induced by a relatively high level of VOCs within the sealed bulb. This mechanism could explain why the lamp 3, more rich of VOCs contaminants, shows the fastest flux decay in the lamps group. This fact would suggest that small molecules such as methane, supposed to come from large VOCs decomposition, play a minor role in the lumen degradation while large not-decomposed compounds have an influence as such. However is important to take in mind that even methane or other low thermal conductivity gases would get an influence when their concentration increases because their presence would degrade the helium sink effect. From our evaluations it comes out that at 3% v/v CH4 concentration results a decrease of 6% thermal conductivity, with an almost proportional (6%) increment of the filament surface temperature.

It is worth to remind that gas analysis is a technique which is sensitive only to the volatile fraction of compounds enclosed in the lamp volume. Gas analysis is not capable of directly measuring heavy molecules either trapped in the silicone matrix or surface of other materials residing in the jacket. In order to find further evidence of the degradation mechanisms related to heavy molecular compounds, other analytical techniques are in place.

4. Conclusion

In this work we collect data on the optical flux and gas filling composition of different glass-sealed LED filament lamps under aging. We actually found a variation in both luminous flux and gas composition after 1300h operation.

In particular we observed in all lamps a general trend with an increase of H2 and CH4 concentrations while O2 decreases. We have also identified that all three different lamp types used for these investigations showed different amounts of heavy VOC molecules. The lamp with higher increase in larger molecules contamination exhibited higher rate of luminous flux degradation.

As these tests are initial attempts at determining the effects of VOC contaminants on lamp performances, further studies are required to quantify and identify the specific mechanism that leads to performance degradation. However, magnitude of VOC evolution within a sealed LED lamp has been captured and has given insight to the possible correlation between VOC evolution and lumen output degradation.

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