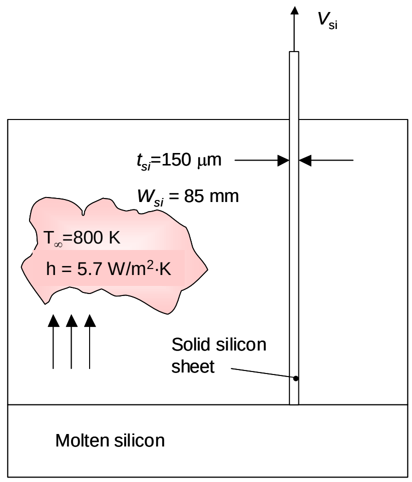
PROBLEM 3.110

KNOWN: Process for growing thin, photovoltaic grade silicon sheets. Sheet dimensions, ambient temperature and heat transfer coefficient.

FIND: The velocity at which the silicon sheet can be extracted from the pool of molten silicon.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state, one-dimensional conditions, (2) Negligible radiation heat transfer, (3) Silicon sheet behaves as an infinite fin, (4) Constant properties, (5) Neglect advection inside the silicon sheet, (6) Neglect the presence of the strings, (7) Molten silicon is isothermal at the melting point (1685 K).

PROPERTIES: *Table A-1*, Silicon ($\bar{T}$ = (1685 K + 800 K)/2 = 1243 K): k = 25.3 W/m·K, ρ = 2330 kg/m^3, h_{sl} = 1.8 × 10^6 J/kg (given).

ANALYSIS: The velocity is expected to be very small. Therefore, heat transfer *within* the silicon sheet may be considered to be by conduction only. In addition, thermal energy is generated due to solidification at the solid-liquid interface, and must be removed by conduction along the silicon sheet. Therefore,

$$\dot{m}h_{sl} = \rho W_{\text{si}} t_{\text{si}} V_{\text{si}} h_{\text{sl}} = q_{\text{cond}} \qquad (1)$$

From Table 3.4 for an infinite fin

$$q_{\text{cond}} = q_f = M = \sqrt{hPkA_c}\,\theta_b = \sqrt{h2(W_{si}+t_{si})kW_{si}t_{si}}\,(T_f - T_\infty) \qquad (2)$$

Combining Equations (1) and (2) yields

$$V_{\text{si}} = \frac{\sqrt{2h(W_{\text{si}}+t_{\text{si}})kW_{\text{si}}t_{\text{si}}}}{\rho W_{\text{si}} t_{\text{si}} h_{\text{sl}}}\left(T_f - T_\infty\right)$$

$$= \frac{\sqrt{2\times 5.7\text{W/m}^2\cdot\text{K}\times(0.085\text{m}+150\times10^{-6}\text{m})\times 25.3\text{W/m}\cdot\text{K}\times 0.085\text{m}\times 150\times10^{-6}\text{m}}}{2330\text{kg/m}^3\times 0.085\text{m}\times 150\times 10^{-6}\text{m}\times 1.8\times 10^{6}\text{J/kg}}\left(1685\text{K}-800\text{K}\right)$$

$$= 292\times10^{-6}\text{m/s}\times 1000\text{mm/m}\times 60\text{s/min} = 17.5\text{ mm/min}$$ <

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PROBLEM 3.110 (Cont.)

COMMENTS: (1) The rate at which the photovoltaic sheet can be manufactured is limited by heat transfer effects. If the velocity were increased above the value calculated, the solid sheet would be lifted out of the molten pool of silicon, and the manufacturing process would stop. If the velocity were below the value calculated, the solid-liquid interface would begin to propagate downward into the pool, increasing the thickness of the silicon sheet. (2) As the thickness of the photovoltaic sheet is reduced, less silicon is needed to fabricate a solar panel, reducing manufacturing costs, reducing energy consumption in the manufacturing process, and conserving natural resources. Equally important, as the thickness of the sheet is reduced, the velocity at which the sheet can be pulled from the pool of molten silicon can be increased, resulting in production of more photovoltaic surface area per unit time.