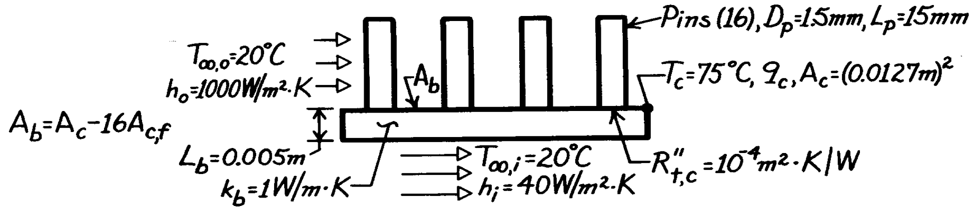
PROBLEM 3.146

KNOWN: Geometry and cooling arrangement for a chip-circuit board arrangement. Maximum chip temperature.

FIND: (a) Equivalent thermal circuit, (b) Maximum chip heat rate.

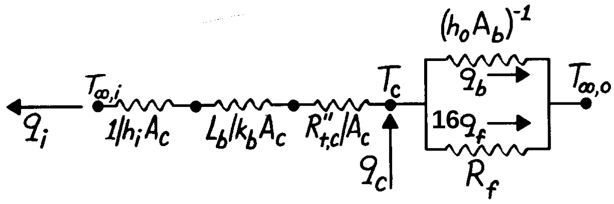
SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) One-dimensional heat transfer in chip-board assembly, (3) Negligible pin-chip contact resistance, (4) Constant properties, (5) Negligible chip thermal resistance, (6) Uniform chip temperature.

PROPERTIES: *Table A.1*, Copper (300 K): k ≈ 400 W/m·K.

ANALYSIS: (a) The thermal circuit is



$$R_f = \frac{\theta_b}{16q_f} = \frac{\cosh mL + (h_o/mk)\sinh mL}{16\left(h_oPkA_{c,f}\right)^{1/2}\left[\sinh mL + (h_o/mk)\cosh mL\right]}$$

(b) The maximum chip heat rate is

$$q_c = 16q_f + q_b + q_i.$$

Evaluate these parameters

$$m = \left(\frac{h_oP}{kA_{c,f}}\right)^{1/2} = \left(\frac{4h_o}{kD_p}\right)^{1/2} = \left(\frac{4\times1000\ \text{W/m}^2\cdot\text{K}}{400\ \text{W/m}\cdot\text{K}\times0.0015\ \text{m}}\right)^{1/2} = 81.7\ \text{m}^{-1}$$

$$mL = \left(81.7\ \text{m}^{-1}\times0.015\ \text{m}\right) = 1.23,\qquad \sinh mL = 1.57,\qquad \cosh mL = 1.86$$

$$\left(h_o/mk\right) = \frac{1000\ \text{W/m}^2\cdot\text{K}}{81.7\ \text{m}^{-1}\times400\ \text{W/m}\cdot\text{K}} = 0.0306$$

$$M = \left(h_o\pi\ D_pk\pi\ D_p^2/4\right)^{1/2}\theta_b$$

$$M = \left[1000\ \text{W/m}^2\cdot\text{K}\left(\pi^2/4\right)\left(0.0015\ \text{m}\right)^3 400\ \text{W/m}\cdot\text{K}\right]^{1/2}\left(55^\circ\text{C}\right) = 3.17\ \text{W}.$$

Continued …

The fin heat rate is

$$q_f = M\frac{\sinh mL + (h_o/mk)\cosh mL}{\cosh mL + (h_o/mk)\sinh mL} = 3.17\ \text{W}\frac{1.57+0.0306\times1.86}{1.86+0.0306\times1.57}$$

$$q_f = 2.703\ \text{W}.$$

The heat rate from the chip top by convection is

$$q_b = h_o A_b \theta_b = 1000\ \text{W/m}^2\cdot\text{K}\left[(0.0127\ \text{m})^2 - (16\pi/4)(0.0015\ \text{m})^2\right]55^\circ\text{C}$$

$$q_b = 7.32\ \text{W}.$$

The convection heat rate from the board is

$$q_i = \frac{T_c - T_{\infty,i}}{\left(1/h_i + R''_{t,c} + L_b/k_b\right)(1/A_c)} = \frac{(0.0127\ \text{m})^2\left(55^\circ\text{C}\right)}{\left(1/40+10^{-4}+0.005/1\right)\text{m}^2\cdot\text{K/W}}$$

$$q_i = 0.29\ \text{W}.$$

Hence, the maximum chip heat rate is

$$q_c = \left[16(2.703) + 7.32 + 0.29\right]\text{W} = \left[43.25 + 7.32 + 0.29\right]\text{W}$$

$$q_c = 50.9\ \text{W}.$$ <

COMMENTS: (1) The fins are extremely effective in enhancing heat transfer from the chip (assuming negligible contact resistance). Their effectiveness is $\varepsilon = q_f/\left(\pi D_p^2/4\right)h_o\theta_b = 2.703$ W/0.097 W = 27.8

(2) Without the fins, q_c = 1000 W/m^2·K(0.0127 m)^{2}55°C + 0.29 W = 9.16 W. Hence the fins provide for a (50.9 W/9.16 W) × 100% = 555% enhancement of heat transfer.

(3) With the fins, the chip heat flux is 50.9 W/(0.0127 m)^2 or $q''_c = 3.16\times10^5\ \text{W/m}^2 = 31.6$ W/cm^2.

(4) If the infinite fin approximation is made, q_f = M = 3.17 W, and the actual fin heat transfer is overestimated by 17%.