Detection of Light. Problem Set 10

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1 Design of a bolometer

Suppose you want to build a high performance bolometer based on a cubic thermo-element (0.53mm on a side) made of gallium-dopped germanium connected to the heat sink via two cylindrical thin brass leads 1cm long each. The bolometer is to be operated at $T = 2K$. Assume that the dopping is such that the element resistance is of $1 \times 10^6\ \Omega$ at the operating temperature, and that the temperature dependence of its resistance is given by:

$$R = R_0 \left(\frac{T}{T_0}\right)^{-4}$$

Assume also that the detector is blackened so that its quantum efficiency is $\eta = 0.5$

- To obtain a good performance, suppose that you want the detector to have a thermal-noise limited NEP of 5×10^{-15} W Hz$^{-1/2}$. What must be the radius of the cylindrical leads to achieve this performance? (At the operating temperature the electrical conductivity of brass is $\sigma = 3.1 \times 10^5\ \Omega^{-1}\ \mathrm{cm}^{-1}$)
- Derive the load curve (current vs. voltage) for the bolometer. Tip: Use the definition of conductance and the relation given above for the temperature dependance of resistance.
- The temperature coefficient of resistance is defined as:

  $$\alpha(T) = \frac{1}{R}\frac{\mathrm{dR}}{\mathrm{dT}}$$

  and a more accurate definition of the Johnson NEP is:

  $$\mathrm{NEP_J} = \left(\frac{\mathrm{4kT}}{\mathrm{P}}\right)^{1/2} \frac{\mathrm{G}}{\eta|\alpha(\mathrm{T})|}$$

  where $P = I^2 R$ is the electrical power dissipated in the detector.

  Calculate the Johnson-noise-limited NEP for the bolometer, if it is connected in a circuit (as shown) with $V_{\mathrm{bias}} = 1.5V$ and load resistance

$R_L = 10^7 \Omega$. (Here, remember that to first order the current through the bolometer is regulated by the load resistor. This should help you to find the electrical power dissipated in the detector). Which type of noise dominates for this detector?

- In semiconductors at low temperature, the heat capacity is dominated by the cristal lattice term. From Debye theory, it can be shown that this term is proportional to T^3. For the particular case of germanium:

  $$c_v^{\mathrm{lat}} \approx 7 \times 10^{-6}\, T^3\, \mathrm{J\,K^{-4}\,cm^{-3}}$$

  On the other hand, the contribution from the brass leads is dominated by the free electrons, and it is proportional to T:

  $$c_v^{e} \approx 1.3 \times 10^{-4}\, T \mathrm{J\,K^{-2}\,cm^{-3}}$$

  Calculate these two terms given the dimenssions of the brass leads and the thermo-element. Which one dominates? How do they relate to each other as T approaches 0K?