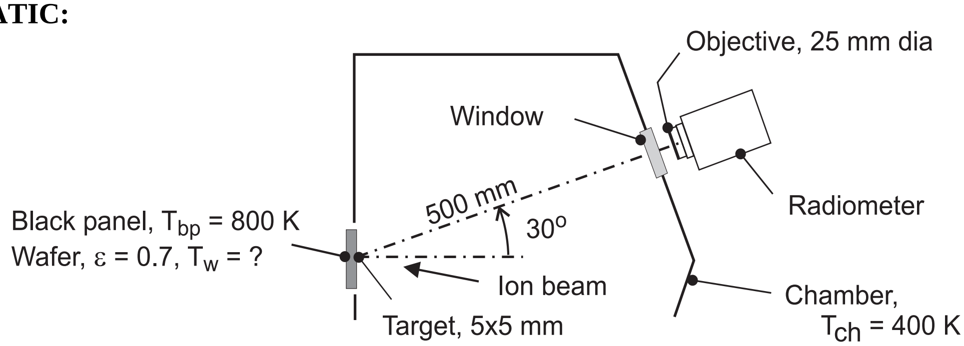
PROBLEM 12.97

KNOWN: Wafer heated by ion beam source within large process-gas chamber with walls at uniform temperature; radiometer views a 5 × 5 mm target on the wafer. Black panel mounted in place of wafer in a pre-production test of the equipment.

FIND: (a) Radiant power (μW) received by the radiometer when the black panel temperature is T_{bp} = 800 K and (b) Temperature of the wafer, T_w, when the ion beam source is adjusted so that the radiant power received by the radiometer is the same as that of part (a)

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Chamber represents large, isothermal surroundings, (3) Wafer is opaque, diffuse-gray, and (4) Target area << square of distance between target and radiometer objective.

ANALYSIS: (a) The radiant power leaving the black-panel target and reaching the radiometer as illustrated in the schematic below is

$$q_{bp-rad} = \left[E_{b,bp}\left(T_{bp}\right)/\pi\right] A_t \cos\theta_t \cdot \Delta\omega_{rad-t} \tag{1}$$

where θ_t = 0° and the solid angle the radiometer subtends with respect to the target follows from Eq. 12.7,

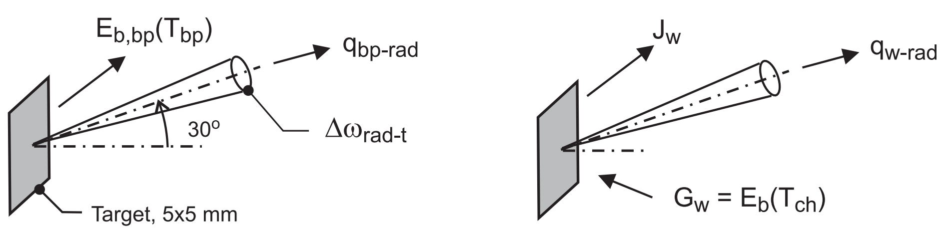
$$\Delta\omega_{rad-t} = \frac{dA_n}{r^2} = \frac{\left(\pi D_o^2/4\right)}{r^2} = \frac{\pi(0.025\text{ m})^2/4}{(0.500\text{ m})^2} = 1.964\times10^{-3}\text{ sr}$$

With $E_{b,bp} = \sigma T_{bp}^4$, find

$$q_{bp-rad} = \left[5.67\times10^{-8}\text{ W/m}^2\cdot\text{K}^4(800\text{ K})^4/\pi\text{ sr}\right]$$

$$\times(0.005\text{ m})^2\times\cos 30°\times1.964\times10^{-3}\text{ sr}$$

$$q_{bp-rad} = 314\ \mu\text{W}$$ <



(a) Black panel, T_{bp} = 800 K **(b) Wafer, ε_w = 0.7, T_w = ?**

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(b) With the wafer mounted, the ion beam source is adjusted until the radiometer receives the same radiant power as with part (a) for the black panel. The power reaching the radiometer is expressed in terms of the wafer radiosity,

$$q_{w-rad} = \left[J_w / \pi\right] A_t \cos\theta_t \cdot \Delta\omega_{rad-t} \tag{2}$$

Since $q_{w-rad} = q_{bp-rad}$ (see Eq. (1)), recognize that

$$J_w = E_{b,bp}\left(T_{bp}\right) \tag{3}$$

where the radiosity is

$$J_w = \varepsilon_w E_{b,w}\left(T_w\right) + \rho_w G_w = \varepsilon_w E_{b,w}\left(T_w\right) + \left(1 - \varepsilon_w\right) E_b\left(T_{ch}\right) \tag{4}$$

and G_w is equal to the blackbody emissive power at T_{ch}. Using Eqs. (3) and (4) and substituting numerical values, find

$$\sigma T_{bp}^4 = \varepsilon_w \sigma T_w^4 + \left(1 - \varepsilon_w\right) \sigma T_{ch}^4$$

$$(800\text{ K})^4 = 0.7\ T_w^4 + 0.3(400\text{ K})^4$$

$$T_w = 871\text{ K}$$ <

COMMENTS: (1) Explain why T_w is higher than 800 K, the temperature of the black panel, when the radiometer receives the same radiant power for both situations.

(2) If the chamber walls were cold relative to the wafer, say near liquid nitrogen temperature, T_{ch} = 80 K, and the test repeated with the same indicated radiometer power, is the wafer temperature higher or lower than 871 K?

(3) If the chamber walls were maintained at 800 K, and the test repeated with the same indicated radiometer power, what is the wafer temperature?