

# Automatic device for testing thermal resistance with thermoelectric effect

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**Abstract.** This paper presents the results of the developed device for testing thermal resistance of thermointerface. Experiments to determine thermal resistance in different cases of thermal interface application were carried out. Dependence of thermoEMF value is obtained, which occurs between semiconductor element body and cooling system radiator at different quality of thermal interface application.

## 1. Introduction

The thermal loss of a semiconductor device may cause overheating, decreasing efficiency and system reliability. The simplest solution to this problem is a cooling system radiator. The efficiency of heat transfer between the electronic component and the cooling system radiator depends on the quality of the mating surfaces, which have many tiny roughnesses [1–5].

Therefore, air cavities form in the mating zones that prevent direct heat transfer. To improve heat transfer, the semiconductor element is attached to the cooling system radiator through a layer of heat-conducting compound or thermointerface (TIS). Thereby, reducing thermal resistance, allows for maintaining acceptable temperature of the semiconductor element and, consequently, extend its durability.

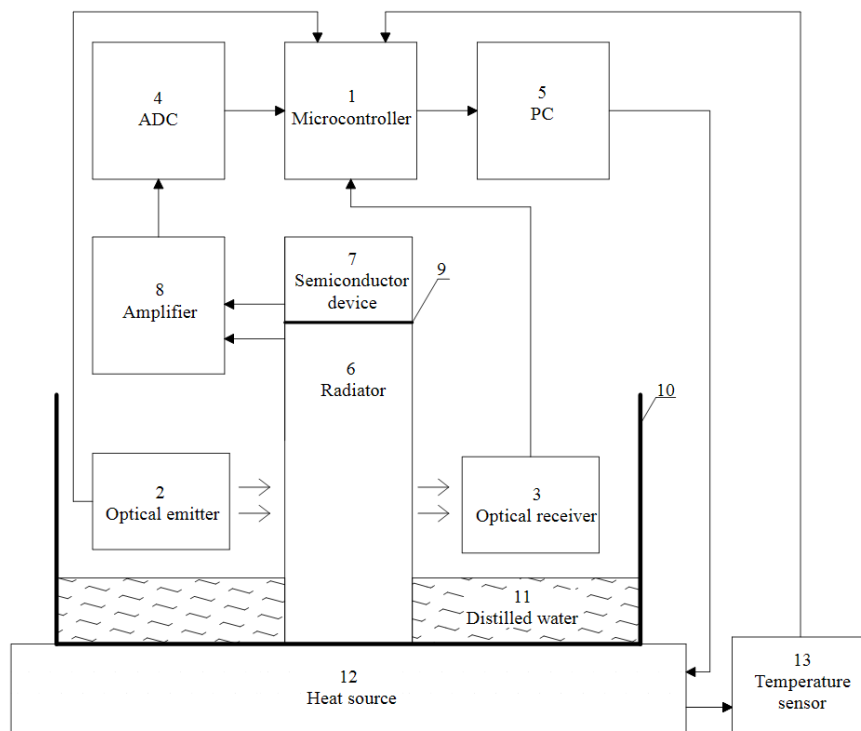
## 2. Experimental Instruments and Methodology

The device to testing the thermal interface layer was developed (Figure 1), whose operating principle is based on the use of thermoelectric effect [6–21]. In the mating zones of the semiconductor device and the cooling system radiator, thermoelectric power arises, the value of which can be used to determine the thermal resistance.

The block diagram of the installation is shown in the Figure 1. To find the value of thermal resistance, a semiconductor device (7) with the cooling system radiator (6) is placed in a water container (10) and filled with distilled water (11). The heat source (12) heats water to 100 °C. An important condition is that only the cooling system radiator is placed in the water. When heating the cooling system radiator, part of the heat will be transferred through a TIS (9) to the semiconductor device. At the same time thermoelectric power is created, which goes through an amplifier (8) and an



analog-to-digital converter (4) to microcontroller (1). The microcontroller transfers this data to the personal computer (5), which determines the average value of the thermal resistance "body-radiator". In this device, the heat source is a laboratory electric stove with a temperature controller. The temperature sensor (13) is a thermocouple, which measures the temperature of the water. The cooling system radiator with a semiconductor device is mounted on an aluminum strip mounted on the shaft of a stepper motor. After the start, a command is given through the computer, and the stepper motor begins to move the strip down until a signal from the optical emitter (2) about immersion of the cooling system radiator in water comes to the optical receiver (3). After that, with a frequency of 3 Hz, the thermopower value is recorded using a computer controlled by PC UltraSensor software. After heating the cooling system radiator for 2 minutes, the program calculates the value of thermal resistance at each moment in time. For the convenience of the user, the arithmetic mean value of thermal resistance is displayed at the end.



**Figure 1.** The block diagram of the installation for testing thermal resistance «body-radiator»

The operator interface is divided into several functionally different bookmarks (Figure 2). Upon measuring thermoelectric power, it is worth considering that measuring the difference in potentials between two different conductors is relative to each other, but not relative to temperature  $0\text{ }^{\circ}\text{C}$  – the resulting thermoelectric power, according to the additive rule, is determined by summing all thermoelectric powers included in the measurement loop. This means that when you attach measuring electrodes with the studied objects, for example by soldering, and they all consist of one material, a thermoelectric potential also occurs at the junction between the solder material and the conductor. It is necessary to take into account that the direction of thermoelectric power occurring between metals forms a closed measurement loop (Figure 3).

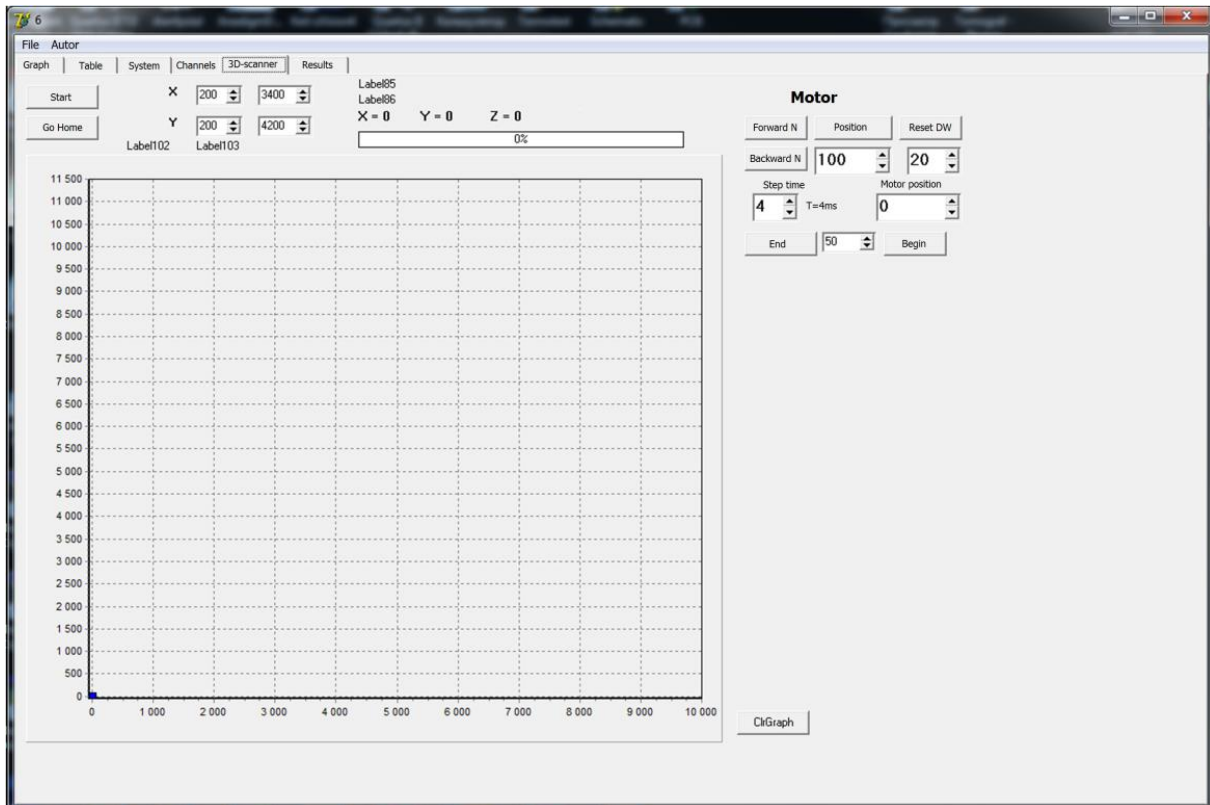


Figure 2. Thermoelectric power visual control tab

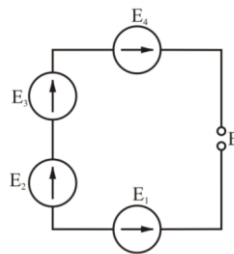


Figure 3. Equivalent circuit for thermoelectric power measurement

The resulting thermoelectric power is then calculated by the formula [22]:

$$E_{res} = \sum_i E_i \quad (1)$$

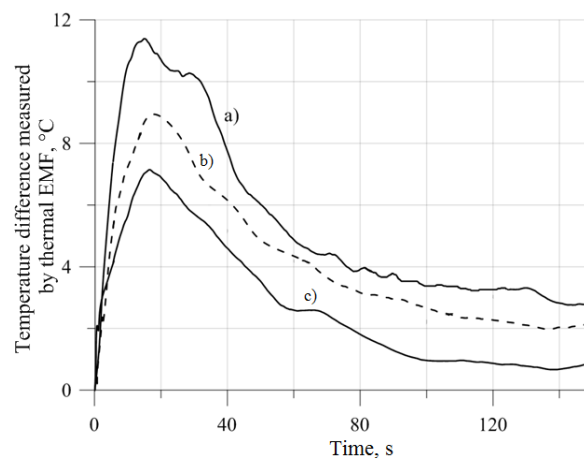
### 3.Experimental result

During the experiment, a power semiconductor device in the housing of the TO-220 was selected, which is often used in semiconductor engineering, and also an aluminum cooling system radiator in the form of a cylinder.

During the experiment, boiling water was heated by the semiconductor device body through the cooling system radiator, placing a cooling system radiator in it, so that water does not touch the body of the semiconductor device. The boiling point of water at normal atmospheric pressure is constant and equal to 100° C. The thermoelectric power value data were transmitted to the PC.

Figure 4 shows the temperature difference characterizing thermal resistance at application of heat-conducting paste, its partial application and its absence, considering that coating of substrate of semiconductor device is made of tin, and the cooling system radiator is made of aluminum.

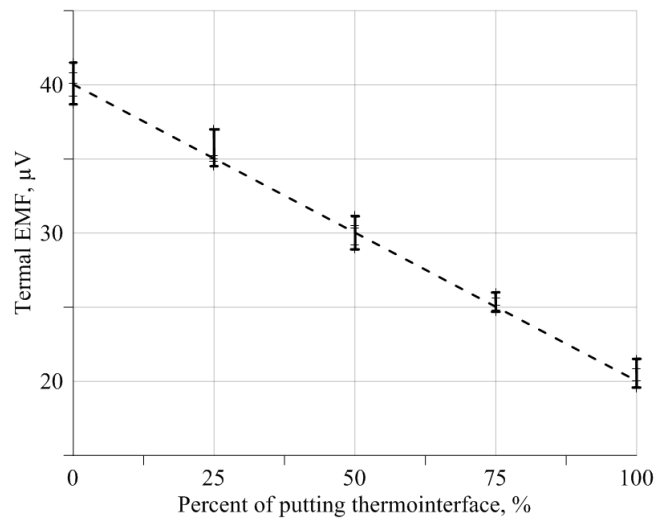
Figure 4 shows us, at the initial point of time, temperature difference between the body of the semiconductor device and the cooling system radiator increases for each version of thermal interface application due to fast heating of the radiator placed in boiling water and slow heating of semiconductor device body. After heating the cooling system radiator, a smooth heating of the body of the semiconductor device occurs and the temperature difference begins to decrease smoothly, reaching a steady value. The duration of the transient process for each case of thermointerface application is constant, as this value is characterized by thermal capacity of the cooling system radiator and the semiconductor device body, and the influence of thermal resistance of the heat conducting layer is very small.



**Figure 4.** Dependence of temperature difference between the body of the semiconductor device and the cooling system radiator, obtained with the help of thermoelectric power a) without TIS, b) with partially applied TIS, c) with applied TIS

The fluctuations of the temperature difference change are presented in Figure 4, and is caused by small fluctuations in ambient temperature and the presence of uncontrolled air flows in the experimental zone, which mainly has an influence on the cold junction of thermocouples.

Experimental studies of the dependence of thermal EMF on the area of the coating of the housing of the power element with a heat conducting layer are shown in Figure 5.



**Figure 5.** Graph of thermoelectric power dependence on the coating area with a heat-conducting layer

It can be seen from Figure 5 that almost linear dependence is observed. As the coating area increases, the thermoelectric power decreases linearly. The confidence interval does not exceed 6%.

#### 4. Conclusion

If the known materials of which the semiconductor device body and cooling system radiator are made, this device can detect the quality of thermal interface by the thermoEMF. The results of the study can be used to look for low-quality thermointerface in non-destructive testing before shipment to the consumer, that allow to avoid loss of reputation at the manufacturer of equipment.

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