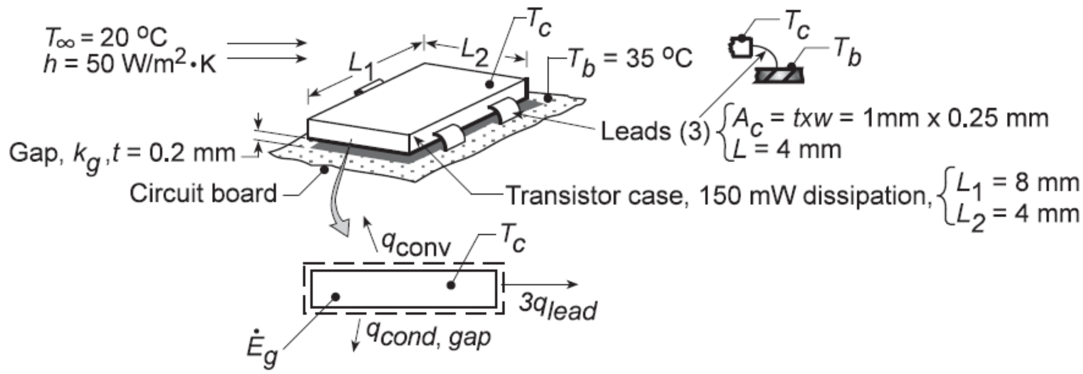
PROBLEM 1.53

KNOWN: Surface-mount transistor with prescribed dissipation and convection cooling conditions.

FIND: (a) Case temperature for mounting arrangement with air-gap and conductive paste between case and circuit board, (b) Consider options for increasing $\dot{E}_g$, subject to the constraint that T_c = 40°C.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Transistor case is isothermal, (3) Upper surface experiences convection; negligible losses from edges, (4) Leads provide conduction path between case and board, (5) Negligible radiation, (6) Negligible energy generation in leads due to current flow, (7) Negligible convection from surface of leads.

PROPERTIES: (Given): Air, $k_{g,a}$ = 0.0263 W/m·K; Paste, $k_{g,p}$ = 0.12 W/m·K; Metal leads, k_ℓ = 25 W/m·K.

ANALYSIS: (a) Define the transistor as the system and identify modes of heat transfer.

$$\dot{E}_{in} - \dot{E}_{out} + \dot{E}_g = \Delta\dot{E}_{st} = 0$$

$$-q_{conv} - q_{cond,gap} - 3q_{lead} + \dot{E}_g = 0$$

$$-hA_s\left(T_c - T_\infty\right) - k_g A_s \frac{T_c - T_b}{t} - 3k_\ell A_c \frac{T_c - T_b}{L} + \dot{E}_g = 0$$

where $A_s = L_1 \times L_2$ = 4 × 8 mm² = 32 × 10⁻⁶ m² and A_c = t × w = 0.25 × 1 mm² = 25 × 10⁻⁸ m².

Rearranging and solving for T_c,

$$T_c = \left\{hA_s T_\infty + \left[k_g A_s/t + 3\left(k_\ell A_c/L\right)\right]T_b + \dot{E}_g\right\} / \left[hA_s + k_g A_s/t + 3\left(k_\ell A_c/L\right)\right]$$

Substituting numerical values, with the *air-gap condition* ($k_{g,a}$ = 0.0263 W/m·K)

$$T_c = \left\{50\,\text{W/m}^2\cdot\text{K} \times 32\times10^{-6}\,\text{m}^2 \times 20^\circ\text{C} + \left[\left(0.0263\,\text{W/m}\cdot\text{K} \times 32\times10^{-6}\,\text{m}^2/0.2\times10^{-3}\,\text{m}\right)\right.\right.$$

$$\left.\left. +3\left(25\,\text{W/m}\cdot\text{K} \times 25\times10^{-8}\,\text{m}^2/4\times10^{-3}\,\text{m}\right)\right]35^\circ\text{C}\right\} / \left[1.600\times10^{-3} + 4.208\times10^{-3} + 4.688\times10^{-3}\right]\text{W/K}$$

$$T_c = 47.0^\circ\text{C}.$$ <

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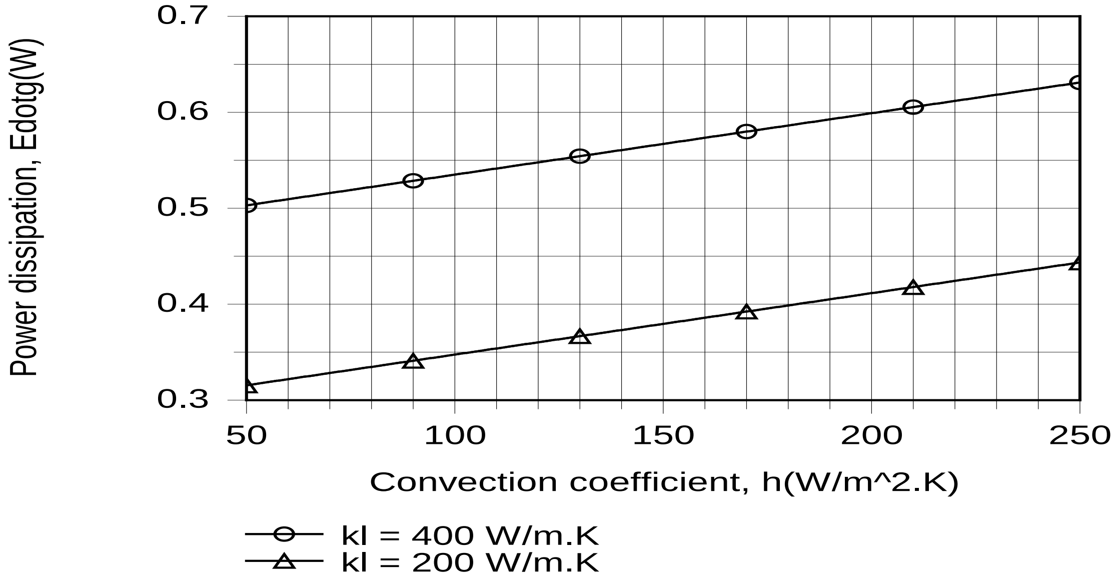
PROBLEM 1.53 (Cont.)

With the *paste condition* ($k_{g,p}$ = 0.12 W/m·K), T_c = 39.9°C. As expected, the effect of the conductive paste is to improve the coupling between the circuit board and the case. Hence, T_c decreases.

(b) Using the keyboard to enter model equations into the workspace, IHT has been used to perform the desired calculations. For values of k_ℓ = 200 and 400 W/m·K and convection coefficients in the range from 50 to 250 W/m^2·K, the energy balance equation may be used to compute the power dissipation for a maximum allowable case temperature of 40°C.



As indicated by the energy balance, the power dissipation increases linearly with increasing h, as well as with increasing k_ℓ. For h = 250 W/m^2·K (enhanced air cooling) and k_ℓ = 400 W/m·K (copper leads), the transistor may dissipate up to 0.63 W.

COMMENTS: Additional benefits may be derived by increasing heat transfer across the gap separating the case from the board, perhaps by inserting a highly conductive material in the gap.