Resistivity, Sheet Resistance and Mobility

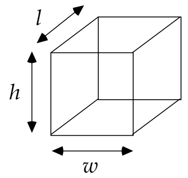
Overview

Topics:

- **Resistivity**
- **Sheet resistance**
- **Examples**
- **Conductivity and Electric Field**
- **Current Density**
- **Carrier concentration**
- **Mobility**

Resistivity

- **Resistivity is the property of a material that determines the electrical resistance of a specific sample.**



- **The block of material has resistance (*R*) and resistivity (ρ).**
- **ρ remains constant regardless of size or shape.**

3

Resistivity

- **Calculate resistance between front and back faces :**

$$R = \rho \frac{l}{w \cdot h} = \rho \frac{l}{A}$$

- ***A* is the area through which the current must pass and can be used where the cross-section is not rectangular, e.g. for a wire with circular cross-section.**
- **If length increases, resistance increases and vice versa. Opposite for area.**
- **The S.I. unit of resistivity is the Ω m, but the practical unit is the Ω cm.**

4

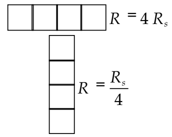
Sheet resistance

- In IC technology we often have conducting layers with constant depth (*h* in figure).
- Resistance therefore depends upon the aspect ratio as viewed from the surface (*l*/*w*).
- Define sheet resistance (R_s) so that resistance is:

$$R = R_s \frac{l}{w}$$

- R_s is given in Ω/square where $l = w$.

Sheet Resistance



The relation between ρ and R_s is:

$$R_s \frac{l}{w} = \rho \left(\frac{l}{w \cdot h} \right)$$

But since $l = w$:

$$\rho = R_s \cdot h$$

Using sheet resistance, define resistance of an area (e.g. in a silicon IC) by number of squares.

Example 1

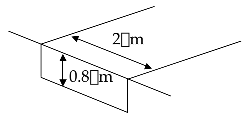
An aluminium rod 30cm long with a cross-section of 0.5cm x 0.25cm has a voltage of 100mV applied across it and a current of 13.9A is observed to flow. Calculate the resistivity, ρ, of the aluminium.

- **$R = V/I$ = 0.1/13.9A = 7.2 x 10^{-4} Ω**
- **$R = \rho l/wh$ or $\rho = Rwh/l$**
  so ρ = 7.2 x 10^{-4} x 0.005 x 0.0025/0.3 = 3 x 10^{-8} Ω m.

7

Example 2

An area of undoped (high resistivity) silicon contains a region of doped silicon (so much lower resitivity) for fabricating a 20 kΩ resistor, as shown in the figure. If the resistivity, ρ, of the doped silicon is 10^{-3} Ω m, calculate the sheet resistance, R_s, the number of squares of doped silicon required for the resistor, and hence the length of the resistor.



8

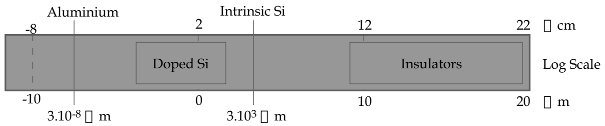
Example 2 Solution

- **We can assume that the doped silicon is a conducting area surrounded by insulator.**
- **$R_s = \rho/h = 10^{-3}/0.8 \times 10^{-6} = 1.25 \times 10^{3}\ \Omega$/square = 1.25k$\Omega$/square.**
- **No of squares = aspect ratio l/w since all squares must have sides of length w (in this case 2μm). $R = R_s l/w$ or $l/w = R/R_s$.**
- **No of squares = Value of resistor/Rs = 20k/1.25k = 16 squares.**
- **Length of resistor = No of squares x length of side of a square =16 x 2μm = 32μm.**
- **Alternatively to find the length:**

  $R = R_s l/w$ or $l = Rw/R_s = 20 \times 10^3 \times 2 \times 10^{-6}/1.25 \times 10^3 = 32\mu$m.

9

Range of Resistivity Values



Values cover 30 orders of magnitude!

10

Conductivity and Electric Field

Conductivity

- **The conductivity is the reciprocal of resistivity, i.e. the conductivity σ is given by:**

$$\sigma = \frac{1}{\rho}$$

- **The S.I. unit is obviously Ω^{-1} m^{-1} , but the unit of conductance (Ω^{-1}) is the Siemen (S), so conductivity actually has unit S m^{-1}.**

Electric Field

- **The gradient of the potential.**
- **The electric field, *E* between two points distance *l* apart with potential difference *V* is:**

$$E = \frac{V}{l}$$

- ***E* has units of V m^{-1} .**
- **Also** $E = -\frac{dV}{dx}$

Current Density

- **The current density is the current per unit area.**
- **If *I* is the total current flowing through an area *A*, the current density *J* is:**

$$J = \frac{I}{A}$$

- ***J* has units of A m^{-2} .**
- **Divide electric field by current density to get:**

$$\frac{E}{J} = \frac{V/l}{I/A}$$

$$= R\frac{A}{l} = \rho$$

i.e. $\frac{E}{J} = \rho$

- **This is just a slightly different form of Ohm's Law.**

Electric Current

- **Current is a flow of charge.**
- **We can measure current by measuring the charge that flows by in unit time ($I = Q/t$).**
- **Current is carried by charged particles (carriers) each carrying a known charge.**
- **Current is therefore determined by three factors:**
  - The amount of charge on each carrier.
  - The number of charge carriers in unit volume (known as the carrier concentration or density).
  - The velocity of the charge carriers.

13

Carrier Concentration

- **Electric current carried by charged particles (positive or negative).**
- **Called carrier concentration *n* or *p* (depending whether the charge is negative or positive).**
- **S.I. unit for *n* and *p* is carriers/m^3 (or simply m^{-3}).**
- **Practical unit used is cm^{-3} rather than the m^{-3}.**

14

Carrier Concentration

- Each carrier has charge.
- Negative charge carriers are electrons and charge is electronic charge (q = 1.602 x 10^{-19} C) .
- Positive charge carriers have positive charge of same amount.
- Sometimes charge carriers have multiples of q, but not in normal conduction, and we will not consider these more unusual situations.

15

Mobility

- Another important factor contributing to current.
- Carrier mobility (μ).
- Carriers accelerated by electric field, but decelerated again by collisions with atoms.
- Leads to a mean carrier velocity, $\bar{v}$, per applied electric field.
- The formula for mobility is:

$$\mu = \frac{velocity}{electric\ field} = \frac{\bar{v}}{E}$$

- Units are $m^2\ v^{-1}\ s^{-1}$. Practical unit is $cm^2\ v^{-1}\ s^{-1}$.

16