copper \( (k = 390 \text{ W/m} \cdot \text{K}) \). When used to boil water, the surface of the bottom exposed to the water is nominally at 110°C. If heat is transferred from the stove to the pan at a rate of 600 W, what is the temperature of the surface in contact with the stove for each of the two materials?

1.11 A square silicon chip \( (k = 150 \text{ W/m} \cdot \text{K}) \) is of width \( w = 5 \text{ mm} \) on a side and of thickness \( t = 1 \text{ mm} \). The chip is mounted in a substrate such that its side and back surfaces are insulated, while the front surface is exposed to a coolant.

If 4 W are being dissipated in circuits mounted to the back surface of the substrate, what is the steady-state temperature difference between back and front surfaces?

1.12 A gage for measuring heat flux to a surface or through a laminated material employs five thin-film, chromel/ alumel (type K) thermocouples deposited on the upper and lower surfaces of a wafer with a thermal conductivity of 1.4 W/m \cdot K and a thickness of 0.25 mm.

(a) Determine the heat flux \( q' \) through the gage when the voltage output at the copper leads is 350 \( \mu \text{V} \). The Seebeck coefficient of the type-K thermocouple materials is approximately 40 \( \mu \text{V/K} \).

(b) What precaution should you take in using a gage of this nature to measure heat flow through the laminated structure shown?

Convection

1.13 You've experienced convection cooling if you've ever extended your hand out the window of a moving vehicle or into a flowing water stream. With the surface of your hand at a temperature of 30°C, determine the convection heat flux for (a) a vehicle speed of 35 km/h in air at -5°C with a convection coefficient of 40 W/m^2 \cdot K and (b) a velocity of 0.2 m/s in a water stream at 10°C with a convection coefficient of 900 W/m^2 \cdot K. Which condition would feel colder? Contrast these results with a heat loss of approximately 30 W/m^2 under normal room conditions.

1.14 Air at 40°C flows over a long, 25-mm-diameter cylinder with an embedded electrical heater. In a series of tests, measurements were made of the power per unit length, \( P' \), required to maintain the cylinder surface temperature at 300°C for different freestream velocities \( V \) of the air. The results are as follows:

<table>
<thead>
<tr>
<th>Air velocity, ( V ) (m/s)</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>8</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power, ( P' ) (W/m)</td>
<td>450</td>
<td>658</td>
<td>983</td>
<td>1507</td>
<td>1963</td>
</tr>
</tbody>
</table>

(a) Determine the convection coefficient for each velocity, and display your results graphically.

(b) Assuming the dependence of the convection coefficient on the velocity to be of the form \( h = CV^n \), determine the parameters \( C \) and \( n \) from the results of part (a).

1.15 An electric resistance heater is embedded in a long cylinder of diameter 30 mm. When water with a temperature of 25°C and velocity of 1 m/s flows crosswise over the cylinder, the power per unit length required to maintain the surface at a uniform temperature of 90°C is 28 kW/m. When air, also at 25°C, but with a velocity of 10 m/s is flowing, the power per unit length required to maintain the same surface temperature is 400 W/m. Calculate and compare the convection coefficients for the flows of water and air.

1.16 A cartridge electrical heater is shaped as a cylinder of length \( L = 200 \text{ mm} \) and outer diameter \( D = 20 \text{ mm} \). Under normal operating conditions the heater dissipates \( 2 \text{ kW} \) while submerged in a water flow that is at 20°C and provides a convection heat transfer coefficient of \( h = 5000 \text{ W/m}^2 \cdot \text{K} \). Neglecting heat transfer from the ends of the heater, determine its surface temperature \( T \). If the water flow is inadvertently terminated while the heater continues to operate, the heater surface is exposed to air that is also at 20°C but for which \( h = 50 \text{ W/m}^2 \cdot \text{K} \).

A common procedure for measuring the velocity of an air stream involves insertion of an electrically heated wire (called a hot-wire anemometer) into the air flow, with the axis of the wire oriented perpendicular to the flow direction. The electrical energy dissipated in the wire is assumed to be transferred to the air by forced convection. Hence, for a prescribed electrical power, the temperature of the wire depends on the convection coefficient, which, in turn, depends on the velocity of the air. Consider a wire of length \( L = 20 \text{ mm} \) and diameter \( D = 0.5 \text{ mm} \), for which a calibration of the form, \( V = 6.25 \times 10^{-2} h^2 \), has been determined. The velocity \( V \) and the convection coefficient \( h \) have units of m/s and W/m^2 \cdot K, respectively. In an application involving air at a temperature of \( T_a = 25°C \), the surface temperature of the anemometer is maintained at \( T_s = 75°C \) with a voltage drop of 5 V and an electric current of 0.1 A. What is the velocity of the air?

1.18 A square isothermal chip is of width \( w = 5 \text{ mm} \) on a side and is mounted in a substrate such that its side and back surfaces are well insulated, while the front surface is exposed to the flow of a coolant at \( T_c = 15°C \). From reliability considerations, the chip temperature must not exceed \( T = 85°C \).

1.19 The case of a power transistor, which is of length \( L = 10 \text{ mm} \) and diameter \( D = 12 \text{ mm} \), is cooled by an air stream of temperature \( T_a = 25°C \).

Under conditions for which the air maintains an average convection coefficient of \( h = 100 \text{ W/m}^2 \cdot \text{K} \) on the surface of the case, what is the maximum allowable power dissipation?