Thermal characteristics simulation of LED emitting element containing filled polyaluminosilicate in structure as heat-conducting adhesive coating

A A Ivanov[1], K N Afonin[1] and A S Chermoshentseva[2]

[1] Tomsk State University of Control Systems and Radioelectronics, Tomsk, 634050, Russia
[2] Bauman Moscow State Technical University, Moscow, 105005, Russia.

E-mail: alexchemtsu@rambler.ru

Abstract. The modern development of a general-purpose lamp is focused on using LED-emitting elements in its structure. Despite the fact that the general-purpose lamp development is a well-studied field of lighting engineering, there is a problem to improve the removal and dissipation efficiency of the generated heat into the environment with the beginning of LED emitting structures use in such a lamp. The computer simulation results of the emitting structures of a general-purpose LED lamp containing various materials that contribute to heat removal in a LED linear design are considered in the article.

1. Introduction

Despite the fact that more than one hundred years has passed to our time since the discovery of the generated by a semiconductor material emission, semiconductor lighting engineering continues to develop rapidly. The development is aimed both at increasing the generated emission intensity, which leads to the appearance of high-power emitters, and at creating more known form factors of emitting devices for a human. To such form factor, one can relate the known physical configuration of a filament lamp, which is a glass bulb with a luminous element inside. In both cases, the used structural solutions have limitations on the generated emission intensity that is due to the strong negative susceptibility of a semiconductor emitter to emissivity deterioration with temperature increase up to overheat and performance loss due to the Joule heat.

A method to remove heat from the emitting element followed by the dissipation in the environment with the use of the materials with high thermal conductivity, for example copper or aluminum, is used to manufacture high-power semiconductor emitters. When one develops a semiconductor emission source with the shape close to a filament lamp, it is practically impossible to use a massive radiator, since such a lamp has a closed structure, the so-called filament lamp. It makes it difficult to remove heat from the emitting semiconductor (chip) with subsequent dissipation in the environment. The fact that complicates the situation is that glass, which is a very poor heat conductor, is the main material by means of which the closed volume is created. Therefore, the problem to maximize the heat removal efficiency is very acute. It is known that the LED element operating temperature directly affects its operating mode and service life [1, 2].

The standard filament lamp is a glass bulb, inside of which from four up to eight linears (LED filaments) are located. Twenty-eight blue emitting semiconductor chips are located on the linears.

To obtain white emission the chips are coated with a layer of the optically transparent sealing polymer material with phosphor powder that converts the portion of blue emission into yellow one. A mixture of blue and yellow emissions produces white emission.

The space inside the lamp is filled with helium to increase the heat removal efficiency from chips and LED filaments.

The study purpose is to determine the influence of factors (the chip location on the substrate, the substrate material characteristics, and the physicochemical adhesive properties) on the overheat of the emitting planar semiconductor GaN chip.

2. Experiment

To increase the heat removal efficiency it is possible to use various adhesives, with the help of which the semiconductor chips are glued to the LED linear base. It is also possible to make the LED linear base of various materials, for example sapphire, aluminum, and ceramics. A change in the heat removal efficiency is also possible due to the change in the semiconductor chips location on the linear.

It has been decided to compare the results under the equal conditions of heat removal and dissipation when analyzing the filament lamp design features and set tasks.

Due to the fact that blue semiconductor chips are used in a filament lamp, their efficiency is usually 45-50%. It has been experimentally found that the most effective method of heat emission is heat generation in the volume of the chip active area, which is 0.35 W. Since it has been determined that one linear with semiconductor chips consumes 0.7 W of electrical power, and 50% of this power is emitted in the form of emission and removed out of the lamp. It is known from the experimental measurements that the thermal conductivity of the compound and phosphor mixture is much less than that of a metal linear. Consequently, we neglect the heat removal through the phosphor. In addition, there is no need to consider them in simulation due to the exclusion of heat removal through the compound and phosphor mixture.

The ES–EABCF08Q chip model (480 by 200 μm in size and with a total thickness of 130 μm) by Epistar Company has been used as the emitting element. The emitting elements have been glued homogeneously at the substrates of various chemical nature along the whole length with heat-conducting adhesives (Loctite Ablestik 84–1LMIT1, Tok-2, Diemat DM6030HK, Dow Corning, and our own filled polyaluminosilicate (FPAS)) with various properties and a layer thickness of 30 μm [3, 4].

The chips with various bases have been arranged so that the long side of the chip is codirectional with the long side of the base.

The emitting chip model is the sequence of the following layers:
– Sapphire layer with a thickness of 124 μm;
– GaN semiconductor layer with a thickness of 5 μm;
– GaN active semiconductor layer with a thickness of 0.3 μm;
– GaN semiconductor layer with a thickness of 0.7 μm.

The temperature distribution in the entire simulated structure is possible not only after the model development but also after the boundary conditions application that specify the areas and conditions for heat emission and the areas for heat removal. The active chip areas have been chosen as a heat-emitting area. The emitted heat power is homogeneously distributed between all the chips. Taking into account that the entire structure is coated with a phosphor composition with a very poor ability to remove heat, the surfaces with various bases that are not coated with the phosphor composition have been chosen as the heat-removing areas. Such surfaces are those ones that are 3 mm from the base edge of the LED linear. Convection is used as a simplified method to remove heat from the heat-dissipating surface provided that the ambient temperature 25 °C is constant.

2.1. Experimental obtainment of LED filaments

The following materials have been chosen as the base for a LED filament: steel, sapphire, a ceramic substrate based on AlN and Al_2O_3, the AMG-6B aluminum.

The heat-conducting adhesives Loctite Ablestik 84–1LMIT1, Tok-2, Diemat DM6030HK, and Dow Corning have been applied with a screw feeder. One can get a dose with a diameter of 200 µm and less with high frequency using the screw feeder. The adhesive doses on the LED linear base have been obtained by screw dosing with the help of the Spectrum II S2-920 dosing unit (one-track version) produced by Asymtek.

A screw or Archimedean screw is the main element that influences the quality of dose formation. The material is fed from a syringe into the channel with the screw by compressed air. Then the material is forced through a needle onto the substrate surface by the normalized screw rotation. The screw rotation angle and internal needle diameter determine the dose volume. Both heads are equipped with motors with encoders and the feedback system that allows setting the rotation angle with an accuracy of 0.0095 degrees per one encoder value. The interval between the dosing points is set by an operator of the dosing unit. It corresponds to the homogeneous subsequent chip adhesion on the base. After the emitting chip adhesion the adhesive is dried at various temperatures depending on its technical characteristics.

The filled polyaluminosilicate developed by us has been applied on LED linear bases by the pneumatic method of 3D aerosol printing with the Aerosol Jet 15EX 3D printer of Neotech AMT company. The applied polyaluminosilicate filled with a highly dispersed filler is injected into an aerosol generator. The pneumatic aerosol generator allows applying the material with a wide range of viscosity and various diameters of solid particles. A working gas (nitrogen or air) is injected into the pneumatic generator through the narrow Venturi hole under pressure to produce the aerosol. The pressure increase causes the ink rise along the channel, and the aerosol is produced by the gas-ink contact. The exit pressure decreases, the gas velocity increases significantly. Consequently, fluid is sucked into the reduced pressure area through narrow channels from a chamber reservoir. When the liquid meets the air stream by the gas jet action, it is broken into small particles. These particles vary in size from 15 to 500 µm, it is the so-called *primary* aerosol. The particles then collide with a *flap* (plate, ball, etc.) that results in the *secondary* aerosol formation in the form of ultrafine particles ranging in size from 0.5 to 10 µm (about 0.5% of the initial aerosol). The secondary aerosol is then inhaled, and a large proportion of the primary aerosol particles (about 99 %) is deposited on the inner walls of the chamber and is drawn back in the aerosol formation. The aerosol jet is focused at a distance of up to 5-15 mm from a nozzle that allows applying the ink on a three-dimensional base. It can be technically achieved by moving the printing head along three axes (x, y, z) and by inclinating the base along two axes. After the filled polyaluminosilicate is applied, the emitting chip is glued followed by the ultraviolet, infrared or in a heating furnace material drying depending on the number of layers and the base, on which they are applied [4].

After obtaining the LED linear samples with various bases and gluing emitting chips on them by different adhesives and on the materials of various chemical nature, an experimental estimation of the obtained sample efficiency has been made. The estimation results are given in our earlier articles. It is shown that the LED linear efficiency is higher at the metal base with the polyaluminosilicate applied on its surface, on which the emitting chips are glued, in comparison with other experimental samples.

3. Results and discussion

Temperature distribution profiles have been obtained as a result of the thermal characteristics simulation of the LED emitting elements in the specific models in a thermodynamic equilibrium state and with each set of changing parameters.

Figures 1-6 show a general view of temperature distribution in the simulated structures volume.

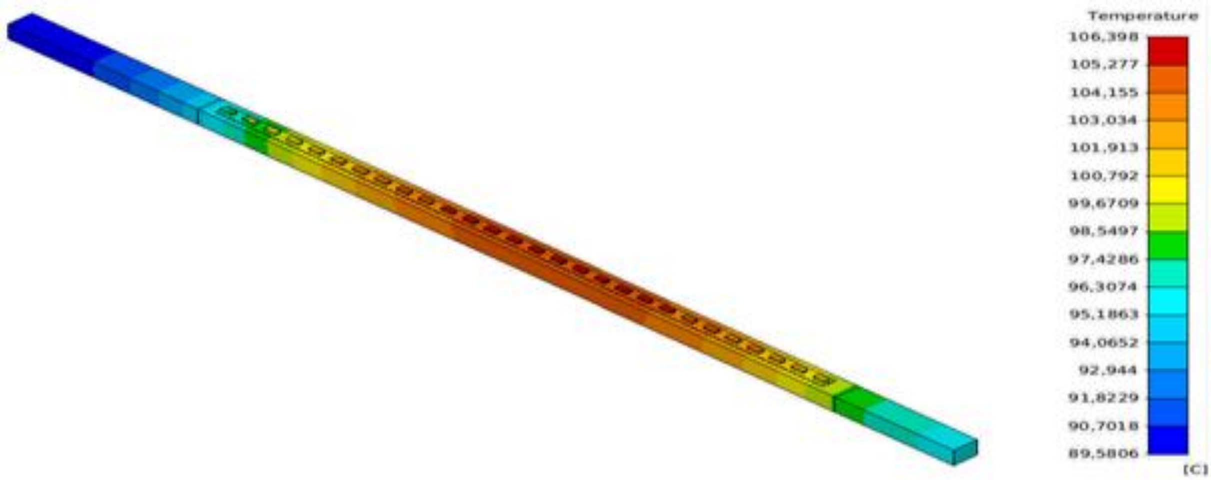

Figure 1. Photograph of LED linear with sapphire base with emitting chips glued on it by Loctite Ablestik 84–1LMIT1 heat-conducting adhesive with thermal conductivity 9 W/m·K.

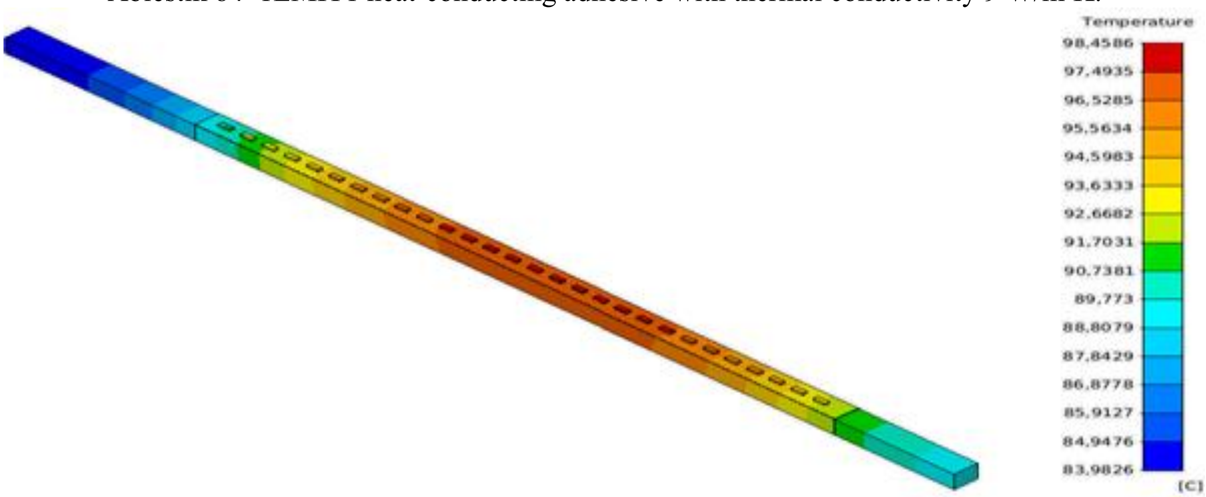

Figure 2. Photograph of LED linear with sapphire base with emitting chips glued on it on filled polyaluminosilicate with thermal conductivity 130 W/m·K.

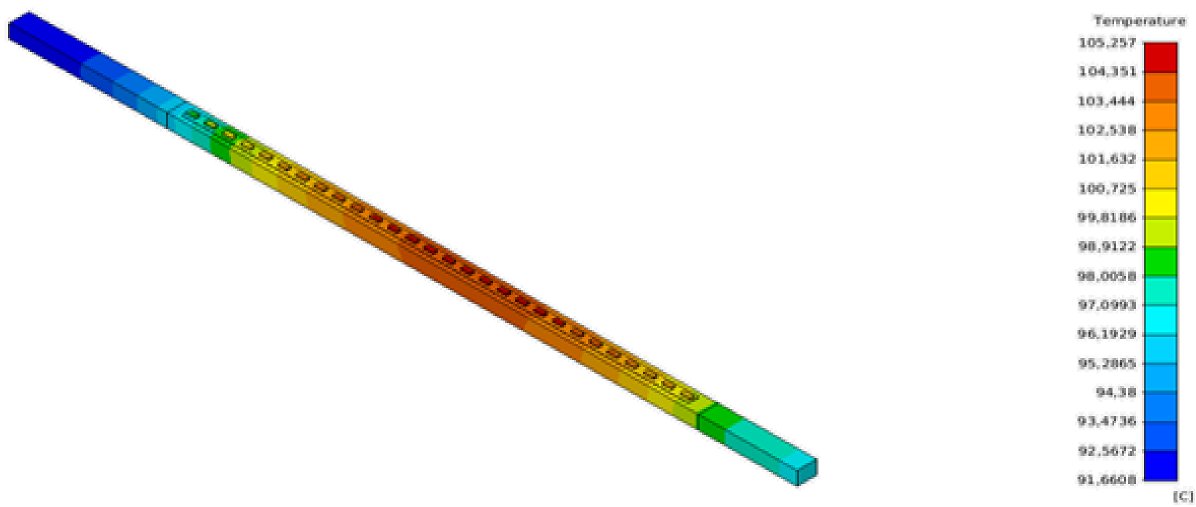

Figure 3. Photograph of LED linear with steel base with emitting chips glued on it by Loctite Ablestik 84–1LMIT1 heat-conducting adhesive with thermal conductivity 9 W/m·K.

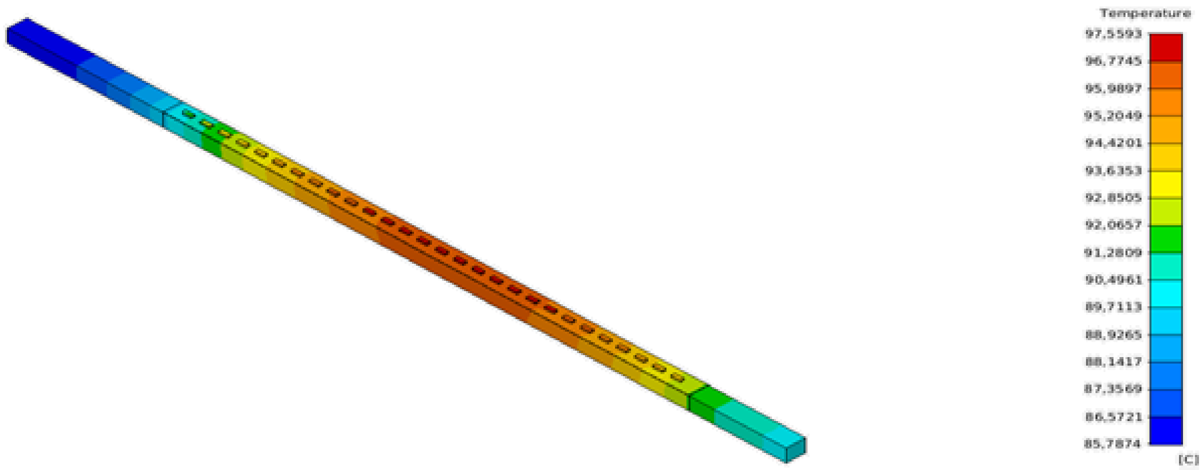

Figure 4. Photograph of LED linear with steel base with emitting chips glued on it on filled polyaluminosilicate with thermal conductivity 130 W/m·K.

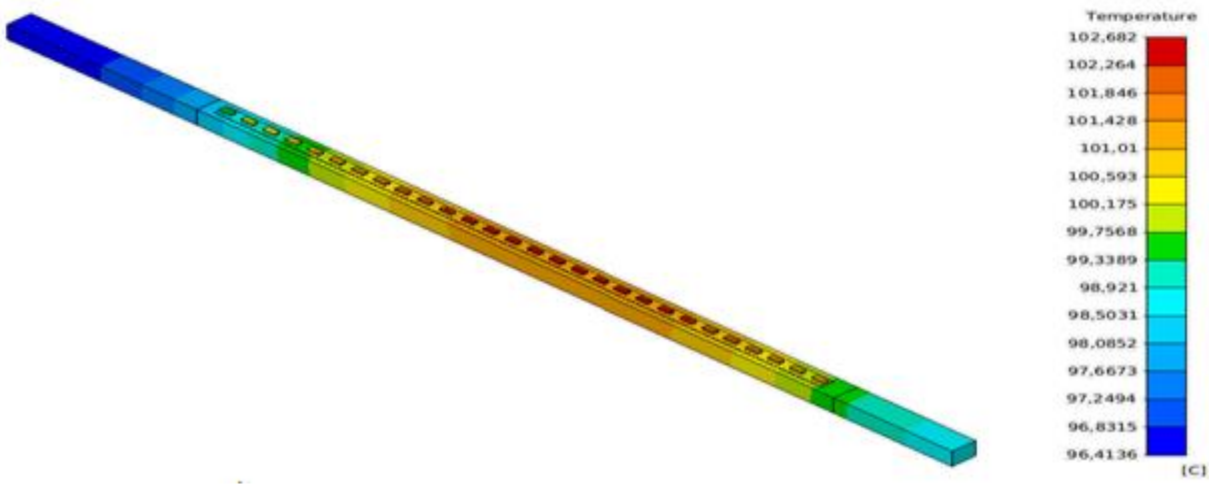

Figure 5. Photograph of LED linear with aluminum base with emitting chips glued on it by Loctite Ablestik 84–1LMIT1 heat-conducting adhesive with thermal conductivity 9 W/m·K.

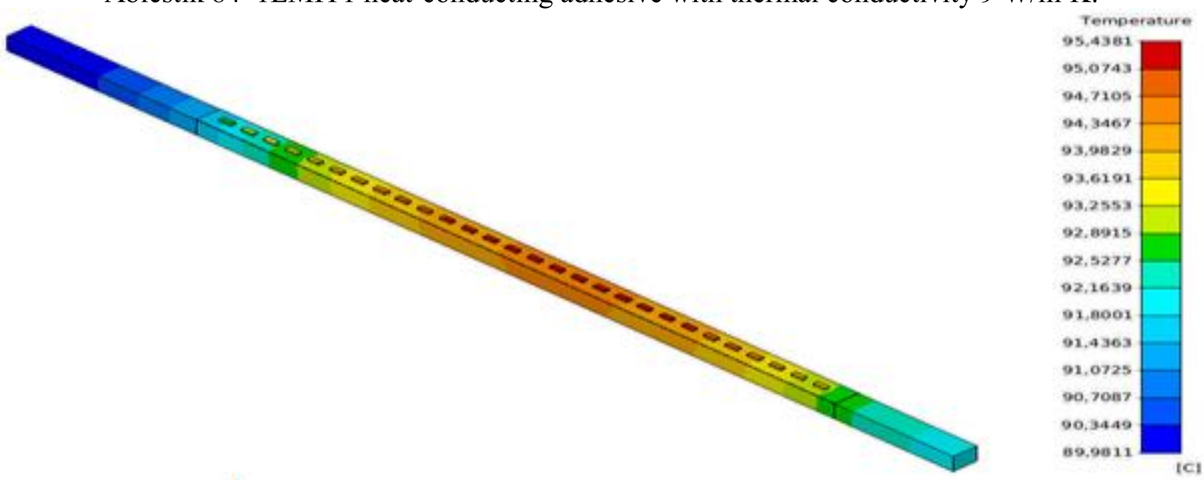

Figure 6. Photograph of LED linear with aluminum base with emitting chips glued on it on filled polyaluminosilicate with thermal conductivity 130 W/m·K.

Table 1 shows the maximum (T_{max}) and minimum (T_{min}) temperatures in the simulated structures depending on the material used as an adhesive and supporting structure respectively, provided that the chip long side is parallel to the long side of the supporting structure.

Table 1. Simulation results to arrange chip along long side of base.

Base	Adhesive	T_{min}, °C	T_{max}, °C
Sapphire	Loctite	89.5806	106.398
Steel	Loctite	91.6608	105.257
Aluminium	Loctite	96.4136	102.682
Sapphire	FPAS	83.9826	98.4586
Steel	FPAS	85.7874	97.5593
Aluminium	FPAS	89.9811	95.4381

4. Conclusion

Taking into account the results shown in Figures 1-6 and Table 1, we can conclude that the combination of the base material and adhesive has different heat removal efficiency and heat-conducting characteristics. However, the most suitable variant to increase the heat removal efficiency from the chip with subsequent dissipation into the environment is to use the aluminum base and material with higher thermal conductivity based on the filled polyaluminosilicate as an adhesive.

When analyzing the results of the chips arrangement on the supporting structure (base), one can discover the regularity, according to which the chip long side should be placed in the direction of the long side of the supporting structure.

Acknowledgement

The reported study was funded by RFBR according to the research project no. 18-29-11018\19.

References

[1] Kang B D, Park K S, Yong G J, Lee J G and Son S M 2005 *KSAE spring and autumn conference* **5** 868
[2] Kang B D 2006 *KSAE* **28 (2)** 82
[3] Marx P LED-Anwendungstechniк *Licht* 2009 **3** 184-188
[4] Chen C H, Hargis M, Woodall J M, Melloch M R, Reynolds J S, Yablonovitch E and Wang W 1999 *Appl. Phys. Lett*. **74** 3140
[5] Ivanov A A, Polyushko V A and Khomykov A Yu 2019 *IOP Conf. Series: Materials Scienc and Engineering* **537** 022020