

# Filled polyaluminosilicates application as dielectric layers in car headlight module design to provide required temperature conditions

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**Abstract.** The simulation results of two LED light source designs of a car headlight module have been obtained. The headlight modules, where a filled polyaluminosilicate has been used as an intermediate heat-conducting layer, have been experimentally obtained. It has been found that the design with the filled polyaluminosilicates as dielectric layers has much higher thermal conductivity and can provide necessary temperature conditions compared to the classic design. The simulation results coincide with the experimental research results.

## 1. Introduction

Automobile transport is an integral part of every person's life in the modern world and should ensure not only the safety of a driver and passenger but also that of a pedestrian in any weather and at any time of the day or night. A modern car is equipped with a large number of different driver's assistants designed to reduce an emergency risk on the road. However, no one of them is able to replace the driver completely. Road safety, first of all, depends on the driver's experience and speed of reaction and is impossible without the proper amount of the information about a traffic situation, most of which the driver receives by their organs of vision. Car headlights are designed to help the driver at night time and in poor visibility conditions [1].

Currently, LED light sources having such advantages as a long service life and high light intensity gradually displace the traditional light sources used in automobiles.

The main requirements for the modern LED engineering market are to reduce energy consumption and to increase luminous flux, service life, and heat removal. One can achieve the mentioned characteristics by using new materials and implementing modern technologies [2]. First of all, this requirement relates to the LED light source design, namely the materials that are used as intermediate layers to bond chips and LEDs to a heat-removing base.

Despite the fact that the energy efficiency of LED light sources is a sequence higher than that of traditional halogen filament lamps and gas-discharge xenon ones, most of the consumed energy is converted into the dissipated heat (about 70%) [3]. At the same time, LED light sources unlike traditional light sources are sensitive to high temperatures. When the operating temperature rises above 80°C, the LED energy efficiency decreases by approximately 15% compared to the LED temperature at room temperature [3].



The modern domestic technologies to manufacture headlight module designs use mainly imported conducting adhesives and dielectric compositions as intermediate layers to bond LEDs. The market analysis indicates that the most available conducting composition is EPO-TEK H20E-175 produced by Epoxy company with a specific electrical resistance of  $4 \cdot 10^{-6}$  Ohm $\times$ m. Namics and Ferro companies offer silver-based pastes with high thermal conductivity and low electrical resistivity.

The dielectric adhesives produced by Namics and Dow Corning with a thermal conductivity of up to 2.4 W/m $\cdot$ K and an adhesive strength of up to 25 N/mm<sup>2</sup> are available. The chip soldering technology on a heat-removing base is used along with heat-conducting pastes and adhesives, but soldering is not possible in a number of designs [2, 4].

The main disadvantages of the mentioned materials are their high cost, the limited choice of LED device support substrates, which they can be applied on, high sintering temperatures, and expensive equipment used for their production. The manufacturers of LED devices are constantly looking for new functional composite materials that meet modern requirements. The need for new composite materials, which are highly resistant to mechanical stress, aggressive environments, various radiation types, extreme vacuum, high pressure, and high or low temperatures, encourage us to look for new approaches to synthesize polymers and develop composites that meet these requirements. The traditional methods to synthesize composite materials do not always allow achieving the necessary performance characteristics, especially in cases where the materials are structured by nanoparticles.

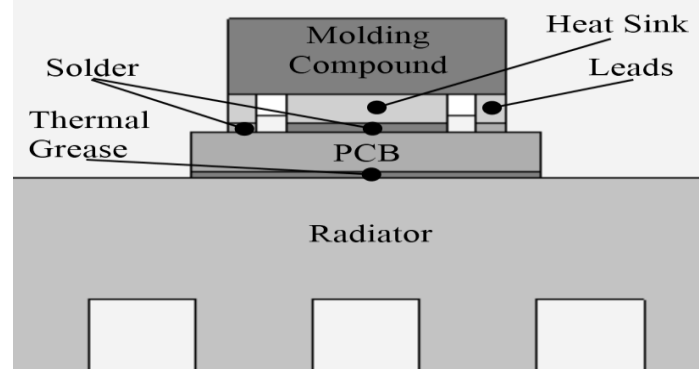
In addition to the above mentioned, there is a problem to manufacture the headlight modules, the design of which has a complex geometric shape. The intermediate layer application on such a form is difficult due to the characteristics of the used materials. Thus, ink-jet printing by the materials with different structures and chemical properties eliminates many problems encountered when printing layers and topologies on complex-shaped parts. These technologies accelerate manufacturing of a part and then of a device and eliminate the problem of excessive material consumption. The additive printing methods also suit better for manufacturing parts of a larger area in comparison with the commonly used methods. Thus, 3D printing allows manufacturing the headlight module designs of a larger size than the commonly used methods [4].

The study objective is to adapt and use the developed filled polyaluminosilicates (FPAS) as dielectric layers in the car headlight module design to provide the necessary temperature conditions in the p-n-junction area of the emitting chips.

## 2. Experiment

It is important to provide the necessary temperature conditions of the emitting chips for the effective operation of a LED light source. An effective method to solve these problems is the preliminary simulation of the headlight module designs.

Currently, the most effective method to remove excess heat from a high-power LED is to transfer it to a printed circuit board with a metal base followed by installation on a radiator (Figure 1).



**Figure 1.** Classic design diagram of car headlight module with heat transfer level indication (PCB – printed circuit board)

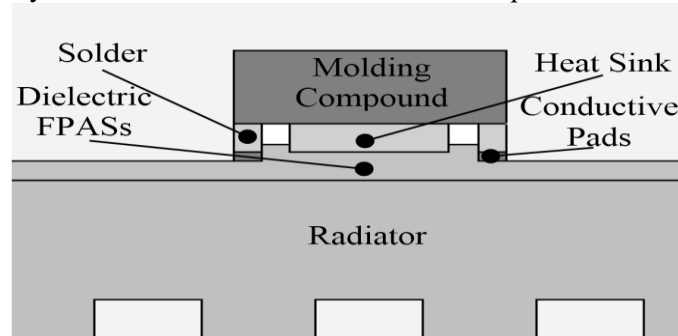
Let us consider several levels of heat transfer in the typical LED light source (Figure 1).

Level 1: heat transfer from the LED to the circuit board or base. This level is characterized by a very small heat flux area and a relatively large amount of transferred heat. Thus, we need a material that provides minimal heat resistance in the surface contact area to ensure efficient heat transfer. The LED heat-removing base is often bonded or soldered to the board to ensure heat transfer at the first level. Soldering is a good method to transfer heat, since the thermal conductivity factor of the typical solder is  $85 \text{ W/m}\cdot\text{K}$ . However, this method application is limited due to technological features in some cases. Adhesive joints also have several disadvantages such as low thermal conductivity, sealing material degradation, etc.

Level 2: heat transfer from the board (module) with LEDs to the radiator or other heat dissipating surface. This level is characterized by a large heat transfer area and a less powerful specific heat flux in comparison with the considered earlier first level. The materials with relatively low thermal conductivity (within  $2 \text{ W/m}\cdot\text{K}$ ) are mainly used to ensure heat transfer at the second level. Silicone heat-conducting pastes, adhesives, substrates or compounds listed above can be used as the heat-conducting material (depending on a product design).

The first and second heat transfer levels coincide when the LEDs are mounted directly on the radiator (Figure 2). In this case, it is necessary to use heat-conducting pastes or adhesives with high thermal conductivity as a heat-conducting material.

Thus, the polyaluminosilicate filled with a highly dispersed filler with a thermal conductivity of  $131 \text{ W/m}\cdot\text{K}$  developed by us has been used to manufacture the experimental headlight module.



**Figure 2.** Design diagram of car headlight module with developed filled polyaluminosilicates and heat transfer level indication

### 3. Results and discussion

The preliminary simulation of the LED light source designs has been carried out by ANSYS R18.1 software environment. A powerful  $10 \text{ W}$  LED has been chosen as the light source. The filled polyaluminosilicate (fig 3b) and solder joint (fig 3a) have been chosen as intermediate layers, and the aluminum radiator of a deliberately larger size has been chosen as the supporting heat-removing structure to estimate the thermal conductivity of the LED light source design and to mount LED emitting chips.

Figure 3a shows the simulated temperature profile of the LED light source classic design. The following values of the construction material thermal conductivity have been taken for the simulation:

- Soldering area thermal conductivity (level 1, fig 1) is  $85 \text{ W/m}\cdot\text{K}$ ;
- Printed circuit board thermal conductivity is  $23 \text{ W/m}\cdot\text{K}$ ;
- Heat-conducting paste thermal conductivity between the printed circuit board and the radiator (level 2, fig 1) is  $7 \text{ W/m}\cdot\text{K}$ .

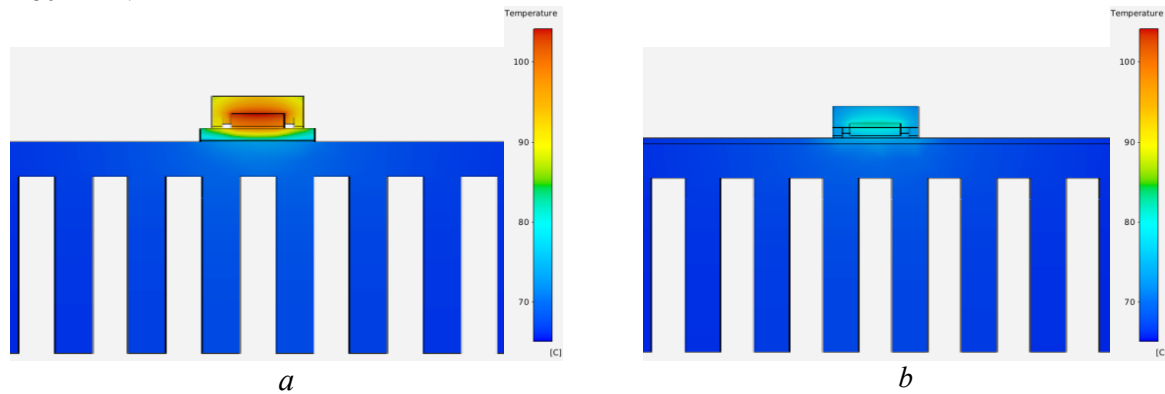
According to the simulation results, the chip temperature in the emitting chip p-n-junction area is  $104.39^\circ\text{C}$ .

Figure 3b shows the simulated temperature profile of the LED light source design with the filled polyaluminosilicate as an intermediate layer. The following values of the construction material thermal conductivity have been taken for the simulation:

- The filled polyaluminosilicate (dielectric layer) thermal conductivity is  $131 \text{ W/m}\cdot\text{K}$ ;

- The conductive topology thermal conductivity is 390 W/m·K.

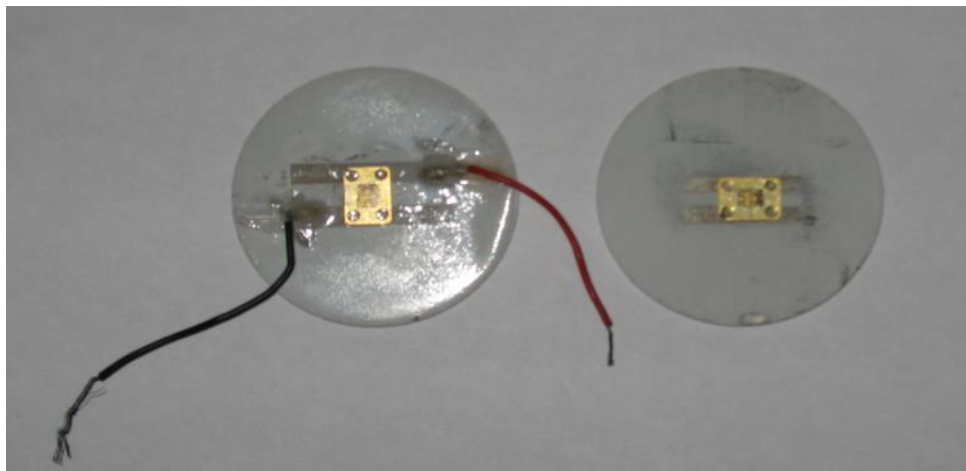
According to the simulation results, the chip temperature in the emitting chip p-n-junction area is 80.14°C.



**Figure 3.** Photographs of headlight module designs with simulated temperature profile: *a*) LED device classic design (fig 1); *b*) LED device design with filled polyaluminosilicate as intermediate layer.

#### 4. Conclusion

The simulation results of two LED light source designs of the automobile headlight modules (fig. 1 and 2) show that the design with the filled polyaluminosilicates as dielectric layers (fig. 4) has much higher thermal conductivity and can provide the necessary temperature conditions compared to the classic design. The simulation results coincide with the experimental research results, which will be published in our next article.



**Figure 4.** Photograph of headlight module sample with filled polyaluminosilicate as intermediate layer in its design, on which conductive topologies are applied followed by gluing LEDs

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