Cost benefits of **LED luminaires in Ex environments**

New technologies are being established in the field of lighting - in particular, the use of LEDs is becoming much more common. It is very important to analyse and know the possible failure modes of LED sources in order to design reliable and safe lighting fixtures. This is particularly true in relation to the use of LED lighting equipment in potentially explosive atmospheres that require quite complex safety systems to avoid igniting dangerous gases, vapours and dust. At present, ATEX Standards do not adequately cover LED luminaires, whether white or coloured. Therefore, these sources are often used as traditional light sources (incandescent, discharge, induction). The safety of such equipment is entrusted exclusively to the mechanical strength of the casing and not the internal electrical equipment.

This article, by Roberto Sebastiano Faranda of Politecnico di Milano and Kim Fumagalli of Nuova ASP, explains currently available LED electrical and mechanical characteristics, and evaluates different possible causes of failure and their implication in relation to explosive atmospheres.

I. Introduction

In recent years, the first devices with LED light sources also appeared in the Ex field.

Even if LED technology is more expensive than traditional sources, from a technical point of view, there are advantages that can offset this high cost.
The most important are [1]:

- low power consumption, that permits both electrical energy savings and the installation of small section cables and lower protection;
- high number of operating hours, that allow savings on the cost of maintenance and the hourly cost of a LED lamp.

In traditional environments, LEDs do not have any evident mechanical protection, because their failure is not perceived as a condition of danger (just think of the wiring for Christmas decorations). Instead, in the Ex field, in order to ensure safety, since LED fault condition behaviour is not known, LED light sources are made of Power LEDs mounted in heavy, thick, bulky and expensive metal flameproof casings, mostly made of aluminium. These casings are also often difficult to install and maintain.

In fact, while only waterproof LED units have to conform to the relevant product standards, LED fixtures for potentially explosive atmospheres must also comply with specific anti-explosion regulations. The assessment of the possible causes of ignition of LED lighting sources must therefore be carried out carefully.

In order to ignite an explosive atmosphere, the simultaneous presence of the following three components, under particular conditions, is essential:

1. oxygen;
2. fuel;
3. a trigger.

The absence of one of the three components is sufficient to avoid an explosion.

Current IECEx International Standards contain two main protection strategies, Ex-d and Ex-e.

With Ex-d, parts which can ignite in potentially explosive atmospheres are surrounded by a casing capable of withstanding the pressure of an explosive mixture exploding inside, and this prevents the transmission of the explosion to the atmosphere surrounding the casing.

With Ex-e, additional measures are applied to increase the level of safety, thus preventing the possibility of excessive temperatures and the occurrence of sparks or electric arcs within the enclosure or on exposed parts of electrical apparatus, where longer available ignition sources would not occur in normal service.

Both protection methods described above are valid for installations in the hazardous areas defined as 1 and 21. The substantial difference between the two protection methods is that the first (Ex-d) has a robust housing to contain potential explosions (simultaneous presence of all three components), while the second protection method uses only electrical components without possible causes of ignition (which are therefore also Ex-e), and therefore explosions cannot occur (due to lack of a trigger); this is why the casing does not need to contain an explosion and therefore it can be made as if it were a normal casing for traditional environments.

In the specific case of lighting fixtures, the use of an Ex-d casing is justifiable for traditional light sources (discharge or fluorescent lamps) since it is not possible to eliminate the possible causes of ignition (high temperatures or electrical arcing) caused by these sources. In the case of LEDs, however, it does seem possible, but it is necessary to perform a careful failure analysis.

At the moment, no official analysis (accepted by a Standard) is available, and therefore for reasons of prudence, which means reasons of safety, most manufacturers of ATEX equipment use LEDs with the maximum protection method - Ex-d.

However, in so doing, a lot of money and resources are wasted. The construction method for Ex-d lighting fixtures requires a great deal of material compared to lighting devices which use other protection methods. Indeed, Ex-e lights can give considerable benefits compared with Ex-d lights:

- Cost benefits: Ex-e devices are not as robust as Ex-d devices (about 1:10), so the cost of materials is often lower;
- Luminous efficiency: at the same installed power, Ex-e devices are more efficient than Ex-d devices because they use thinner glass, which allows better optical performance;
- Installation: Ex-e devices installed at different heights ensure easier and safer installation than the heavier Ex-d equipment.

The aim of this article is to analyse the behaviour of LEDs in case of failure, not to confirm the reliability and durability of LED sources, but rather to ascertain the possible causes of dangerous faults for installation in potentially explosive atmospheres.

II. Lighting comparison

Consider the two following products used for lighting large areas, set up to use the same 400W Sodium discharge lamp:
1) The SFD floodlight (Nuova ASP), ATEX/IECEx certified with an Ex-d protection method, and which can be installed in Zones 1-21;

SFD (Ex-d) floodlight – Nuova ASP

2) The SFNR floodlight (Nuova ASP) ATEX/IECEx, Ex-nR certified, and which can only be installed in Zones 2-22.

SFNR (Ex-nR) floodlight – Nuova ASP

The Ex-nR protection (low breathing) method is defined as a simplified protection method which can be used in Zones 2-22. This unit cannot be used in Zones 1-21 because of the electrical components installed in it, which are not Ex-e certified for such use.

From a technical point of view, the Ex-nR floodlight has a better lighting efficiency for two reasons:

1. the thickness of the glass is about 5 millimetres, compared with that of the Ex-d floodlight, which is about 20 millimetres. Considering a loss of lighting efficiency equal to 10% for every 10mm of glass, this means that the Ex-nR floodlight has a yield of 15% more than the Ex-d floodlight.

2. the transparent part is about double the thickness of the Ex-d floodlight. The luminous flux is subject to fewer internal reflections and therefore gives a better performance.

Photometric measurements show that the SFNR floodlight has a better luminous efficiency than the SFD floodlight, and therefore a greater emission of luminous flux of approximately 25%.

From a cost point of view, taking into account that there is a ratio of 1:10 between the thickness of the container of the SFNR floodlight and the SFD floodlight, and then that the aluminium used to produce such an apparatus is 10 times greater, the production cost of the SFD floodlight is about 60% more.

The reason the SNFR appliance cannot be used in Zones 1-21 is the possibility of ignition of the explosive mixture. These devices, made with discharge lamps, allow the triggering of the explosive mixture, and the electrical components (such as ballast, igniters, etc…) are not Ex-e certifiable (or have such high production/certification costs that certification would not be practical).

By substituting the discharge lamp with LED light sources it could instead be possible, as long as some small changes to the unit are made, to use the SFNR LED floodlight in 1-21 areas.

If the SFNR device could be Ex-e certified (and therefore was no longer certified Ex-nR) , it could be installed in the same 1-21 danger areas as the SFD floodlight, resulting in huge cost benefits. Since it is more efficient, it would be possible to obtain the same lighting values on the ground with a smaller number of installed devices.

In the sections below we evaluate the various types of LED failures that can lead to dangerous situations where explosive substances could be triggered, in order to evaluate scenarios and possible measures that can be taken to make these devices safe for use in Zones 1-21.

III. LED Technology

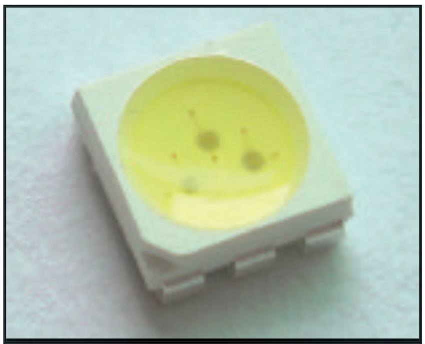
An LED (Light Emitting Diode) is a particular type of diode that emits ultraviolet, electromagnetic or infrared radiation, or radiation in the visible spectrum, when fed with a continuous electric current, by exploiting the phenomenon of electroluminescence.

There are different types of LED structures with very different characteristics; we describe below the four types currently on the market.

LEDs with THT (Through Hole Technology) are the classic LED capsules, with a diameter between 3 and 5mm normally used as warning lights or infrared signals, and sometimes for lighting, but with relatively low power for each device. Their characteristic is that of having the contacts (anode and cathode) made of metal wires that are inserted into the holes of a printed circuit board and then soldered in the assembly phase. In these LEDs, the chip is soldered and electrically connected to a reflective metal cup, a continuation of the metal filament that constitutes the cathode. The chip is connected to the anode through a thin gold wire. The structure is then encased in a epoxy plastic resin (see below).

LED THT

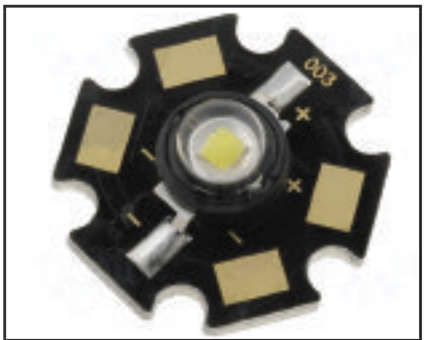
SMD (Surface Mounted Device) or SMT (Surface Mounted Technology) LEDs are a direct evolution of THT LEDs. In this technology, the electrical terminals are placed laterally to the housing and consist of small metal plates (see below).



LED SMD

High lighting efficiency LEDs, for this reason referred to as **Power LEDs** (see below). are capable of emitting a luminous flux greater than previous models.

One or more chips, generally larger than normal ones, are placed inside the casing made of plastic or ceramic material. The system is enclosed in a transparent dome of silicone material and often surmounted by additional optics that focus the light and protect the LED. A characteristic is the need to use a heatsink of a suitable size in relation to the power of the device, to ensure that the temperature of the LED is kept below the limits set for the optimal operation of the device [2].

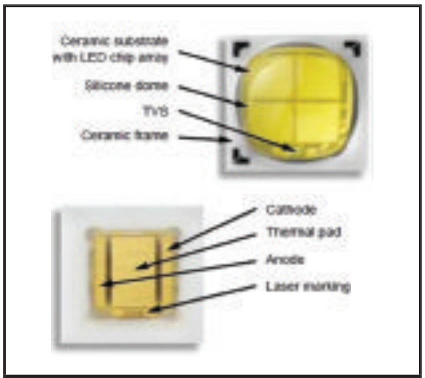


Power LED mounted on a Star PCB

With the **"FLIP chip" LED** system (see top right), the semiconductor forming the p-n joint does not need a filament (or filaments) made of gold for electrical connection. The chip is connected "upside down", in other words the contacts of the epitaxial layers of the junction are at the base of the chip, as well as welded directly to the anode and cathode, placed at the base of the housing [3] [4] [5].

This technology offers certain advantages in terms of robustness and performance.

Heat dissipation is more efficient by about 25% [6] [7].



FLIP chip LED

IV. Cause and analysis of LED failures

LED and Power LED devices are very robust and reliable, especially when compared with more traditional light sources. However they are not free from faults, albeit increasingly rare compared to other types of lighting.

Possible faults involve the outer casing and internal components. The cause of damage is mainly due to a current value that is too high, or excessive heat or mechanical stress. The main effects are a decrease in the luminous efficiency of the device and in rarer cases, the complete breakdown of the LED [8].

The following are the two groups of possible faults:

A. LED casing failures:

A.1 Epoxy resin degradation;
A.2 Mechanical stress caused by deformation of the covers;
A.3 Phosphor degradation.

B. Semiconductor and LED metallic parts failures:

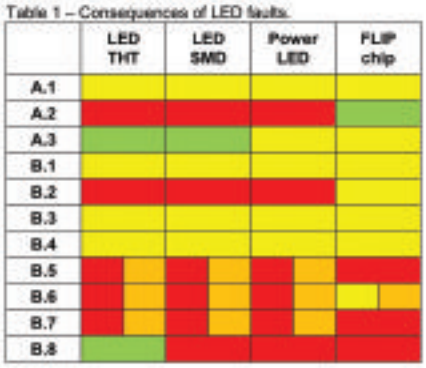
B.1 Nucleation and dislocation;
B.2 Electromigration;
B.3 Glass passivation;
B.4 Current crowding;
B.5 Electrostatic discharge (ESD);
B.6 Electrical overstress (EOS);
B.7 Reverse polarisation;
B.8 Moisture and popcorn effect.

The possible consequences of each failure have been defined for each type of LED (See Table 1, below):

- Open circuit (red) is a serious consequence which may result in the possible ignition of an explosive atmosphere;
- Short circuit (orange) is a serious consequence which may result in the possible ignition of an explosive atmosphere;
- Degrading (yellow) only involves a reduction in the luminous output and a decrease in luminous efficiency, but no possible cause of ignition of an explosive atmosphere;
- Not applicable (green) does not result in any consequences, since the fault is not considered applicable to the type of LED considered.

According to the constructive characteristics of each type of LED, performance degradation could lead to an open circuit condition or a short circuit condition. FLIP chip LEDs cannot have an open circuit condition, because there is no gold filament. The only open circuit condition is represented by "Moisture and Popcorn effect" failure, but it is imputable to PCB and not to LED. It may happen with particularly intense electrostatic discharges, also depending on the size and robustness of the specific LED.

Table 1 – Consequences of LED faults



As can be seen from Table 1 (above), the FLIP chip LED is the one that shows the lesser number of open/short circuit conditions, and, therefore, the possible triggering of minor sparks and/or high temperature. These conditions can only occur for failures B.5, B.6 and B.7.

Unlike the other three types of LEDs, the FLIP chip degrades in terms of optical efficiency, and this is mainly due to the total absence of an internal gold filament, which makes the device intrinsically safe.

V. Conclusions

LED technology has demonstrated and still demonstrates good characteristics in terms of quality, reliability and stability. Its intrinsic characteristics, from the structure to the low current and voltage values, offer particularly high safety levels.

Most defects and failures involve the atomic structure of the materials they are made of, but they are increasingly rare due to the evolution of the technologies.

In any case, these are failures that do not affect the device's safety, but only its efficiency.

Real problems may arise in electrical and thermal terms. There is no possibility of arcs or sparks, and they can be installed using small and cheap electronic devices, which protect the LED from overcurrent and overvoltage coming from the power supply, or even by electrostatic discharge. If the atmosphere contains gas, vapours, combustible or potentially explosive dust, a spark is likely to trigger these atmospheres. The danger can be partially avoided by using a Power LED with "FLIP chip" technology, where there is no inner filament (gold thread). This type of Power LED therefore answers the need for safety at a low cost for LED devices to be used in areas with an explosive atmosphere. In any case, these LEDs cannot be used alone in potentially explosive areas, but they can be used, together with other overcurrent or surge protection devices (fuses or breakdown fuses), effectively in Ex-e devices. These components can easily be installed on PCBs or positioned in the outlet of the driver, certifying them with the same protection method. In particular, resin is recommended (Ex-m).

Moreover, temperatures may be managed using appropriate cooling systems, with the right level of power and with the right size for the light's structure.

There are no current standards that cover this subject; in particular the IEC60079-7 4th Edition standard (Ex-e increased safety type of protection) does not even consider the LED source. The 5th edition of the same standard, currently under discussion and review by the various member states, which may be published in 2015, only marginally deals with LED light sources. This article therefore aims to be a starting point for international standard working groups to enable the correct evaluation of LED light sources.

VI. Bibliography

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