The effect of coolant temperature at the inlet on heat transfer enhancement for LED module cooling by a micro-jet system.

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Abstract. Jet cooling is one of the effective and active methods for thermal control of electronic devices. The paper presents experimental data of the study of heat transfer during multi-jet cooling of a LED module at a power of 100 – 300 W. The influence of the coolant temperature at the inlet on the heat transfer enhancement is investigated. It is shown that with increasing power, the temperature inhomogeneity along the LED surface increases. A significant effect of the coolant inlet temperature on the heat transfer enhancement is shown. Water is used as a coolant. The surface temperature of the LED module is shown to be by 10 ℃ lower for the coolant inlet temperature of 10 ℃ in comparison with the coolant inlet temperature of 25 ℃ at a LED power of 300 W.

1. Introduction
The rapid development of electronic technology and the minimization of the size of electronic devices over the past decades have led to the need for effective cooling systems. Such systems should reduce the operating temperatures of the devices, thereby improving the reliability of the components and ensuring their high efficiency. Due to the escalation of the degree of thermal energy dissipation, it became necessary to switch from compression thermal devices to liquid cooling. Possible technologies for liquid cooling include jet and spray cooling [1, 2], single-phase cooling in microchannels, and two-phase cooling [3]. Each of them has its advantages and disadvantages. One of the most effective ways to enhance heat transfer between a solid surface and a coolant (liquid or gas) is to supply it in the form of jets to the surface.

Jet and spray cooling techniques are the most commonly used active liquid cooling technologies. Spray cooling has the highest heat removal capacity due to the boiling of liquid film and droplets [1, 2]. In recent decades, jet cooling technology has been thoroughly studied and applied for cooling of electronic devices [4,5]. In such systems when the fluid flow is ejected onto the surface, very thin hydrodynamic and thermal boundary layers form a stagnation region that causes extremely high heat transfer coefficients.

Micro-jet system was proposed for cooling high-power light emitting diodes (LEDs) by Luo&Liu [4]. Assessment of the cooling ability was carried out using thermocouples soldered to LED chips. It turned out that such cooling system is quite effective. The temperature of a 2 x 2 LED matrix with an input power of 5.6 W and an ambient temperature without using a cooling system reached 72 ℃ in 2 minutes and continued to increase sharply. When using the proposed system with a pumping rate of 9.7 ml/s, the substrate temperature remained at 36.7 ℃. Numerical optimization was carried out, and with its help the influence of the diameter of the microjets, the height of the upper cavity, the flow rate
of the liquid and the material of the device on the system performance were studied. The jet cooling device developed in [5] allowed maintaining the temperature of a copper heater at 32 ℃ at a fluid flow rate of 1500 ml/min and an output of 500 W. The lowest thermal resistance of 0.041 K/W was recorded for a fluid flow rate of 1800 ml/min. The cooling of a real LED module with a nominal power of 300 W by micro-jet system with five nozzles was experimentally investigated, and the operating limits of the LED module were shown [6].

The aim of this work is to study the influence of the coolant inlet temperature on the heat transfer enhancement while cooling the LED module by a micro-jet array system. The real LED module with a nominal power of 300 W is used for experiments.

2. Experimental setup

The experimental setup is shown in Figure 1. It consists of a cooling system, a LED module with a nominal power of 300 W, and a data recording system. Using a pump (1), the liquid is pumped into a tank (2). Then liquid is pressed by gas flow through a nozzle (7) with five holes with a diameter of 0.4 mm and impacts a LED with an area of 20 × 20 mm² (6), which is connected to a power supply (5). Air in (2) is supplied from an Atlas Copco compressor. The pressure is controlled by gas and liquid manometers. Degassed and deionized water (MilliQ) is used as a coolant. Detailed description of the setup can be found in [6].

![Figure 1. An experimental setup for the study of heat transfer process. 1 – pump; 2 – liquid tank; 3 – flow meter; 4 – data acquisition system KEYSIGHT 34970a; 5 – power supply; 6 – LED module; 7 – nozzle; 8 – PC. P, T icons indicate gas and liquid pressure gauges and thermocouples, respectively.](image)

The experiments were carried out at a pressure difference of 4 bar, which corresponded to a flow rate of ~ 500 ml/min [6]. The experiment was conducted for three different powers: 100, 200 and 300 W. Thermocouple readings were collected using a data acquisition system (4) and Agilent software (8). Temperature measurement was carried out using three K-type thermocouples (Omega) soldered
flush to the LED substrate. The thermocouples were calibrated using two reference resistance thermometers. The total error was estimated to be of 0.2 °C.

3. Results and discussion
The experiments are organized as follows: first the coolant liquid is supplied, and then LED is switched on. Otherwise LED can be destroyed. When the microjet system is supplied, thermocouples record an abrupt temperature decrease by 6 °C for the inlet temperature of 10 °C, Figure 2. When the LED is switched on (power is supplied to the LED), the temperature rises rapidly from 25 to 35 °C for power of 200 W, and up to 39 °C for 300 W when coolant inlet temperature is 25 °C. After several seconds the temperature stabilizes. When the LED module is switched on, the thermocouple records the maximum temperature increase. With an increase in the power supplied to the LED the temperature inhomogeneity over the surface of the LED module increases. The maximum temperature difference between thermocouples is about 2.2 °C for 200 W, while for 300 W the temperature difference is 3.9 °C.

Figure 2. The temperature over time for different coolant inlet temperatures. Power is of 300 W.

Figure 3. Temperature versus power for different coolant inlet temperatures.
The change in the temperature averaged over the readings from three thermocouples over the surface of the LED is shown in Figure 2. There is a significant heat transfer enhancement caused by decreasing the inlet temperature. The temperature difference on LED surface is about 10 °C for a power of 300 W and inlet temperatures of 10 and 25 °C. Figure 3 shows the temperature dependence on the power applied to LED module obtained for water inlet temperatures (10 and 25 °C). It can be noted that this dependence is linear, since for single-phase liquid cooling, the total thermal resistance is independent of the thermal load. The results obtained for different temperatures of the coolant differ on average by 8.2 °C.

Conclusions
In this work, a real LED module (not a simulated heater) with a nominal power of 300 W was used for experiments and the coolant inlet temperature influence on heat transfer was investigated. The multi-jet cooling system with five jets with diameter of 0.4 mm each was used. The LED module power was varied in the range of 100 – 300 W for two different coolant (water) inlet temperatures, 10 and 25 °C. In accordance with measurements, non-uniform temperature distribution over the LED backside increased with increasing power, showing the importance of the nozzle’s arrangement design. Subcooling of inlet liquid is shown to have a significant effect on the heat transfer enhancement. At a power of 300 W, the surface temperatures of the LED module differ by 10 °C at the inlet liquid temperature of 10 °C and 25 °C.

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