Chapter 1

Problem 12: Design

A resistor is made of a suspended, doped polycrystalline silicon beam with the resistance being 5kΩ. Calculate the resistor's Johnson noise when measured in a frequency range of 0 to 100 Hz and 0 to 10 kHz. The temperature of the resistor is 27°C and the bias voltage is 2 V.

Solution:

The magnitude of the Johnson noise for 0-100 Hz is

$$V_{noise} = \sqrt{4kTRB} = \sqrt{4(1.38 \times 10^{-23})300 \cdot 5000 \cdot 100} = 91 pV$$

The magnitude of the Johnson noise for 0-1000 Hz is

$$V_{noise} = \sqrt{4kTRB} = \sqrt{4(1.38 \times 10^{-23})300 \cdot 5000 \cdot 1000} = 287.8 pV$$

Problem 13: Design

Solution:

The volume of the sphere is $V = \frac{4}{3}\pi r^3$. The total buoyancy force is expressed as

$$f_{buoyancy} = Vg\gamma_s - Vg\gamma = \frac{4}{3}\pi r^3 (\gamma - \gamma_s)$$

If we designate the radius to be the characteristic length scale, L, we have

$$f_{buoyancy} \propto L^3$$

Problem 14: Design

Solution:

The mass is proportional to the characteristic length scale to the third power. The static displacement due to gravity is

$$d = \frac{mg}{k} \propto \frac{L^3}{L} = L^2$$

The resonant frequency is

$$f \propto \sqrt{\frac{m}{K}} \propto \sqrt{\frac{L^3}{L}} = L$$

Problem 19: Design

Solution:

The magnitude of the Johnson noise for a bandwidth of 1kHz is

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$$V_{noise} = \sqrt{4kTRB} = \sqrt{4(1.38 \times 10^{-23})300 \cdot 10000 \cdot 1000} = 407\,pV$$

Problem 21: Design

Answer:

Some candidate principles include:

Resistance chance due to temperature variation;

Thermal electric voltage generation;

Variation of infrared radiation intensity;

Thermal bimetallic bending of mechanical members, detected optically;

Thermal bimetallic bending of mechanical members, detected mechanically;

Thermal expansion, detected optically;

Thermal expansion, resulted changes of dimensions of electric pathways;

Thermal expansion, detected capacitively;

Changes of magnetic characteristics due to temperature variation;

Changes of fluorescent emission characteristics of certain molecules due to temperature change.

Problem 22: Design

Answer:

Candidate methods include thermal expansion, magnetic force and torque, optical induced thermal expansion, light pressure, fluid dynamic pressure, phase change materials, shape memory alloy, molecular interaction (e.g., DNA tweezers), bacteria motility, among others.

Chapter 2

Problem 10: Fabrication

Answer:

Photoresist would dissolve in the wet silicon etchant. According to Table II of [77], the etch rate of KOH on photoresist is greater than 13 μm/min, whereas the etch rate on oxide is only 7.7 nm/min.

Problem 11: Fabrication

Answer:

From step *d* to *e*, the silicon nitride can be etched by using plasma etch with photoresist as a mask.

From step *g* to *h*, the etchant is unchanged – wet silicon etchants. Candidate wet etchants include EDP, KOH, or TMAH.

Chapter 3

Problems

Problem 1: Review

Solution:

Silicon assumes diamond lattice. In each unit lattice (bound by a box with each side being 5.43 Å, there are 8 atoms per cell. The volume concentration is

$$\frac{8}{(5.43 \times 10^{-8})^3} = 5 \times 10^{22} \, atoms/cm^3$$

The density of silicon is

$$\frac{5 \times 10^{22}(atoms/cm^3) \times 28.1(g/mole)}{6.02 \times 10^{23}(atoms/mole)} = 2.33g/cm^3$$

Problem 2: Design

Solution:

The resistivity of gold at room temperature is $2.271 \times 10^{-8} \Omega m$ according to CRC Handbook of Chemistry and Physics, 75th edition.

Since

$$50 = 2.271 \times 10^{-8} \frac{l}{0.1 \times 10^{-12}} = 227100l$$

we find the value of length being

l=220 μm

Problem 3: Design

Solution:

The semiconductor is doped n type. The concentration of minority carrier is

$$p = n_i^2/n = 2250cm^{-3}$$

The resistivity is

$$\rho = \frac{1}{\sigma} = \frac{1}{q(\mu_n n + \mu_p p)}$$

$$= \frac{1}{1.6 \times 10^{-19} \times (1350 \times 10^{17} + 480 \times 2250)}$$

$$= 0.046 \frac{V \cdot s \cdot cm}{C} = 0.046 \frac{V \cdot cm}{A} = 0.046\Omega \cdot cm$$

Problem 4: Design

Solution:

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The piece of semiconductor material is doped p type. The concentration of minority carrier is
$$n = n_i^2 / p = 2250 cm^{-3}$$
The resistivity is
$$\rho = \frac{1}{\sigma} = \frac{1}{q(\mu_n n + \mu_p p)}$$
$$= \frac{1}{1.6 \times 10^{-19} \times (1350 \times 2250 + 480 \times 10^{17})}$$
$$= 0.13 \Omega \cdot cm$$

Problem 5: Design

Solution:

The semiconductor is doped n type. The concentration of minority carrier is
$$p = n_i^2 / n = 2.25 \times 10^9 cm^{-3}$$
The resistivity is
$$\rho = \frac{1}{\sigma} = \frac{1}{q(\mu_n n + \mu_p p)}$$
$$= \frac{1}{1.6 \times 10^{-19} \times (1350 \times 10^{11} + 480 \times 2.25 \times 10^9)}$$
$$= 4.6 \times 10^4 \Omega \cdot cm$$

Problem 6: Design

Answer:

The volume doping concentration is simply $\frac{10^{14} atoms / cm^2}{10^{-4} cm} = 10^{18} atoms / cm^3$.

Problem 7: Design

Solution:

The resistor consists of 20 squares. The total resistance is 20x50=1kΩ.

Given the junction depth (d), the resistivity is
$$\rho = \rho_s d = 50 \times 0.3 \times 10^{-4} = 1.5 \times 10^{-3} \Omega cm$$
Assuming the majority carrier concentration dominates, we have
$$\rho = \frac{1}{\sigma} = \frac{1}{q(\mu_p p)}$$
$$= \frac{1}{1.6 \times 10^{-19} \times (480 \times p)}$$
$$= 1.5 \times 10^{-3} \Omega \cdot cm$$
Hence the concentration p is $8.69 \times 10^{18} atoms / cm^3$.

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