PROBLEM 3.32

KNOWN: Operating conditions, measured temperatures and heat input, and theoretical thermal conductivity of a carbon nanotube.

FIND: (a) Thermal contact resistance between the carbon nanotube and the heating and sensing islands, (b) Fraction of total thermal resistance between the heating and sensing islands due to thermal contact resistance for 5 µm ≤ s ≤ 20 µm.

ASSUMPTIONS: (1) Steady-state conditions, (2) Constant properties, (3) One-dimensional heat transfer, (4) Isothermal heating and sensing islands, (5) Negligible radiation and convection heat transfer.

PROPERTIES: $k_{cn,T}$ = 5000 W/m·K

ANALYSIS:

(a) The total thermal resistance between the heated and sensing island is

$$R_{t,tot} = \frac{s}{k_{cn,T}A_{cn}} + 2R_{t,c}$$

The value of this total resistance is the same as the one posed in Example 3.4 with k_{cn} = 3113 W/m·K and $R_{t,c}$ = 0 or

$$\frac{s}{k_{cn,T}A_{cn}} + 2R_{t,c} = \frac{s}{k_{cn}A_{cn}}$$

for which

$$R_{t,c} = \frac{s}{2A_{cn}}\left[\frac{1}{k_{cn}} - \frac{1}{k_{cn,T}}\right] = \frac{5 \times 10^{-6}\ \text{m}}{2 \times 1.54 \times 10^{-16}\ \text{m}^2} \times \left[\frac{1}{3113\ \text{W/m} \cdot \text{K}} - \frac{1}{5000\ \text{W/m} \cdot \text{K}}\right]$$

$$= 1.97 \times 10^{6}\ \text{K/W}$$ <

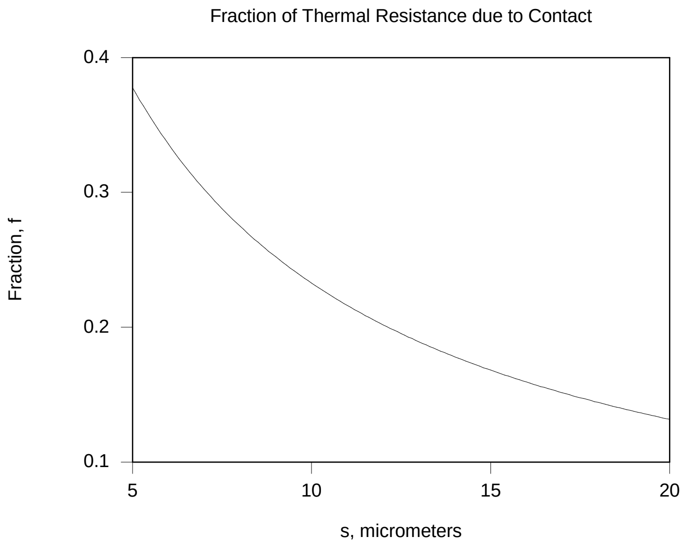
(b) The fraction of the total resistance due to the thermal contact resistance is

$$f = \frac{2R_{t,c}}{2R_{t,c} + \left[\frac{s}{k_{cn,T}A_{cn}}\right]} = \frac{2 \times 1.97 \times 10^{6}\ \text{K/W}}{2 \times 1.97 \times 10^{6}\ \text{K/W} + \left[\frac{s}{5000\ \text{W/m} \cdot \text{K} \times 1.54 \times 10^{-16}\ \text{m}^2}\right]}$$

As evident in the plot below, the fraction of the total thermal resistance due to thermal contact decreases from 0.38 at s = 5 µm to 0.13 at s = 20 µm.

Continued…

PROBLEM 3.32 (Cont.)



COMMENT: To desensitize the experiment to uncertainty due to the unknown thermal contact resistance values, a large separation distance between the islands is desired. As the separation distance becomes large, however, the surface area of the carbon nanotube increases and surface heat losses by radiation may invalidate the assumption of a linear temperature distribution along the length of the nanotube. An optimal separation distance exists that will minimize the undesirable effects of the thermal contact resistances and radiation loss from the surface of the nanotube.