FORCED CONVECTION IN A CHANNEL FILLED WITH HIGH THERMAL CONDUCTIVITY CARBON FOAMS

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Abstract

The feasibility of using a channel filled with carbon foam as a heat sink for a high-performance forced-convection cooler in microelectronics was studied in this paper. Both experimental and numerical investigations are conducted to evaluate the concept. The forced-convection heat transfer coefficient of this channel was measured experimentally. The thermal conductivity and the permeability of carbon foam were also characterized in this study.

Experiments

As shown in Fig. 1, The experimental setup consists of the following three major components: (1) power supply for the heater (0~300V), (2) cooling air supply, (3) a channel filled with highly conductive carbon foam. Both Al and Cu were used for the metallic channel to ensure an intimate contact between the foam and the channel. To further enhance the contact of the two materials, the foam was attached to the metals while they were in a molten state. As a consequence, excellent contact between the metal channel, the foam and the heater was achieved.

First, the thermal conductivity of the carbon foam was quantified by comparing the thermal conductivity of the foam with that of the Al using a wind tunnel. Then, the permeability of carbon foam is measured by forcing air through the carbon foam and measuring the pressure drop across the carbon foam, as well as the flow rate through it. In this experimental study, it was noticed that the performance of the foam agrees very well with the Forchheimer equation:

$$\frac{dp}{dx} = \frac{\mu}{K}u + \frac{\rho F}{\sqrt{K}}u^2$$

where p, μ, K, u, ρ are pressure, dynamic viscosity, permeability of the foam, and linear velocity and density of the air, respectively. F is the inertia coefficient reflecting porous inertia effects. It is a function of the microstructure of the porous medium. The characterization of the heat transfer coefficient of the channel was conducted by varying the power input to the heater while maintaining a constant air-flow rate and inlet temperature. The flow rate, inlet and outlet air temperatures, the local wall temperatures, the pressure drop and the input power were carefully recorded.

The heat transfer coefficient (h) of the channel and Nusselt number (N_u) were calculated as

$$h = \frac{q}{T_w - T_f}$$

$$N_u = \frac{hH}{k_f}$$

where, $q=Q_a/A=(Q_{total}-Q_{loss})/A$, is the net heat input per unit area, and k_f is the thermal conductivity of fluid evaluated at mean temperature, $T_{mean}=(T_{in}+T_{out})/2$. T_W and T_f are wall and fluid temperature, respectively. H is the height of the porous foam.

Summary

The experimental study and numerical analysis of the highly-conductive carbon foam heat sink have led to the following results:

(1) The Forchheimer equation is valid for the air permeability in the forced-convection cooling of the carbon foam.
(2) The thermal conductivity of the carbon foam used in this study falls into a range of 120~180 W/m·K.
(3) Under a constant heat flux, both the wall temperature of the channel and the temperature difference between the wall and the coolant (air or water) can be drastically decreased with the heat flux in the range of $q = 0.4{\sim}10$ W/cm^2 and inlet air pressure of 0.05 - 0.20 atm. For example, the temperature difference between the channel and the cooling air can be reduced from 400^{o}C to 25^{o}C at $q = 2.5$ W/cm^2, see Fig. 3. This demonstrates an excellent heat transfer coefficient in this foam-filled channel.
(4) This carbon foam-filled channel has a great potential to be used as the heat sink for high-performance microelectronics.

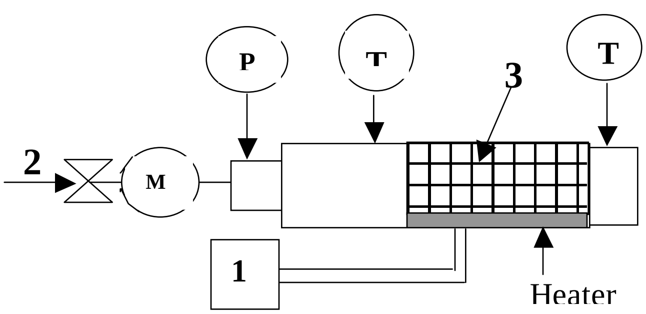

Figure 1. Schematic drawing of experimental setup: (1) power supply, (2) cooling air supply, (3) highly conductive carbon foam filled within a channel.

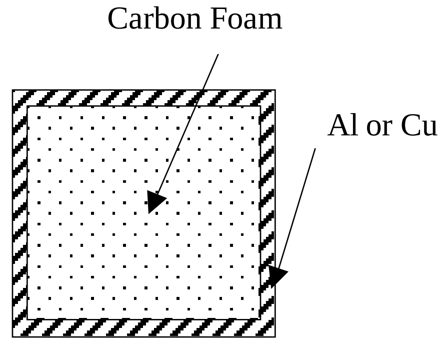

Figure 2. The cross-section view of a metal channel filled with carbon foam.

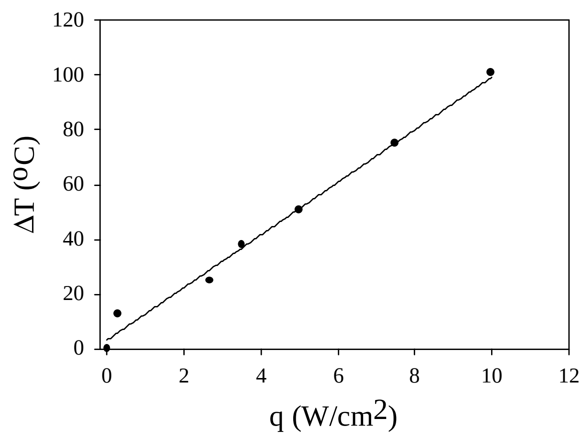

Figure 3. Variation of the average temperature difference between the wall and the air with the average power density at air pressure 0.18 atm.