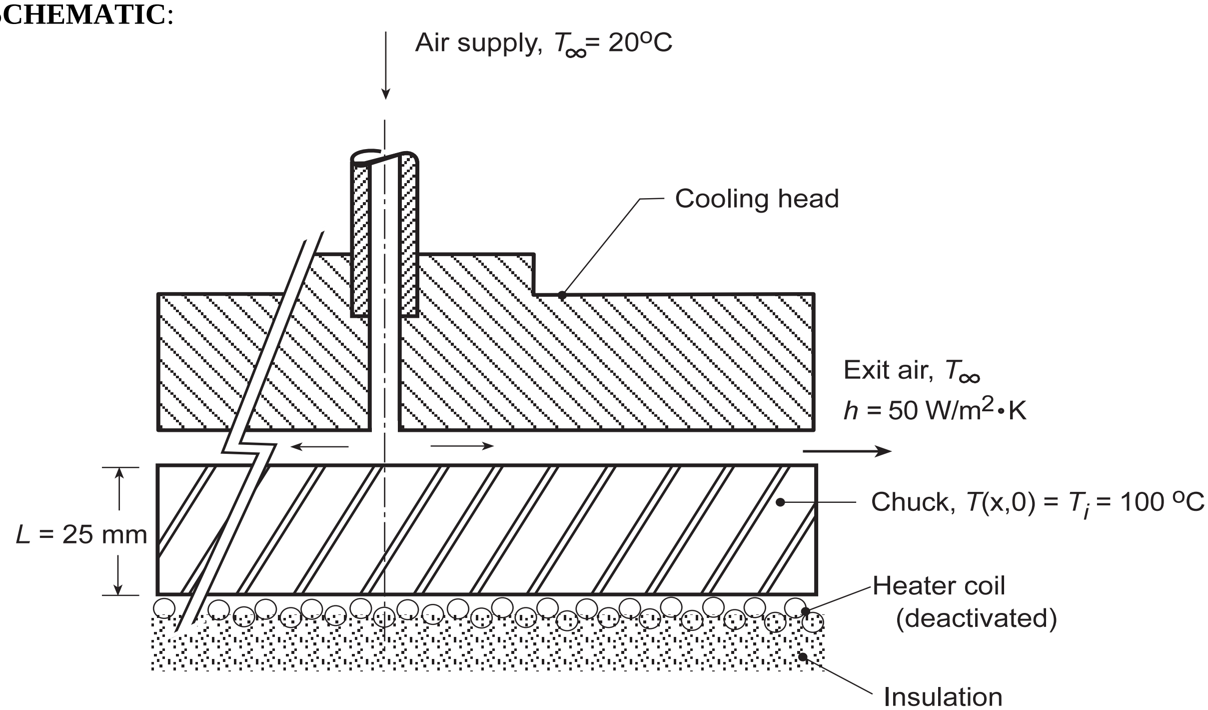
PROBLEM 5.48

KNOWN: The chuck of a semiconductor processing tool, initially at a uniform temperature of T_i = 100°C, is cooled on its top surface by supply air at 20°C with a convection coefficient of 50 $W/m^2 \cdot K$.

FIND: (a) Time required for the lower surface to reach 25°C, and (b) Compute and plot the time-to-cool as a function of the convection coefficient for the range $10 \le h \le 2000$ $W/m^2 \cdot K$; comment on the effectiveness of the head design as a method for cooling the chuck.

SCHEMATIC:



ASSUMPTIONS: (1) One-dimensional, transient conduction in the chuck, (2) Lower surface is perfectly insulated, (3) Uniform convection coefficient and air temperature over the upper surface of the chuck, and (4) Constant properties.

PROPERTIES: *Table A.1*, Aluminum alloy 2024 ((25 + 100)°C / 2 = 335 K): ρ = 2770 kg/m^3, c_p = 880 J/kg· K, k = 179 W/m·K.

ANALYSIS: (a) The Biot number for the chuck with h = 50 $W/m^2 \cdot K$ is

$$\mathrm{Bi} = \frac{hL}{k} = \frac{50\,\mathrm{W/m^2 \cdot K} \times 0.025\,\mathrm{m}}{179\,\mathrm{W/m \cdot K}} = 0.007 \le 0.1 \qquad (1)$$

so that the lumped capacitance method is appropriate. Using Eq. 5.5, with $V/A_s = L$,

$$t = \frac{\rho V c}{h A_s} \ln \frac{\theta_i}{\theta} \qquad \theta = T - T_\infty \qquad \theta_i = T_i - T_\infty$$

$$t = \left(2770\,\mathrm{kg/m^3} \times 0.025\,\mathrm{m} \times 880\,\mathrm{J/kg \cdot K} \Big/ 50\,\mathrm{W/m^2 \cdot K}\right) \ln \frac{(100-20)^\circ\mathrm{C}}{(25-20)^\circ\mathrm{C}}$$

$$t = 3379\,\mathrm{s} = 56.3\,\mathrm{min}$$ <

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PROBLEM 5.48 (Cont.)

(b) When h = 2000 $W/m^2 \cdot K$, using Eq. (1), find Bi = 0.28 > 0.1 so that the series solution, Section 5.5.1, for the plane wall with convection must be used. Using the *IHT Transient Conduction, Plane Wall Model*, the time-to-cool was calculated as a function of the convection coefficient. Free convection cooling condition corresponds to $h \approx 10\ W/m^2 \cdot K$ and the time-to-cool is 282 minutes. With the cooling head design, the time-to-cool can be substantially decreased if the convection coefficient can be increased as shown below.