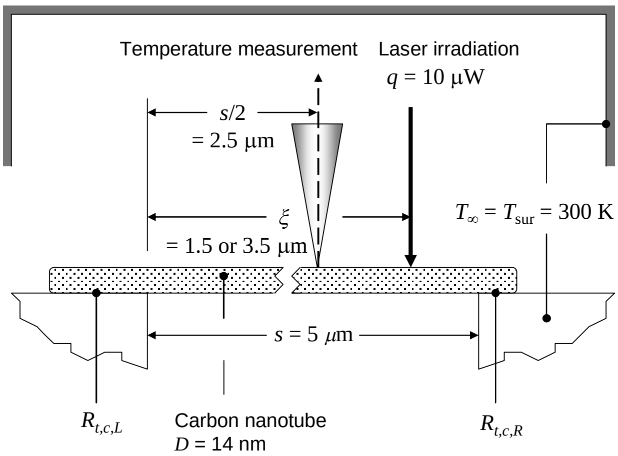
PROBLEM 3.120

KNOWN: Trench length and nanotube diameter. Laser irradiation of known power at two distinct axial locations. Measured nanotube temperatures at the trench half-width. Nanotube thermal conductivity. Island temperature.

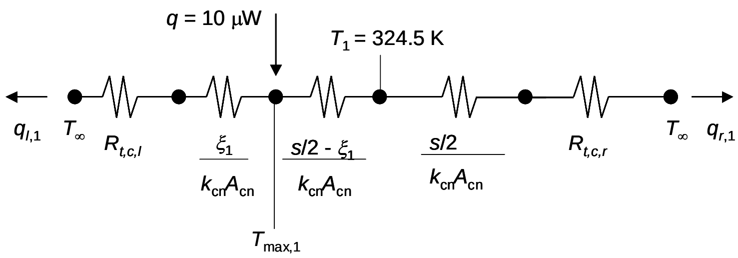
FIND: Thermal contact resistances at the left and right ends of the nanotube.

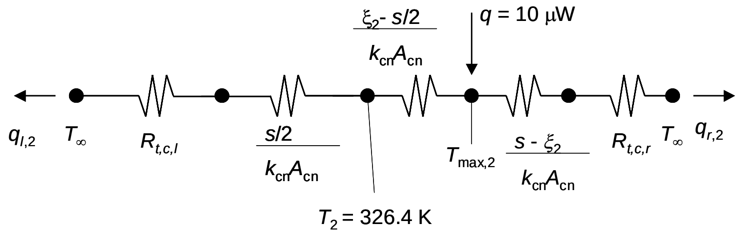
SCHEMATIC:



ASSUMPTIONS: (1) Steady-state, one-dimensional conduction. (2) Constant properties. (3) Negligible radiation and convection losses.

ANALYSIS: Thermal circuits may be drawn for the two laser irradiation locations as follows. The top circuit corresponds to irradiation on the left half of the nanotube. The bottom circuit corresponds to irradiation of the right half of the nanotube.





The following equations may be written for irradiation of the left side of the nanotube (top circuit).

$$q = q_{l,1} + q_{r,1} \tag{1}$$

$$q_{l,1} = \frac{T_{\max,1} - T_\infty}{R_{t,c,l} + \dfrac{\xi_1}{k_{cn}A_{cn}}} \tag{2}$$

Continued…

$$q_{r,1} = \frac{T_{\max,1} - T_\infty}{\frac{s/2 - \xi_1}{k_{cn}A_{cn}} + \frac{s/2}{k_{cn}A_{cn}} + R_{t,c,r}} \tag{3}$$

$$q_{r,1} = \frac{T_1 - T_\infty}{\frac{s/2}{k_{cn}A_{cn}} + R_{t,c,r}} \tag{4}$$

For irradiation of the right side of the nanotube (bottom circuit),

$$q = q_{l,2} + q_{r,2} \tag{5}$$

$$q_{l,2} = \frac{T_{\max,2} - T_\infty}{\frac{s/2}{k_{cn}A_{cn}} + \frac{\xi_2 - s/2}{k_{cn}A_{cn}} + R_{t,c,l}} \tag{6}$$

$$q_{l,2} = \frac{T_2 - T_\infty}{\frac{s/2}{k_{cn}A_{cn}} + R_{t,c,l}} \tag{7}$$

$$q_{r,2} = \frac{T_{\max,2} - T_\infty}{\frac{s - \xi_2}{k_{cn}A_{cn}} + R_{t,c,r}} \tag{8}$$

With k_{cn} = 3100 W/m·K, $A_{cn} = 1.54 \times 10^{-16}$ m^2, ξ_1 = 1.5 μm, T_1 = 324.5 K, ξ_2 = 3.5 μm, and T_2 = 326.4 K, Equations (1) through (8) may be solved simultaneously to yield

$T_{\max,1}$ = 331.0 K, $q_{l,1} = 6.896 \times 10^{-6}$ W, $q_{r,1} = 3.104 \times 10^{-6}$ W
$T_{\max,2}$ = 334.8 K, $q_{l,2} = 4.00 \times 10^{-6}$ W, $q_{r,2} = 6.00 \times 10^{-6}$ W

and

$R_{t,c,l} = 1.35 \times 10^6$ K/W ; $R_{t,c,r} = 2.65 \times 10^6$ K/W <

COMMENTS: (1) Assuming large surroundings, the maximum possible radiation loss is associated with blackbody behavior and $T_{\max,1}$. For this situation, $q_{\text{rad,max}} = \sigma\pi Ds(T_{\max,2}^4 - T_{sur}^4) = 5.67 \times 10^{-8}$ W/m^2·K^4 × π × 14 × 10^{-9} m × 5 × 10^{-6} m × (334.8^4 – 300^4)K^4 = 55 × 10^{-10} W. This is much less than the laser irradiation. Therefore, radiation heat transfer is negligible. (2) The carbon nanotube is not placed symmetrically between the two islands. It is difficult to place a carbon nanotube with such accuracy.