EMCR632/702 - Silicon Processes

Catalog: EMCR632 *Silicon Processes*
EMCR702 *Microelectronics II*

Lecture#20

Ion Implant for ULSI

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1/30/02

Ion Implant - Lecture#20

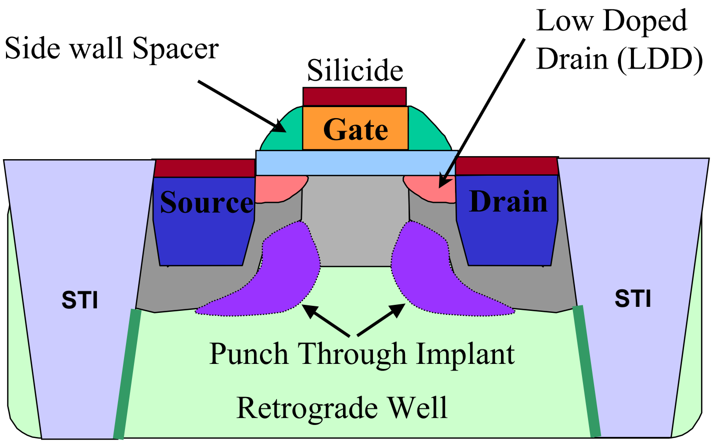
1/30/02

Topics:

- **Motivation: Advanced CMOS device structure**
- **Ion implant**
  - **Pearson distribution**
  - **Ion Channeling**
- **Implant Damage**

- **HW#4 due Friday**

Advanced CMOS Technology

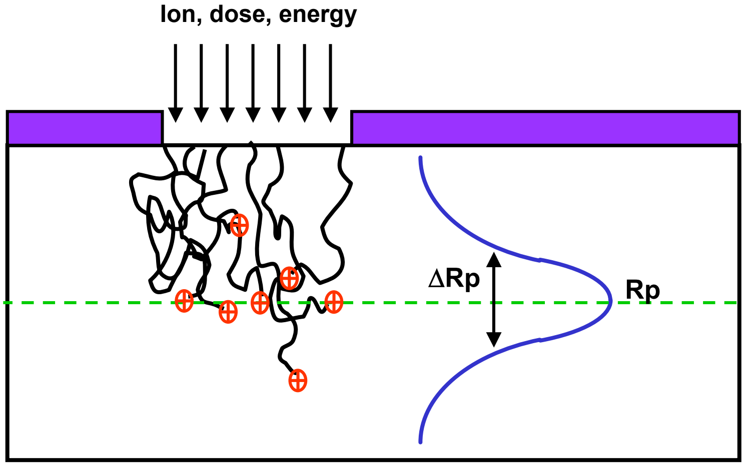


EMCR632/702 Silicon Processes

Ion Implant

Ref: **Campbell chapter 5**
Wolf & Tauber Vol I - chapter 9

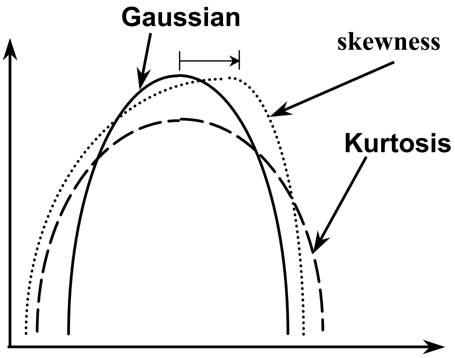
Random interactions with target atoms



Pearson-IV Distribution

•If an analytical solution is used, a higher-moment distribution is needed which can more accurately describe the implanted impurity profile

• Parameters adjusted to fit Monte Carlo simulations (using ion stopping theory) or actual measured profiles (SIMS).



Pearson-IV Distribution

I. Mean (Rp)

II. St.Dev. (ΔRp)

III. Skewness (γ)

- asymmetry of the dist.

IV. Kurtosis (β)

- distortion of peak

- larger value if flatter top

4-Moment Distribution

1) **Projected Range (mean)**

$$R_p = \frac{1}{\Phi}\int_{-\infty}^{\infty} xN(x)dx$$

2) **Straggle (standard deviation)**

$$\Delta R_p = \sqrt{\frac{1}{\Phi}\int_{-\infty}^{\infty} (x-R_p)^2 N(x)dx}$$

3) **skewness**

$$\xcancel{\gamma = \frac{\int_{-\infty}^{\infty} (x-R_p)^3 N(x)dx}{\Phi \Delta R_p^3}}$$

4) **kurtosis**

$$\xcancel{\beta = \frac{\int_{-\infty}^{\infty} (x-R_p)^4 N(x)dx}{\Phi \Delta R_p^4}}$$

Ion Channeling

Pearson-IV distribution works well for implants into amorphous silicon, or if ion channeling is supressed. Otherwise an adjustment must be made to correct for tilt/rotation dependence.

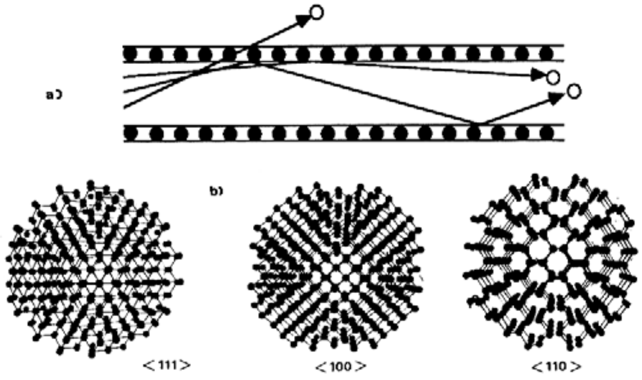
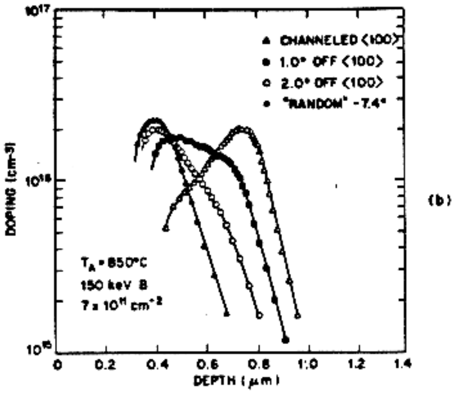


Fig from W & T

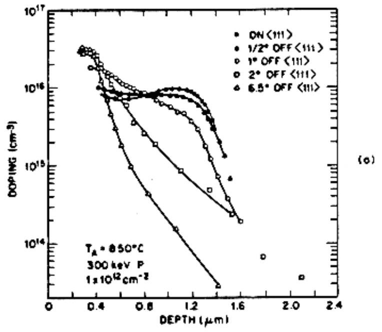
Fig. 10 (a) Schematic representation of ion trajectories in an axial channel for various entrance angles. (b) Ball model showing relative degree of "openness" of the diamond (Si) lattice when traversing in <111>, <100>, and <110> directions.

Channeling Effects



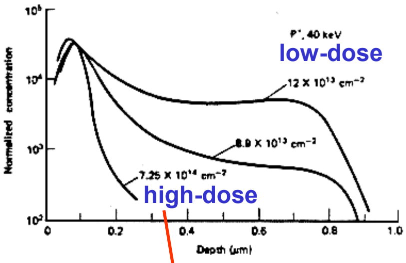
BORON PROFILES FOR VARIOUS ORIENTATIONS AWAY FROM THE <100> AXIS FOR 150KeV B^{11} IMPLANTS

Channeling Effects



IONIZED PHOSPHOROUS PROFILES FOR VARIOUS ORIENTATIONS AWAY FROM THE <111> AXIS FOR 300KeV P^{31} IMPLANTS

normalized profiles



low-dose

high-dose

Fig 9 CHANNELING OF PHOSPHOROUS

self-amorphization

Methods to avoid channeling

Tilt & Twist

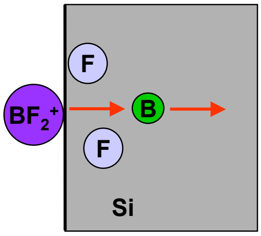
Screen Oxide - amorphous surface layer
  - 200-250Å is thick enough

Pre-amorphization implant
  - silicon implant to pre-amorphize lattice
  - 2-stage BF_2 & B^{11} implant

Self-amorphization
  - arsenic (heavy ions) , high dose

BF_2^+ molecular ion implants

- **Used for shallow p+ junctions**
- **Used for pre-amorphization for boron (B11) implants to reduce channeling effects and avoid buried amorphous regions**
- **Some issues with excess fluorine at high doses**
  - **BF_2 molecule dissociates upon impact**
  - **some electrical activity**
  - **defect cluster formation**



Kinetic Energy associated with boron atom:

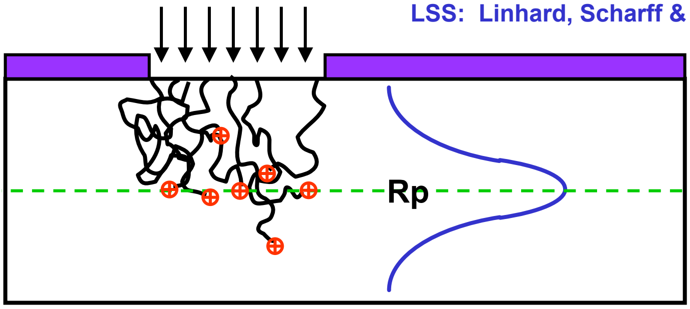
$KE = \frac{1}{2}(m)v^2$

$E_B = E_{BF2}(M_B/M_{BF2}) = E_{BF2}(11/49)$

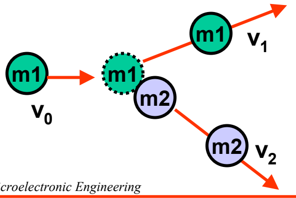
ex: BF_2 @ 100KeV ~ B^{11} @ 20KeV

LSS Theory of Ion Stopping

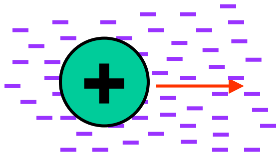
LSS: Linhard, Scharff & Schiott



Nuclear Stopping: Coulombic Scattering



Electronic Stopping



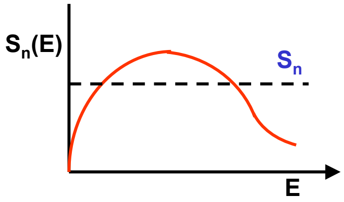
Nuclear Stopping

Energy loss per distance traveled as a function of energy:

$$S_n(E) = \left(\frac{dE}{dx}\right)_n$$

- depends on incident ion and target atom nuclear charge (Z = # protons) and atomic masses (M)

Energy loss due to interactions with atomic nuclei is basically a decreasing function of energy. At high kinetic energy (ion velocity) there is a very short interaction time for any absorption of energy by target atoms.



Approximate nuclear stopping near max of $S_n(E)$:

$$\frac{dE}{dx(n)} = S_n = N\frac{\pi^2}{2}e^2 a\frac{Z_1Z_2M_1}{M_1+M_2}$$

where

N is the atomic density (atoms/Volume)

a ~ $1.4\text{x}10^{-2}$ nm, subscripts 1 and 2 refer to ion and target respectively, Z is atomic number and M is mass number

Electronic Stopping

Due to interactions with electrons in the target material

- like a drag force that is proportional to the ion velocity

Ion velocity α (Energy)$^{1/2}$

$$S_e(E) = \left(\frac{dE}{dx}\right)_e \propto E^{1/2} = k_e E^{1/2}$$

where k_e is relatively independent of the incident ion

For silicon: $k_e \sim 10^7 (\mathrm{ev})^{1/2}/\mathrm{cm}$

Total rate of energy loss = $\boxed{dE/dx = S_n(E) + S_e(E)}$

LSS Calculations

ε & ρ are dimensionless parameters

ε α energy

ρ α range (R) (distance variable)

"like" dE/dx

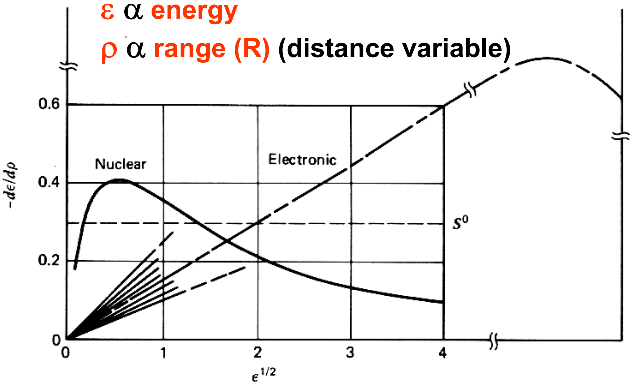


Fig. 6.8 Nuclear and electronic stopping power curves. From J. W. Mayer, L. Eriksson, and J. A. Davies, *Ion Implantation in Semiconductors* [7], 1970. Used with permission of Academic Press, Inc.

Range & Straggle

From LSS Theory:

$$Rp \cong \frac{R}{1+\left[\frac{M_T}{3M_i}\right]} \qquad \Delta Rp \cong \frac{2Rp}{3}\frac{\sqrt{M_i M_T}}{M_i + M_T}$$

Nuclear & Electronic Stopping

Electronic stopping dominates:

Light ions and high energies

Nuclear stopping dominates:

Heavy ions and low energies

Implant damage occurs due to nuclear interactions. The extent of damage depends on $S_n(E)$.