THERMAL SIMULATION OF POWER LED DIODE IN COMSOL ENVIRONMENT

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Abstract

The aim of this paper is to build a dynamic thermal model of power LED for simulation environment COMSOL. The dynamic thermal model was based on technical and application manufacturer's data of power light emitting diode. In this way the assembled electrical and thermal model of power LED was simulated in a dynamic process of load within Comsol simulation program. The simulation results have been subjected to verification in the real environment. Measurements of the real LED showed good agreement with the simulation results.

1   Principle of power LED

Technical solutions of advanced power LEDs make them suitable for their widespread use in lighting techniques. The reason is their high efficiency of conversion of electrical energy to optical as well as their long life. Despite these positive properties, power LEDs have quite large electrical losses that are transformed into heat. It is necessary to take thermal energy of electrical losses from the LED chip into the environment through effective heat sink. The contribution offers an opportunity to obtain the basic information about a thermal field of specific power LED HUEY JANN ELECTRONIC HPB8C-49KYWHB [8] simulated in the COMSOL Multiphysics program [1].

Fig. 1. Display of power LED diode with heat sink and without it

Fig. 1 shows a construction of a power LED (right) and the same diode with the addition of sink (left). Power dissipation heats the LED chip and the diode housing. It is needed to dissipate a heat outside the LED chip so as not to damage components (maximum junction temperature Tj must not exceed 150 ° C). LED power dissipation is related to the specific output of LED, which has a value of 125 Lm / W at an ambient temperature Ta = 25 ° C.

2   Heat dissipation

Power dissipation, which is released into the environment in the form of thermal energy, occurs in a volume of semiconductor device by the action of flowing current. It is primarily the loss in a permeable state (voltage drop at the part and forward current). For the power LED, it is necessary to set the dissipation. The common formula is used to calculate active power in integral form [4]:

$$P = \frac{1}{T}\int_0^t v(t)\,i(t)\,dt \qquad (1)$$

where v(t), i (t) are the instantaneous values of relevant electrical quantities, and T is their period. The product of v(t). i(t) represents the so-called instantaneous power, which is an important indicator of

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heat load of the part. When using the current power supply, the power dissipation calculation is obtained from the following formula [9]:

$$P_e = \frac{1}{T}\int_0^t v(t)\,i(t)\,dt = \frac{1}{T}\int_0^t \left[V_p + \left(R_d\,i(t)\right)\right]i(t) = V_p.I_{str} + R_d.I_{ef} \tag{2}$$

where V_p [V] is the threshold voltage, R_d is the differential resistance, which may be determined by using the current-voltage characteristic, I_{str} [A] denotes the mean value of current at the time, I_{rms} [A] is the rms value of the current.

In case P_e is input electric power and P_{opt} is the output optical power, thermal power dissipation P_s is obtained:

$$P_s = P_e - P_{opt} \tag{3}$$

3   Description of the LED structure

LED diode contains a chip with power 1W, which reaches a luminous flux of 125 lm. The chip is placed in a housing that provides mechanical support and heat-links it to a small metal lead of the bottom. In the housing, there are placed so-called "Gold Wire" leads connected to the anode and cathode. The silicone lenses over the chip extract light generated inside the LED chip. The lenses are designed for a wide range of types. Lens is made from epoxy resin or acrylic polyester. The material, from which it is produced, has a high refractive index. The housing electrically isolates the thermal pad of the diode from the cathode and anode. In this way it is possible to join together the LEDs in series. The whole module is mounted on an aluminum star-shaped substrate, so called star (see Fig. 2).
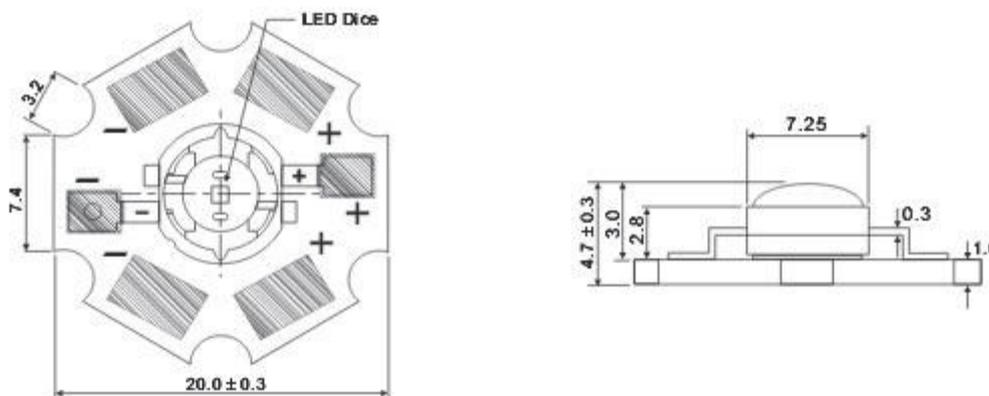

Fig. 2. Construction drawing of power LED [8]

4   The thermal power LED model

COMSOL Multiphysics is software for modeling and solving of all kinds of scientific and engineering problems. It is intended primarily for scientific and research purposes. With this software it is possible to extend the classical physical models for multi physics models that address simultaneously several physical phenomena. Thanks to the offer of the basic physical model with defined physical quantities, such as material properties, energy, flow and load sources, we can reduce the model formation time with equations for the studied physical phenomenon. Such a solution does not require very detailed knowledge of mathematics and physics. The COMSOL used to describe the PDE mathematical application modes, in which we can carry out the various analysis, including stationary and time dependent analysis, linear and nonlinear analysis.

The first step is to create a geometric model. It is possible to create the required model by CAD tools that are integrated directly in the graphical editor. The geometric model can be created also by

import to COMSOL, using Import CAD Data From File. Parameters were obtained from the manufacturer, ensuring that the model most closely resembles the real parts.
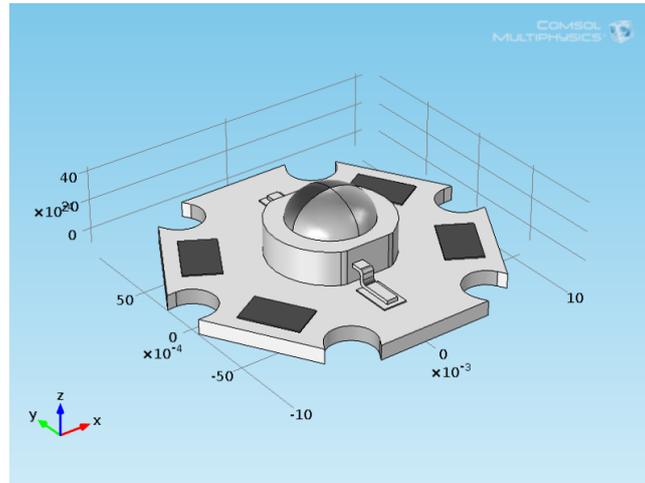

Fig. 3. The geometric model of power LED

4.1 Enter of boundary conditions and properties of domains

The next step of the model creation is setting of materials in all domains of power LED. The Material library, which is part of thermal module of COMSOL [2], offers setting of thermal properties of individual subdomains [7]. Tab. 1 lists the materials used in the different domains.

Tab. 1. Assignment of material parameters to particular domains

Domain	Material	Thermal conductivity	Heat capacity	Density
Lead	Cu	400[W/(m*K)]	385[J/(kg*K)]	8700[kg/m^3]
Housing	Al2O3	22,3[W/(m*K)]	650[J/(kg*K)]	3980[kg/m^3]
Chip	Silicon	163[W/(m*K)]	703[J/(kg*K)]	2330[kg/m^3]
Contact washer	96Sn-4Ag	58[W/(m*K)]	240[J/(kg*K)]	7360[kg/m^3]
Sink	Al	160[W/(m*K)]	900[J/(kg*K)]	2700[kg/m^3]

Domain of LED chip itself is loaded with volumetric power dissipation [5]:

$$Q = \frac{P_S}{V_{ch}} = \frac{0.7[W]}{9.317484e-10[m^3]} = 7{,}5128e8 \ [W/m^3], \tag{4}$$

where P_S characterizes power dissipation of LED and V_{ch} is the volume of the chip in which arises thermal energy. Other domains have Heat Source set to zero. It means that they are not a heat source. The boundaries between LED domains are set to Continuity mode. The boundaries between the LED and environment are set to the laminar air flow, while the orientation of the bottom part of the LEDs washer corresponds to the XY plane. The air flow is in the z axis direction.

In the next step of the task solving it is necessary to create the computing grid in the geometric model. To generate FEM grid we set the grid density to normal. 25,224 elements were generated. The view of the grid is in Fig. 4.
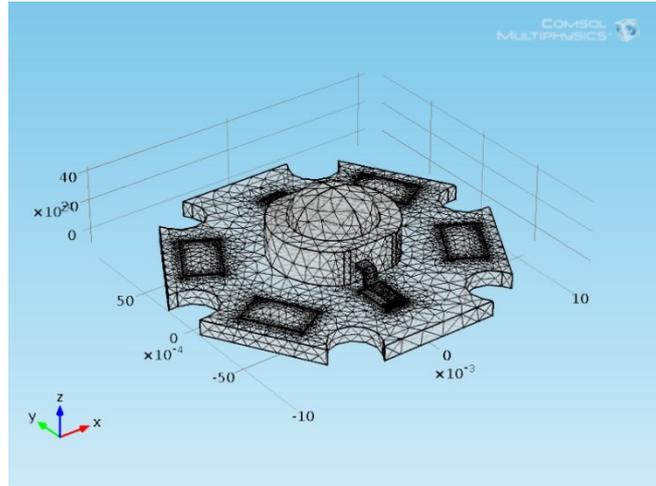
Fig. 4. Generated computing grid of the LED

5 Results

We have performed the thermal simulation under time-dependent solution mode. We have set the time and the interval for the solution run. We have chosen a total time of 1000 seconds with a simulation interval of 30 seconds. The total time is needed in order to achieve a steady state temperature. In Fig. 5 we can see the thermal diode array in the color graphics at the time of 800 s. The heat transfer from the chip to the washer and a LED lens is seen from the model. The scale showing the temperature range and maximum and minimum temperatures of the simulated object is displayed next to the simulated object.
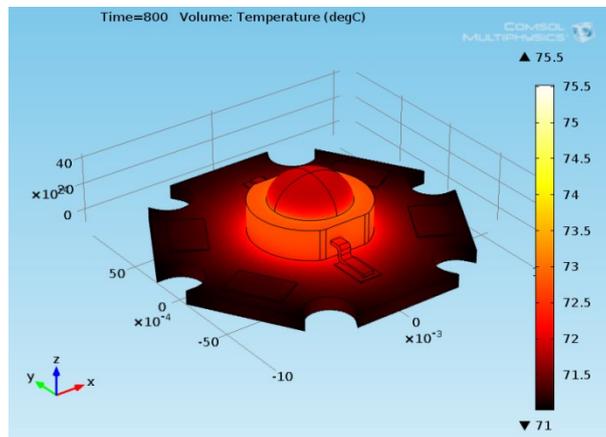

Fig. 5. 3D Temperature field of power LED diode at
simulation time 800 s.

We performed a verification of the simulation results [6] using a thermovision camera FLIR SC640, which was placed in the hole on top of the thermal measuring chamber (Fig. 6). The measured model was placed in the middle of the chamber. To ensure stability and exact position of the sample in the middle of the chamber, we fixed the sample using the nylon, which was mounted along the length of the chamber. We also placed temperature sensor in the chamber, which was recording the ambient temperature during the measurement. The models were powered by the laboratory current source, which we set for single LED to 300 mA and the supply voltage 3V. The results of measurement

confirmed sufficient accuracy of the assembled thermal model of the power LED. The temperature deviation did not exceed 10.2% in the time interval of measurement and simulation.

Fig. 6. Workplace of the thermovision camera
temperature sensing

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