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A System for Cooling Electronic Elements with an EHD Coolant Flow

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Abstract. A system for cooling electronic components where the liquid coolant flow is forced with ion-drag type EHD micropumps was tested. For tests we used isopropyl alcohol as the coolant and CSD02060 diodes in TO-220 packages as cooled electronic elements. We have studied thermal characteristics of diodes cooled with EHD flow in the function of a coolant flow rate. The transient thermal impedance of the CSD02060 diode cooled with 1.5 ml/min EHD flow was 7.8°C/W. Similar transient thermal impedance can be achieved by applying to the diode a large RAD-A6405A/150 heat sink. We found out that EHD pumps can be successfully applied for cooling electronic elements.

1. Introduction

As electronic elements become smaller and more power consuming, more problems with dispersing waste heat arise. Nowadays, traditional cooling techniques are no longer applicable in many fields of technology because of a large size of cooling systems and their low efficiency. Currently, lack of efficient technique of heat removal from electronic elements is one of major obstructions to further miniaturization of an electronic system in such applications as computers, biomedicine, automobile and aerospace technology [1]. Therefore, over the past few decades various cooling systems for electronic elements were proposed, for example: impinging air jets [2], thermoelectric coolers [3], direct immersion cooling [4], miniature heat-pipes [5] and liquid microflow cooling systems. Compared to other cooling techniques, liquid microflow systems seem to be an ideal cooling solution in applications where high efficiency and a small size of the cooling system are indispensable. In this cooling technique, liquid coolant is introduced close to the heat critical part of the electronic element by means of micropumps. Many pumping mechanisms for microflow cooling systems were tested [6]: from traditional mechanical pumps, through phase change pumps [7], magnetokinetic pumps [8], electroosmotic [9] and finally to electrohydrodynamic (EHD) pumps.

The advantages of the EHD pumps are: non-mechanical mechanism of pumping, relatively simple design, low vibration and noise emission, low power consumption and simple control of their



efficiency by varying the applied voltage. In general, when electric field E is applied to a volume of dielectric liquid its driving force can be expressed as (1) [10].

$$F = qE - \frac{1}{2}E^2\nabla\epsilon + \frac{1}{2}\nabla\left[E^2\left(\frac{\partial\epsilon}{\partial\rho}\right)_T\rho\right] \quad (1)$$

where q is the free space charge density, ϵ is the liquid permittivity and ρ is its mass density. The first term of equation (1) represents the Coulomb force which is main driving force in most types of EHD pumps. The second term is dielectrophoretic force caused by the gradient of liquid permittivity. The last term is electrostrictive force. There are three basic mechanisms of EHD pumping in which Coulomb force is the driving force: induction pumping, conduction pumping and ion-drag (injection) pumping [11]. In our system for cooling electronic elements we applied a miniature ion-drag type EHD pumps. The basic mechanism of ion-drag pumping was described by Stuetzer [12] and Pickard [13] in 1960's and was investigated by many groups since then. During the ion-drag pumping free charges are injected into the dielectric liquid from the positive electrode (called emitter). The charges can be injected into the liquid by either a field ionization or field emission process. Next, injected charges are dragged by the Coulomb force towards another electrode (called collector) in high electric field created between the electrodes. Through the friction, a part of kinetic energy of the dragged charges is transferred to adjacent liquid what sets it into motion.

In this paper we present the design and test results of the system for cooling electronic elements in which liquid coolant flow is forced by the miniature, ion-drag type EHD pumps.

2. Experimental set-up

The experimental set-up of the system for cooling electronic elements is presented in figure 1. It consisted of an electronic element (diode Cree CSD02060 SiC in TO-220 package) with integrated U-shaped heat exchanger, set of three EHD pumps (parallel or serial connected) and reservoir of the liquid coolant with traditional heat-sink. Heat exchanger integrated with the diode was done by manufacturing in package of the diode a pattern of microchannels by means of laser micromachining technique. The EHD pumps force the coolant flow, in the closed-loop, from the reservoir to the heat exchanger and back to the reservoir.

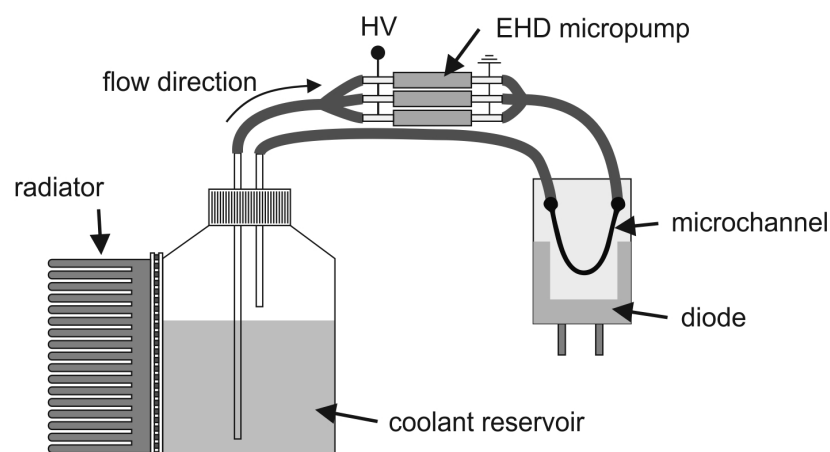


Figure 1. Cooling system for TO-220 packed diode with an EHD-induced coolant flow.

2.1. EHD micropump

The ion-drag type EHD micropump (figure 2) is composed of a ceramic (Al_2O_3) pipe and two stainless-steel electrodes inserted into the ceramic pipe. Each electrode is a 10 mm pipe of external and internal diameter of 0.8 mm and 0.5 mm, respectively. Distance between electrodes was 3 mm. The positive high DC voltage was applied to one electrode while the other electrode was grounded.

Spellman SL300 power supply was used as high voltage source. The pumping effect was observed in the direction from the HV electrode (emitter) towards the grounded electrode (collector). Pure isopropyl alcohol ($(\text{CH}_3)_2\text{CHOH}$) was used as a coolant.

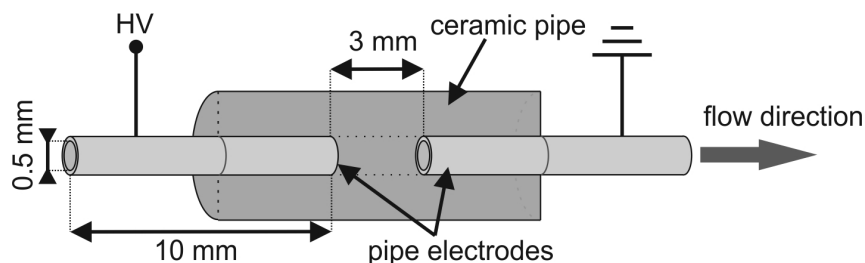


Figure 2. Schematics of EHD pump construction.

The maximum flow rate generated by a single EHD pump was 0.5 ml/min and the maximal pressure was 500 Pa for applied voltage of 12 kV. For higher voltages we observed formation of the gas bubbles in the pumped coolant and in consequence significant drop in both flow rate and pressure. For applied voltage of 12 kV the measured current was $20\mu\text{A}$, thus EHD pump power consumption was 240 mW.

2.2. Microchannels fabrication

In order to make a heat exchanger integrated with the diode we carried out a pattern of microchannels in the metal part of diode package by means of laser micromachining technique, so that the coolant could be introduced close to a heat-critical area of the diode. Geometry of a typical U-shaped microchannel is presented in figure 1. Microchannel was both $500\ \mu\text{m}$ wide and deep and 2 cm long. The microchannel was covered with transparent polydimethylsiloxan (PDMS) resin and thin glass plate. Transparent resin and glass plates were used in order to verify that no gas bubbles were generated in the coolant during the cooling process. The cross-section of complete heat exchanger is presented in figure 3.

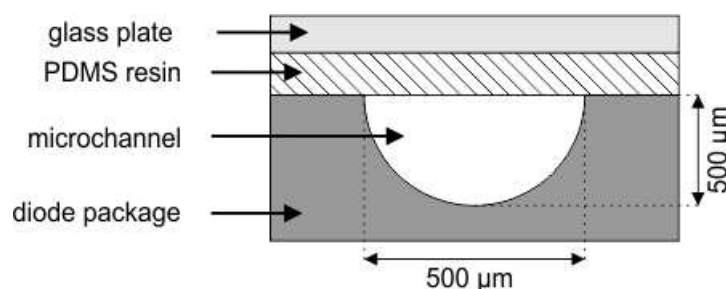


Figure 3. Heat exchanger cross-section.

3. Results

3.1. Micro-PIV measurements

To measure the EHD flow profile across the microchannel we propose to use the micro PIV technique. The micro-PIV stand included a dual pulsed Nd:YAG laser (532 nm, 15 ns pulse duration, 20 mJ pulse energy), a microscope NIKON Eclipse with a Kodak Megapixel CCD camera and Dantec Flow Manager software on a PC. The working liquid contained fluorescent seeding particles (polyamide spheres of diameter 1 and 10 μm with Rhodamine B). During a single measurement, particles were flashed with the laser twice, making the particle emit the fluorescence light. After each flash an image of fluorescent light was taken. The resulting pictures were analyzed to determine the movement of particles. Once the time between laser pulses was known, a flow velocity map could be determined.

A series of such measurements was performed for each observation area along the microchannel and an averaged flow velocity profile and a flow rate was calculated.

The maximum flow rate generated by the three EHD micropumps connected in series and in parallel was measured (figure 4). In case of parallel connection the total flow rate was 1.6 ml/min (flow rate generated by single EHD pump was 0.5 ml/min). On the other hand, in the case of serial connection of three EHD pumps the resulted flow rate was only 0.8 ml/min. Therefore in the final version of the cooling system EHD pumps were connected in parallel.

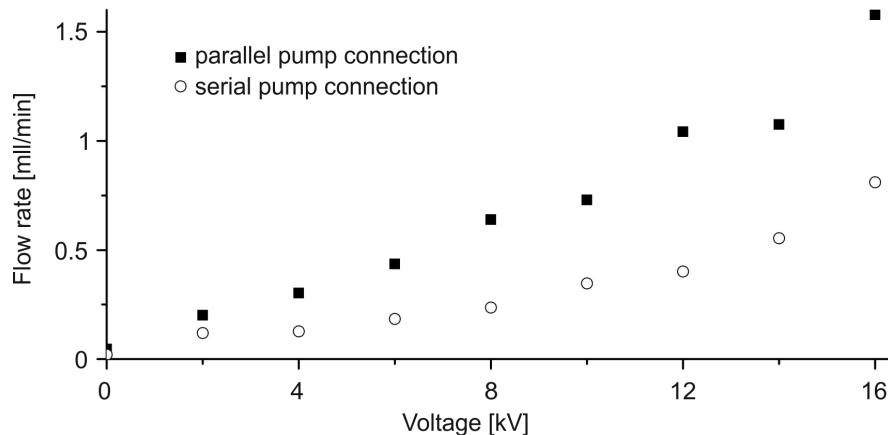


Figure 4. Coolant flow rate in the function of applied voltage for parallel and serial connection of the three EHD pumps.

3.2. Thermal measurements

To examine the performance of the cooling system a thermal impedance of the cooled CSD02060 diode was measured for various coolant flow rates. To obtain the transient thermal impedance first the cooling characteristics was taken. To this end an electric current was applied to the diode, heating it until the electrothermal steady state was reached. Next, the current was switched off and the diode started to cooled down to the ambient temperature. During this cooling process, the thermosensitive parameter of the diode was measured. This parameter was used to calculate the temperature surplus of a measured diode over the ambient temperature. Finally, transient thermal impedance curves were obtained by inverting the cooling curve and dividing the temperature surplus by the value of power used for heating the diode.

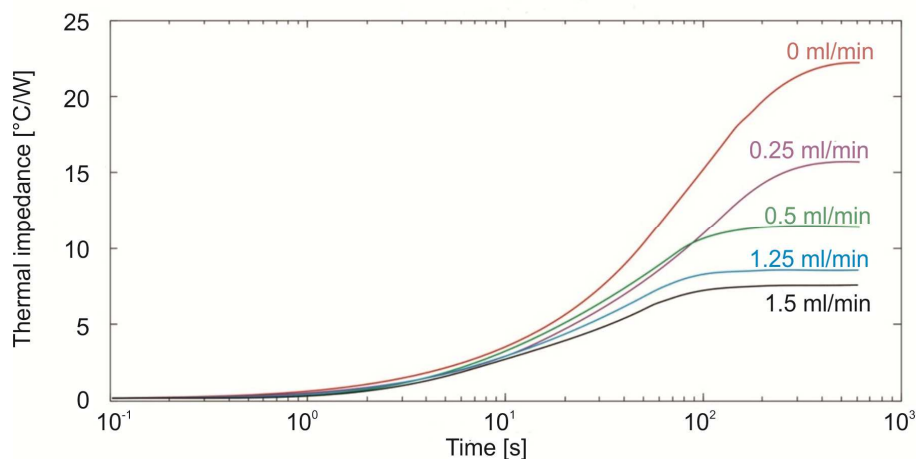


Figure 5. Thermal impedance of the CSD02060 diode.

4. Summary and conclusions

It was demonstrated that ion-drag type EHD pumps can be successfully applied for cooling electronic elements. We have studied the thermal characteristics of the CSD02060 diode cooled with an EHD flow in the function of a coolant flow rate. The transient thermal impedance of the CSD02060 diode cooled with 1.5 ml/min EHD flow was 7.8°C/W. Similar thermal resistance (6°C/W) can be achieved by applying a large RAD-A6405A/150 heat sink to the diode.

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