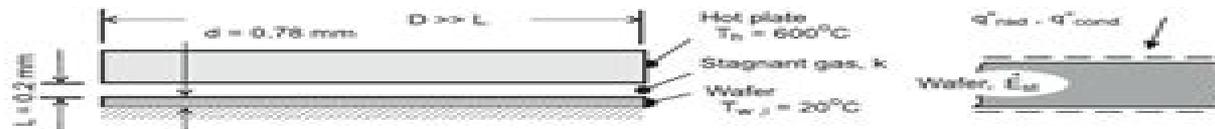


PROBLEM 1.41

KNOWN: Hot plate-type wafer thermal processing tool based upon heat transfer modes by conduction through gas within the gap and by radiation exchange across gap.

FIND: (a) Radiative and conduction heat fluxes across gap for specified hot plate and wafer temperatures and gap separation; initial time rate of change in wafer temperature for each mode, and (b) heat fluxes and initial temperature-time change for gap separations of 0.2, 0.5 and 1.0 mm for hot plate temperatures $300 < T_h < 1300$ C. Comment on the relative importance of the modes and the influence of the gap distance. Under what conditions could a wafer be heated to 900 C in less than 10 seconds?

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions for flux calculations, (2) Diameter of hot plate and wafer much larger than gap spacing, approximating plane, infinite planes, (3) One-dimensional conduction through gas, (4) Hot plate and wafer are blackbodies, (5) Negligible heat losses from wafer backside, and (6) Wafer temperature is uniform at the onset of heating.

PROPERTIES: Wafer: $\rho = 2700 \text{ kg/m}^3$, $c = 875 \text{ J/kg} \cdot \text{K}$; Gas in gap: $k = 0.0436 \text{ W/m} \cdot \text{K}$.

ANALYSIS: (a) The radiative heat flux between the hot plate and wafer for $T_h = 600$ C and $T_w = 20$ C follows from the rate equation,

$$q_{\text{rad}} = \sigma (T_h^4 - T_w^4) = 5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4 (600 - 273)^4 - 20 - 273^4 \text{ K}^4 = 32.5 \text{ kW/m}^2 \quad \leftarrow$$

The conduction heat flux through the gas in the gap with $L = 0.2$ mm follows from Fourier's law,

$$q_{\text{cond}} = k \frac{T_h - T_w}{L} = 0.0436 \text{ W/m} \cdot \text{K} \frac{600 - 20 \text{ K}}{0.0002 \text{ m}} = 126 \text{ kW/m}^2 \quad \leftarrow$$

The initial time rate of change of the wafer can be determined from an energy balance on the wafer at the instant of time the heating process begins,

$$\dot{E}_{\text{in}} - \dot{E}_{\text{out}} = \dot{E}_{\text{st}} \quad \dot{E}_{\text{st}} = \rho c d \frac{dT_w}{dt} \quad \leftarrow$$

where $\dot{E}_{\text{out}} = 0$ and $\dot{E}_{\text{in}} = q_{\text{rad}} + q_{\text{cond}}$. Substituting numerical values, find

$$\frac{dT_w}{dt} = \frac{q_{\text{rad}} + q_{\text{cond}}}{\rho c d} = \frac{32.5 + 126 \text{ kW/m}^2}{2700 \text{ kg/m}^3 \cdot 875 \text{ J/kg} \cdot \text{K} \cdot 0.00078 \text{ m}} = 17.6 \text{ K/s} \quad \leftarrow$$

$$\frac{dT_w}{dt} = \frac{q_{\text{cond}}}{\rho c d} = 68.4 \text{ K/s} \quad \leftarrow$$

Continued

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