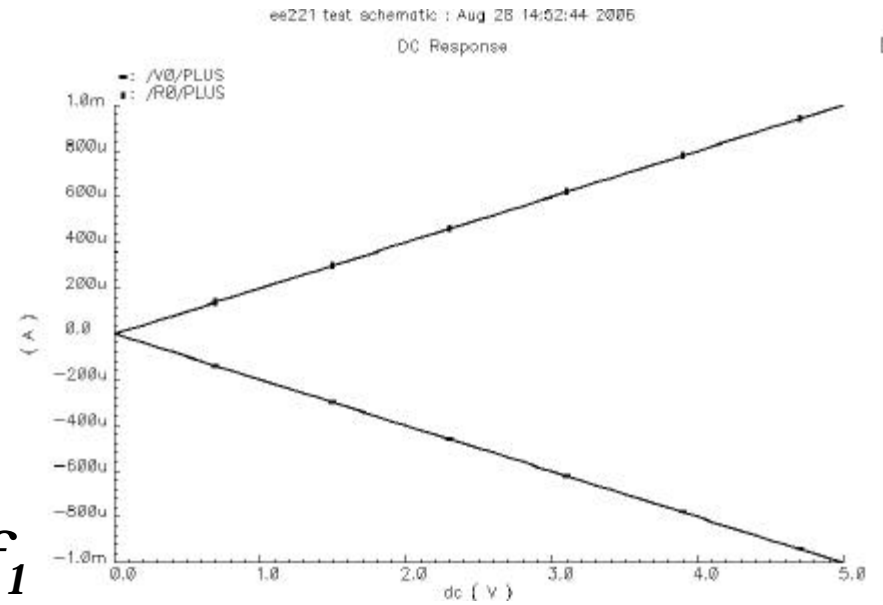
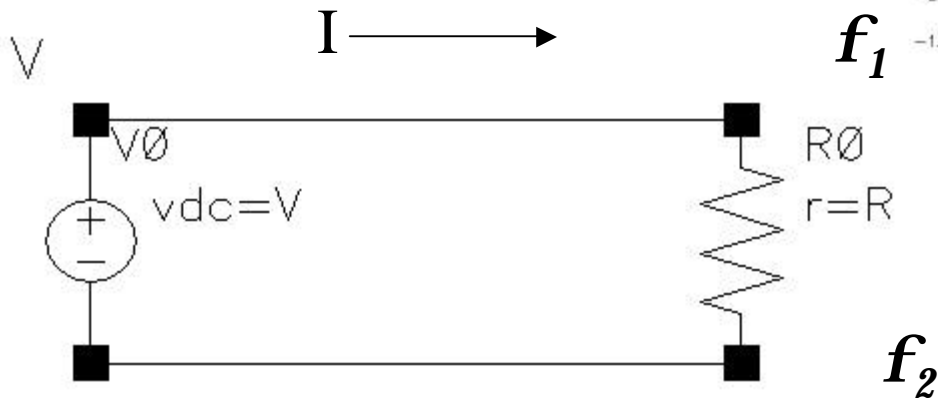


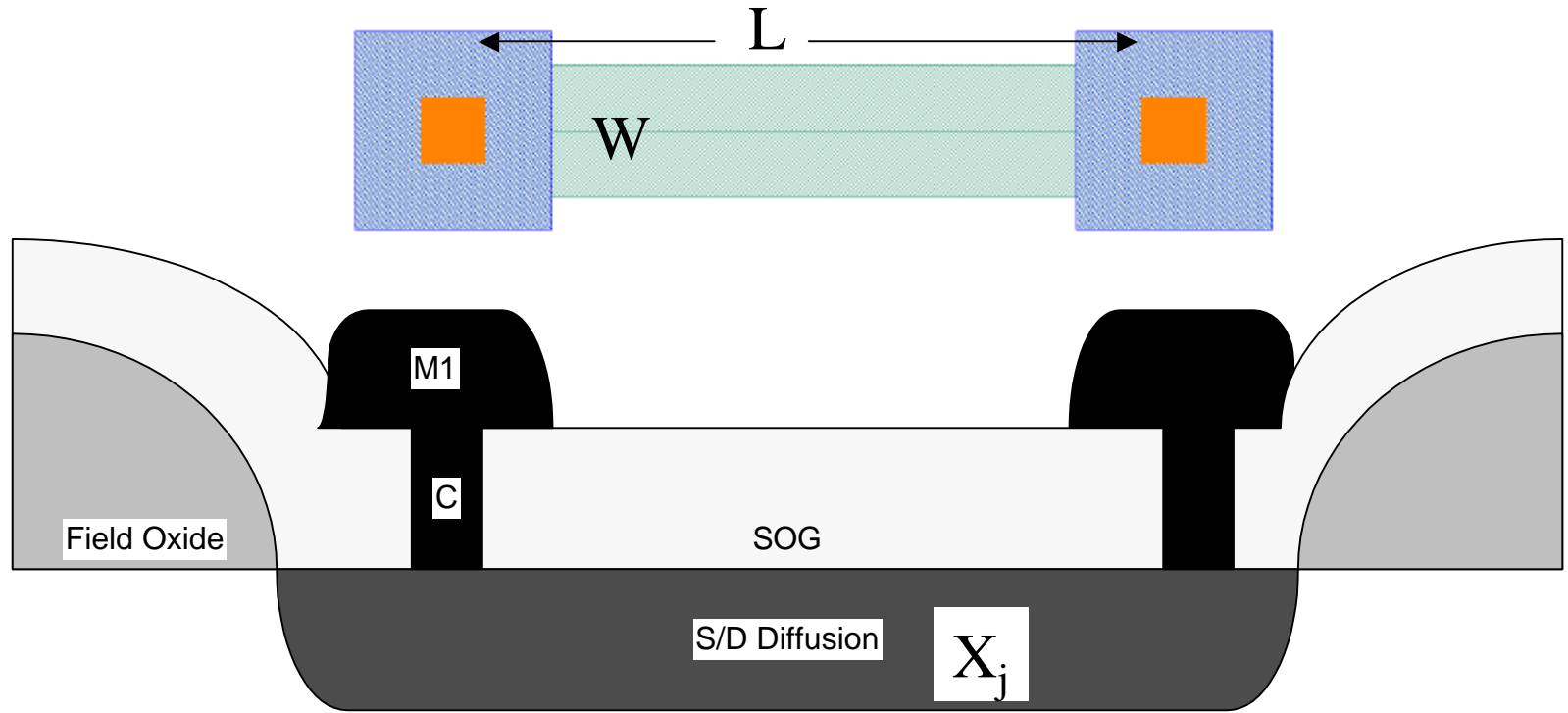
EE 221 Device Physics

Class 2 Resistor Basics

D. W. Parent

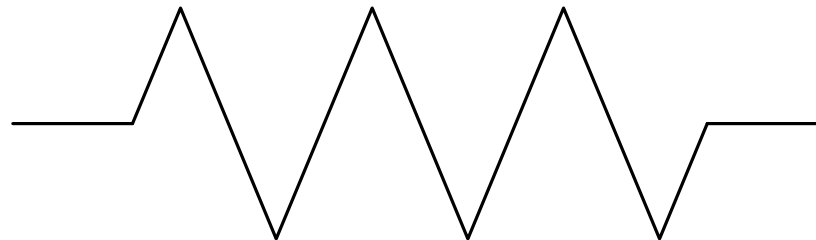
$I=V/R$ (This is simple!)





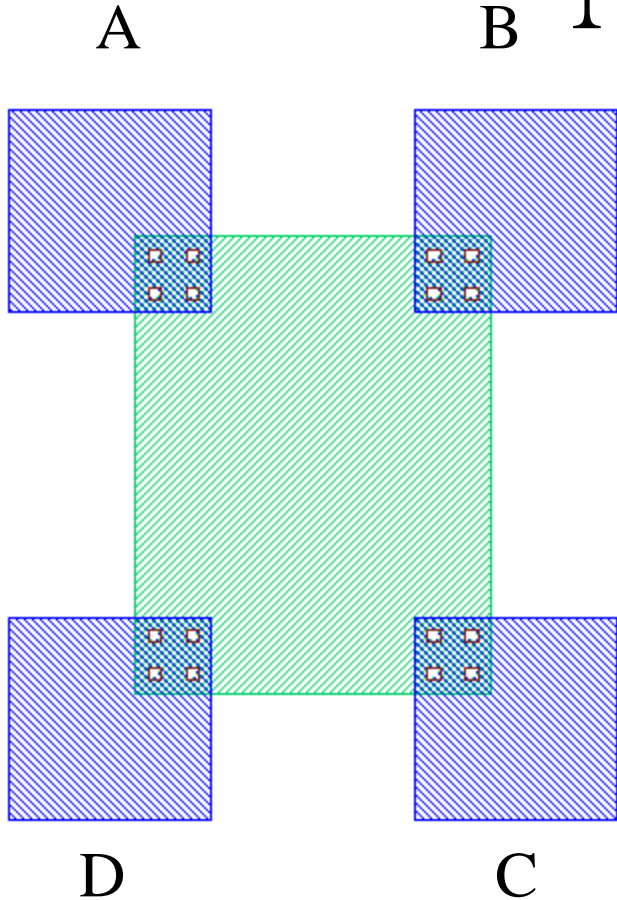
Slightly different definition of X_j .

$$R = \rho \cdot \frac{L}{x_j \cdot W}$$



No Contact resistance.

B NDIFF RS

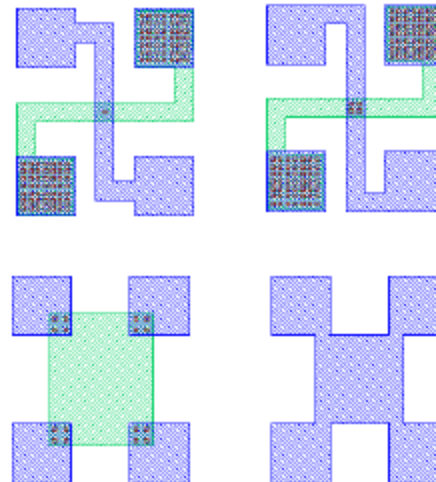


Force a current through A and D.

Measure the voltage difference from B to C.

$$R_S = 4.54 \frac{V_B - V_C}{I_{AD}}$$

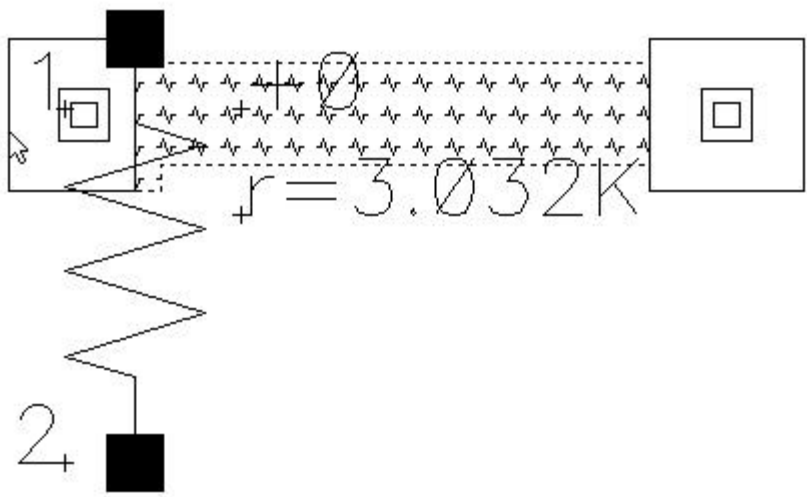
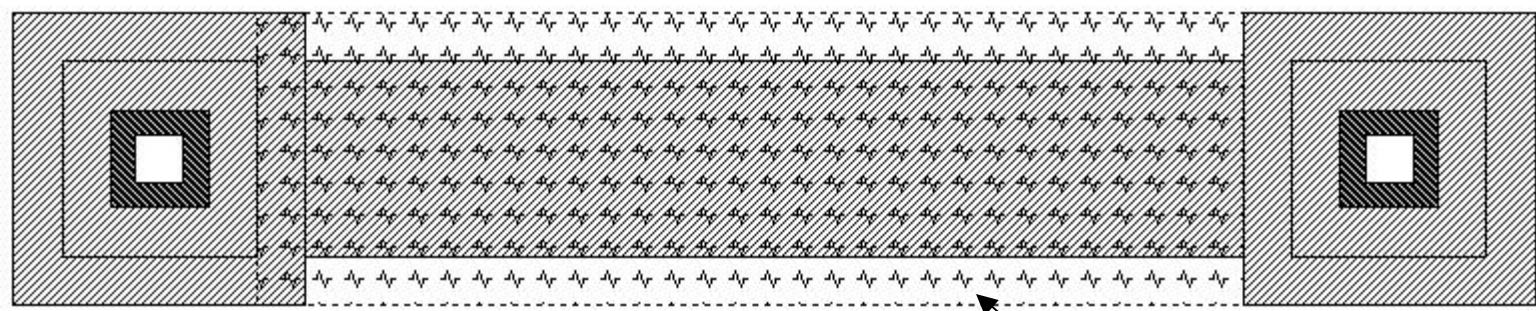
For a more accurate value you can rotate the measurement and average the two RS values.



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; nwell
extractDevice( nwellRes (nBulk "PLUS" "MINUS") "res ivpcell NCSU_Analog_Parts" )

```



RES_ID Layer

PROCESS PARAMETERS	M3	POLY_HRI	M4	M5	M6	N_W	UNITS
Sheet Resistance	0.08		0.07	0.07	0.03	965	ohms/sq
Contact Resistance	8.54		12.80	17.18	19.59		ohms

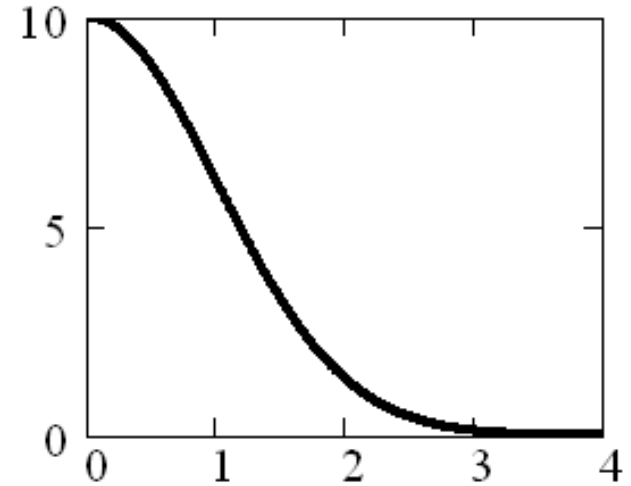
Gaussian curves can be used to model doping profiles easily!

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

$$R_s = \frac{1}{\sigma \cdot x_j} \quad R = R_s \cdot \frac{L}{W}$$

$$R_s = \frac{1}{\sigma_{\text{mean}} \cdot x_j}$$

$$10 \cdot e^{-\left(\frac{x}{\sqrt{2}}\right)^2}$$



$$\sigma_{\text{mean}} = \frac{10}{x_j} \cdot \int_0^{\infty} e^{-\frac{x^2}{2}} dx = \sqrt{\frac{\pi}{2}}$$

Drift current is modeled with the “simple” equations.

$$j = \frac{I}{\text{Area}}$$

$$\text{Area} = W \cdot x_j$$

This is at the heart of electrical TCAD simulations.

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

$$E = \text{Constant}$$

$$j = \sigma \cdot E$$

$$\vec{j} = \sigma \vec{E}$$

$$\frac{d\phi}{dy} = \frac{\Delta\phi}{\Delta y} = \frac{-(\phi_1 - \phi_0)}{L} = \frac{-V}{L}$$

$$E = \frac{-d\phi}{dy}$$

The electric current induced by an electric potential difference or an electric field is called drift current.

Conductivity is proportional to the carrier concentration times the carrier mobility.

Charge carriers in semiconductors

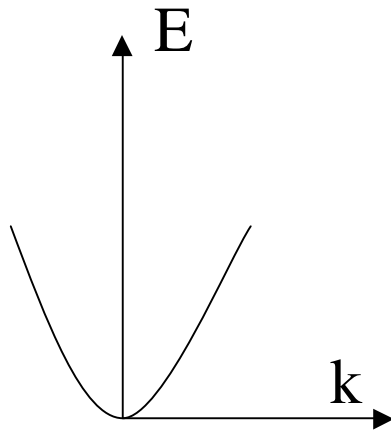
- Electrons and holes
 - Electrons (e) we know about, but what is a hole (h)?
 - When an electron receives enough energy to jump from the valence band to the conduction band it leaves behind an empty state. This creates an electron-hole pair (EHP)
 - Hole current is really due to an electron moving in the opposite direction in the valence band.
 - Electron current is an electron moving from state to state in the conduction band.

Charge carriers in semiconductors

- Effective mass
 - Electrons in a crystal are not totally free.
 - The periodic crystal affects how electrons move through the lattice.
 - We use an effective mass to modify the mass of an electron in the crystal and then use the E+M equations that describe free electrons.

Charge carriers in semiconductors

- Effective mass



$$p = mv = \hbar k$$

$$E = \frac{1}{2}mv^2 = \frac{\hbar^2}{2m}k^2$$

$$\frac{d^2 E}{dk^2} = \frac{\hbar^2}{m}$$

$$m^* = \frac{\hbar^2}{\frac{d^2 E}{dk^2}}$$

Charge carriers in semiconductors

- Effective mass
 - The double derivative of E is a constant
 - Not all semiconductors have a perfectly parabolic band structure
 - The different atomic spacing in each direction gives rise to different effective masses in different crystal directions. This can be compensated by using an average value of effective mass.

Charge carriers in semiconductors

- Effective mass (for density of states calculation)

	Ge	Si	GaAs
m_n^*	0.55 m_0	1.1 m_0	0.067 m_0
m_p^*	0.37 m_0	.56 m_0	0.48 m_0

Charge carriers in semiconductors

- Intrinsic material
 - A perfect semiconductor crystal
 - no impurities or defects
 - No charge carriers at 0K
 - valence band is filled, conduction band empty
 - Heat (lattice vibrations can break a covalent bond and push an electron into the conduction band (EHP))
 - This electron is moving several lattice constants away in a QM probability distribution.

Charge carriers in semiconductors

- Intrinsic material
 - Each electron pumped up to the valence band leaves an empty state behind, thus for intrinsic material the electron concentration in the conduction band (n_e/cm^3)=the hole concentration in the valence band (p_h/cm^3)

$$n = p = n_i$$

Charge carriers in semiconductors

- Intrinsic material
 - If this relation is to hold then the generation rate of EHP's must equal the recombination rate of EHP's

$$n = p = n_i$$

$$r_i = g_i$$

$$r_i = \mathbf{a}_r n_0 p_0 = \mathbf{a}_r n_i^2 = g_i$$

Charge carriers in semiconductors

- Extrinsic material
 - Intrinsic material is not very useful except for devices which change their conductivity based on optical or thermal excitation. There is no gain mechanism involved and thus large areas are needed to detect the effect, thus are slow.
 - One can create extrinsic material by replacing semiconductor atoms in the lattice with atoms from different groups in the periodic table.

Charge carriers in semiconductors

- Extrinsic material.

II	III	IV	V	VI
	B	C		
	Al	Si	P	S
Zn	Ga	Ge	As	Se
Cd	In		Sb	Te

Charge carriers in semiconductors

- Extrinsic material.
 - Elements from group V give rise to energy levels close to the conduction band in Si and Ge and is completely filled at 0K. It only takes a little energy to make an electron jump from this level to the conduction band. This new energy level donates an electron and so group V elements are known as donors (with respect to Si and Ge)

Charge carriers in semiconductors

- Extrinsic material.
 - Elements from group III give rise to energy levels close to the valence band in Si and Ge and is completely empty at 0K. It only takes a little energy to make an electron jump from the valence band to this new level. This new energy level accepts an electron and so group III elements are known as acceptors (with respect to Si and Ge)

Charge carriers in semiconductors

- Extrinsic material.
 - Not all group III and V elements make good dopant sources, if the new energy level is near the middle of the band gap then it takes more energy to accept or donate an electron.
 - In III-VI semiconductors it is more complex
 - group VII elements on a VI site will donate an electron
 - group II elements on a III site will accept an electron
 - group IV elements can go on either a III or VI and thus are amphoteric

Let's do some examples.

$$\sigma = q \cdot n \cdot \mu_n + q \cdot p \cdot \mu_p$$

$$n = p = n_i \quad n \cdot p = n_i^2$$

$$\text{net charge} = p - n - N_A + N_D = 0$$

- Minority carrier concentration example
- Doping and conductivity
- Doping compensation
- Light and resistivity

Problems

- 1.1
- 1.2
- 1.3
- 1.4
- 1.6
- 1.7
- 1.13