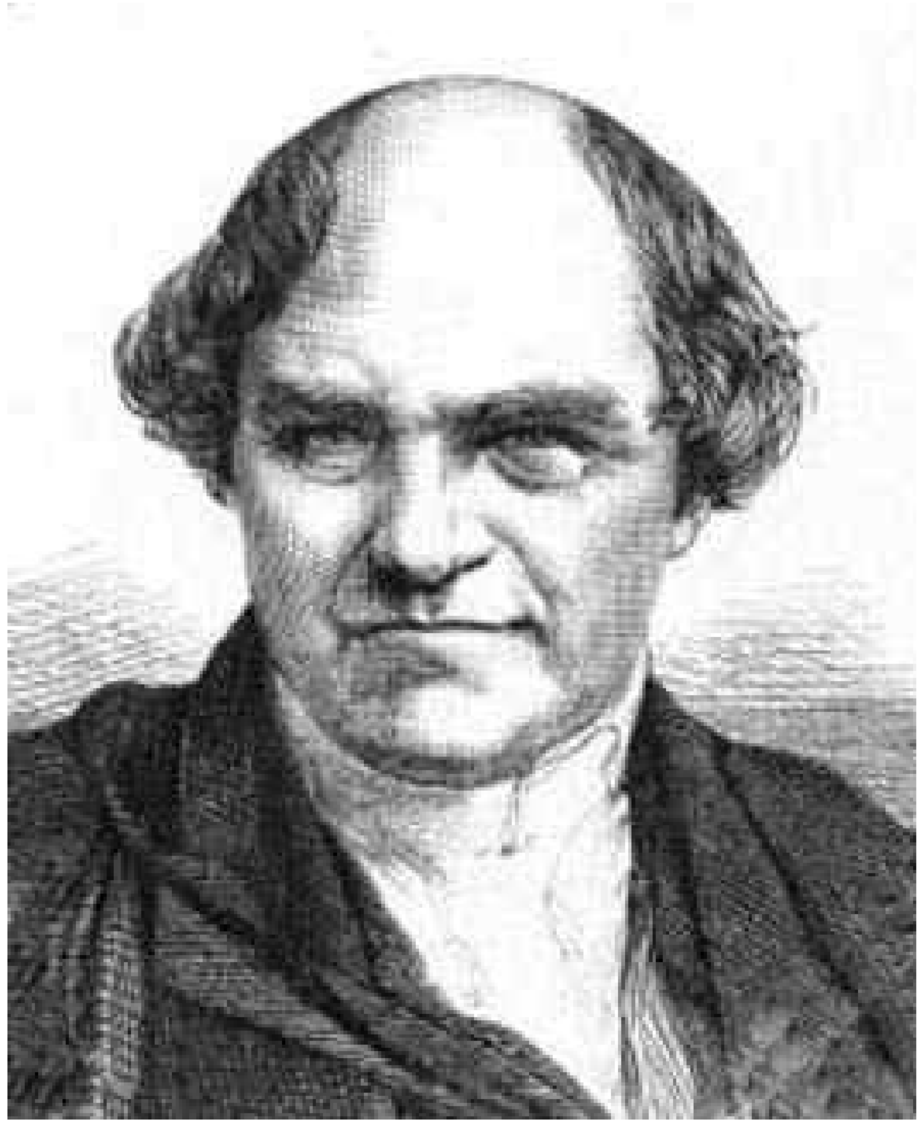
DIELECTRICS & HIGH-K PROPERTIES AND CHALLENGES

With Momem Magdy, Ammar Wardany, Nour Hussein, Momen Medhat, and Mohammed Mahmoud

AMMAR PART

ETYMOLOGY



dia + electric =diaelectric

dielelctric

DIELECTRIC VS INSULATIORS

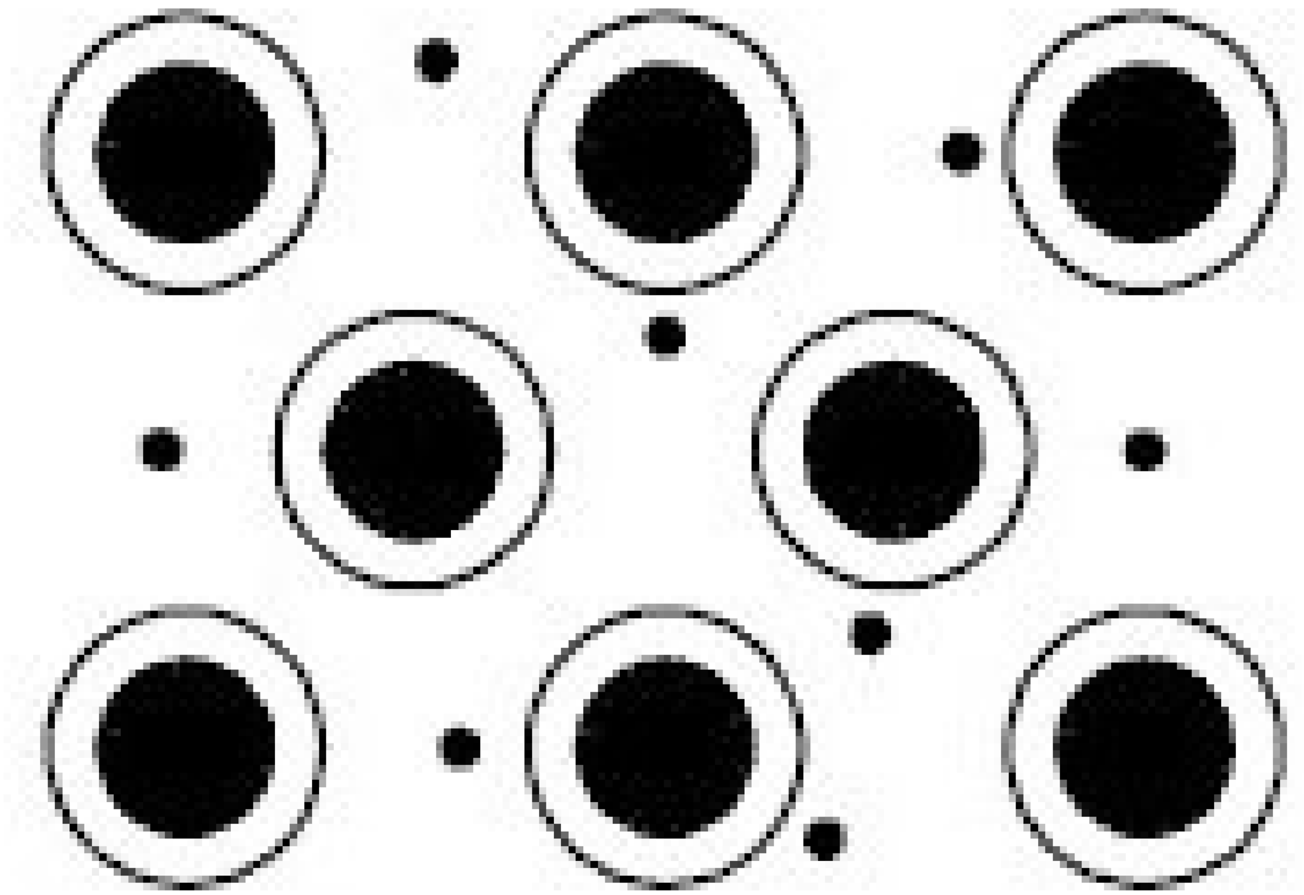
dielectrics

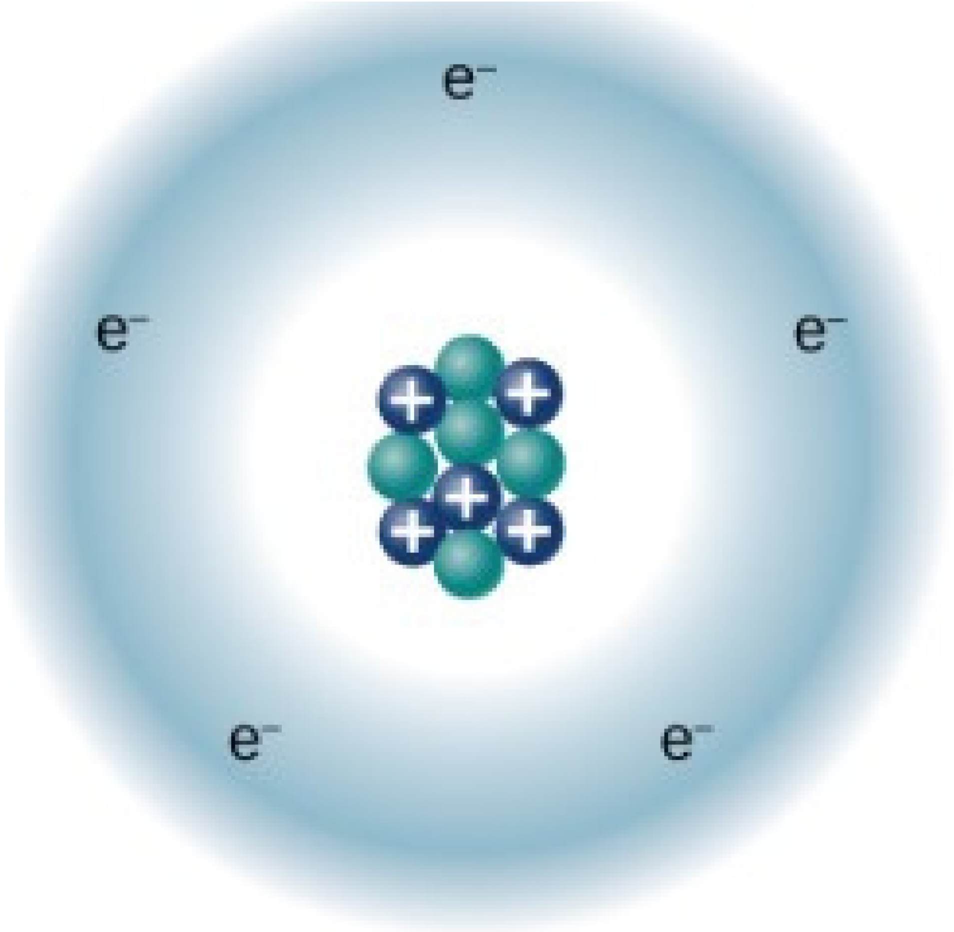
energy storage

insulators

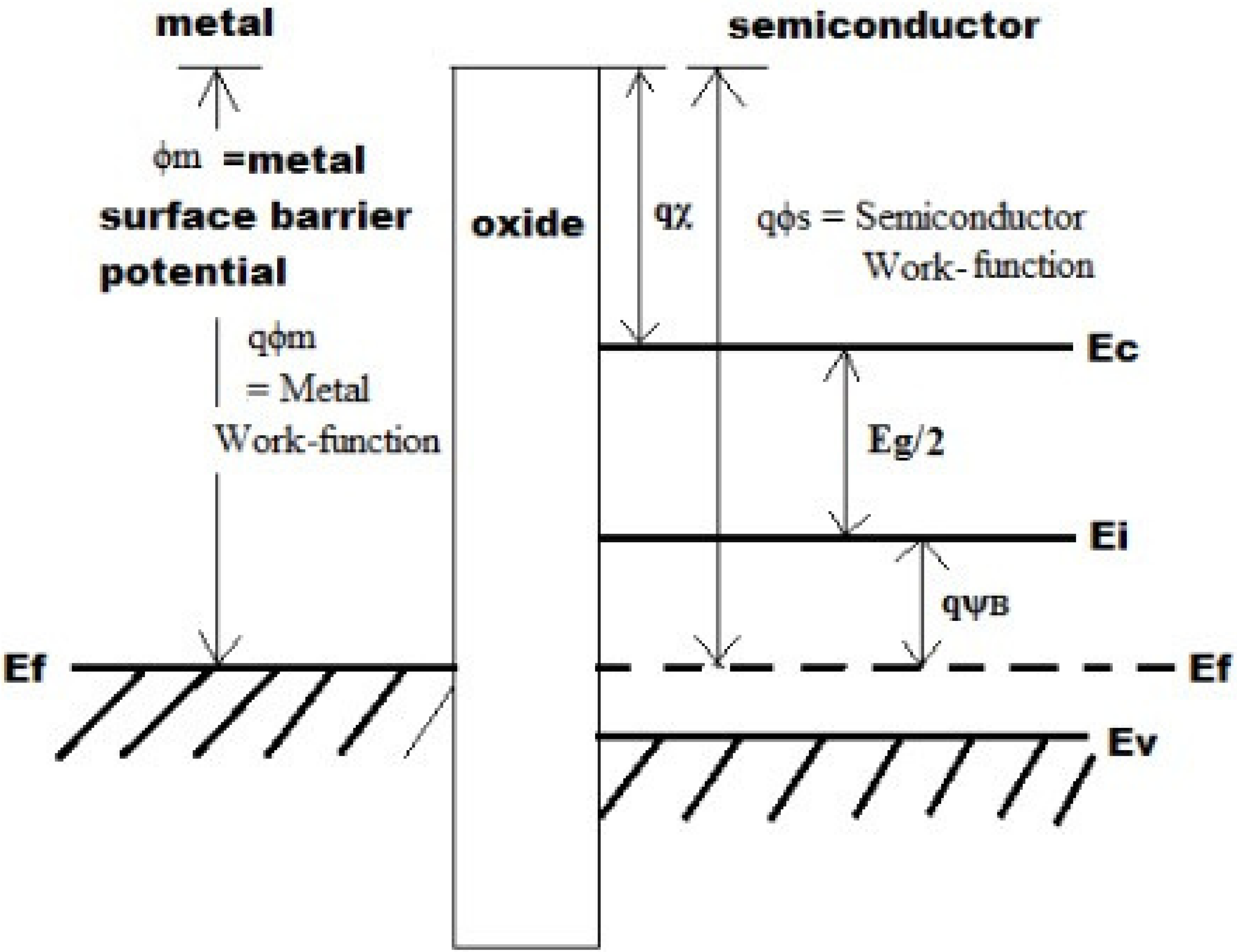
current obstraction

DIELECTRIC VS METAL

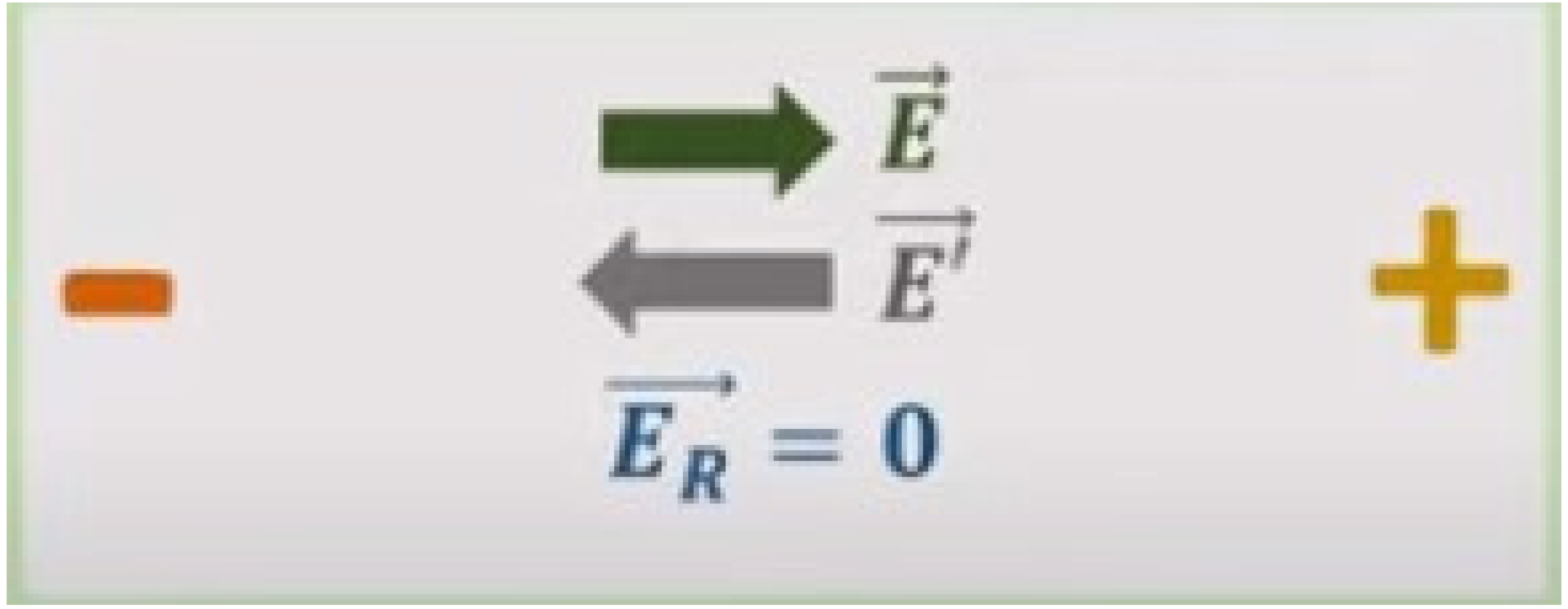




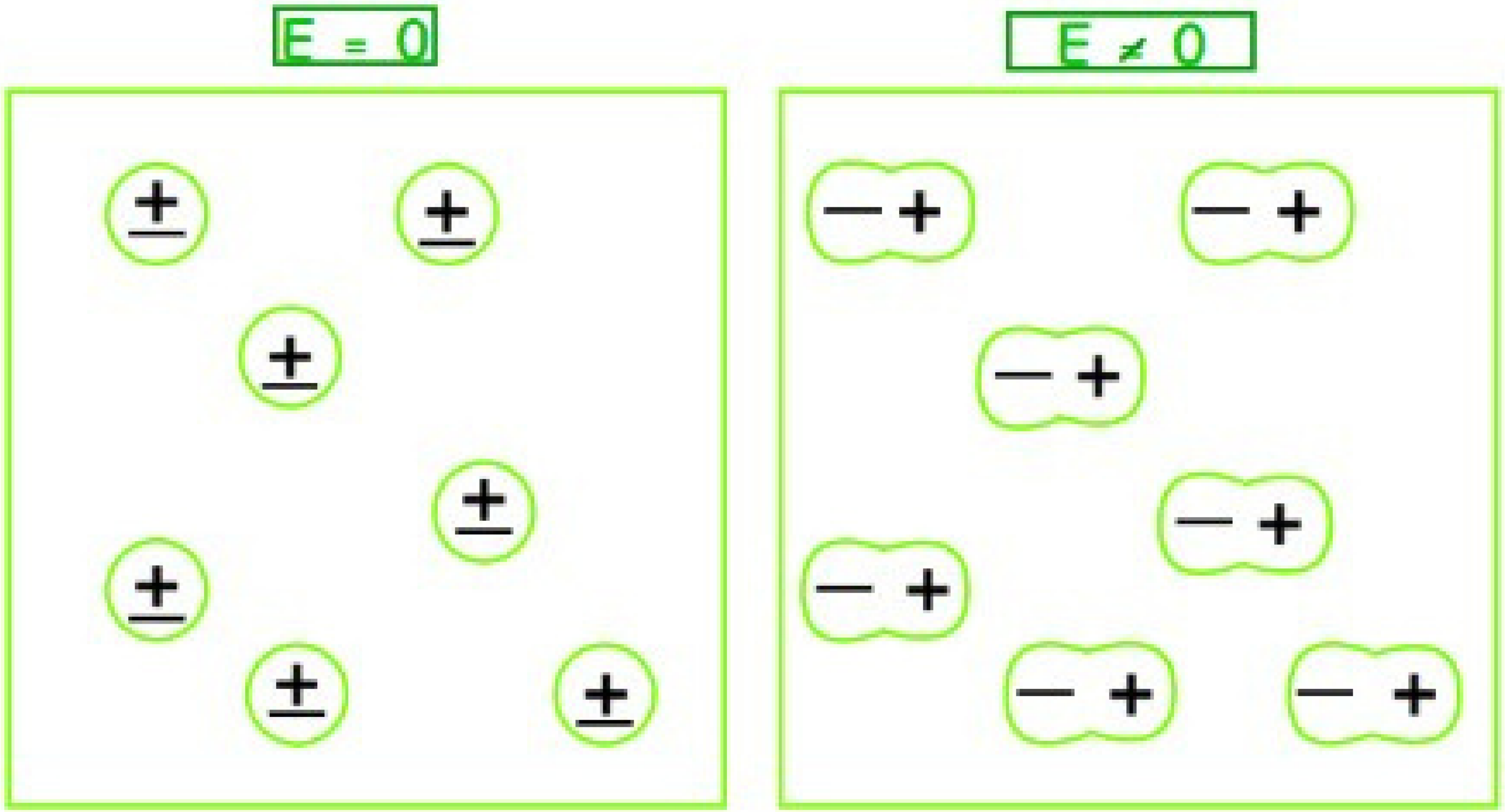
Unpolarized


metal
semiconductor
ϕm =metal surface barrier potential
oxide
qχ
qϕs = Semiconductor Work- function
qϕm = Metal Work-function
Ec
Eg/2
Ei
qψB
Ef
Ef
Ev

dielectric VS metal in the presence of E



$$\vec{E}_R = \vec{E} - \vec{E}' = 0$$



Electric Polarization

$$\vec{E}_R = \vec{E} - \vec{E}'$$

DIELECTRIC PARAMETERS

χ

susceptibility

ϵ

permittivity

κ

dielectric constant

NOUR PART

PARAMETERS AFFECT THE DIELECTRIC PROPERTIES

PARAMETERS AFFECT THE DIELECTRIC PROPERTIES

01 Alternating Field

02 Atomic Structure

03 Temperature

04 Impurities

05 High Electric Field

1.ALTERNATING FIELD

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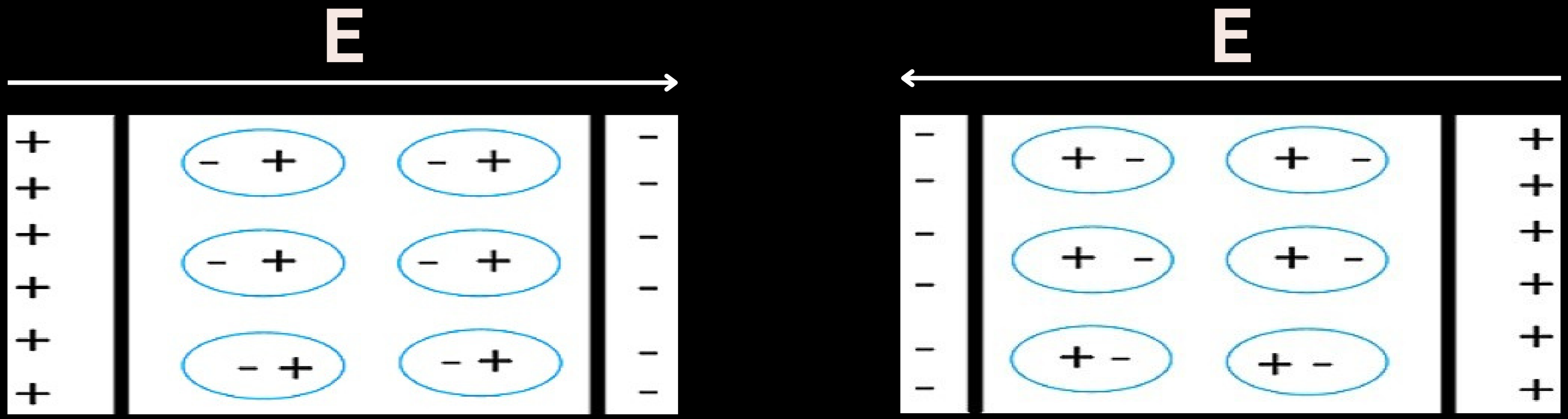

The dipole orientation becomes unable to keep up with the alternating field.

2.ATOMIC STRUCTURE

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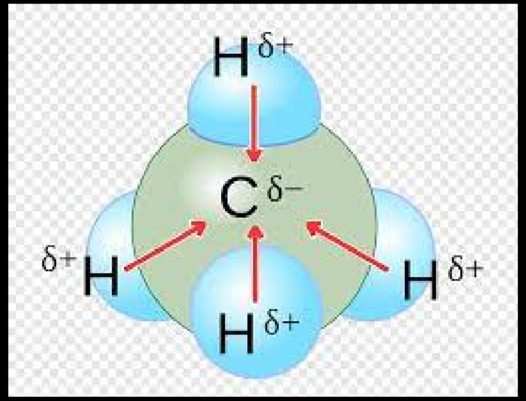
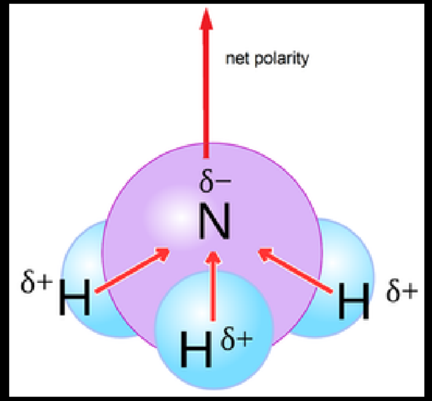
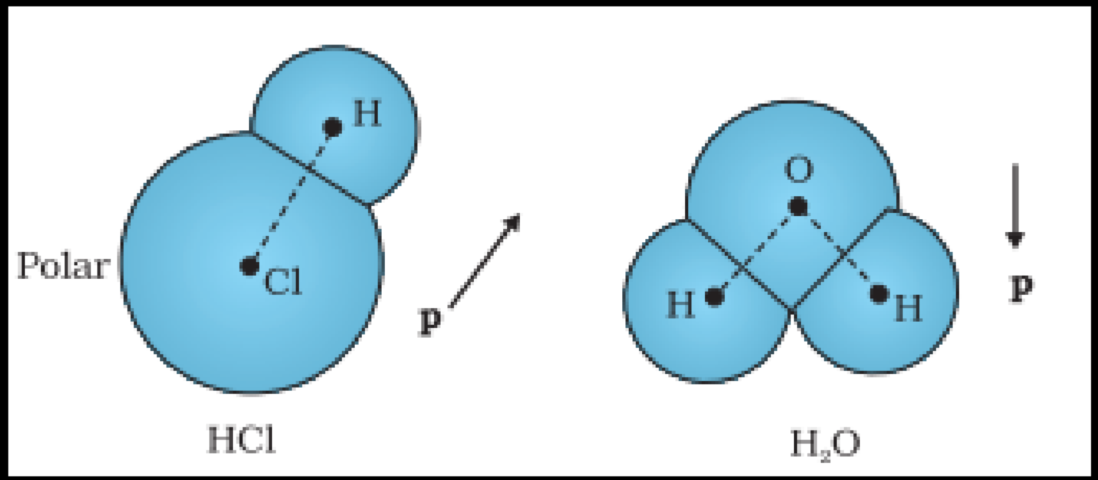
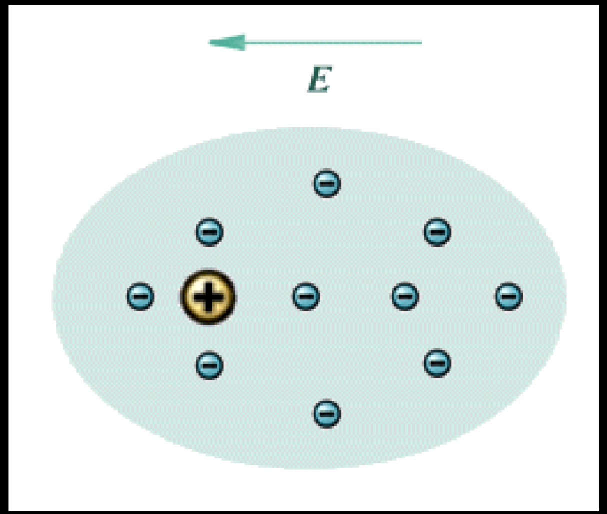
- More polarization mechanisms, the larger dielectric constant.

- Permanent dipole materials have higher dielectric constants than non-polar materials.





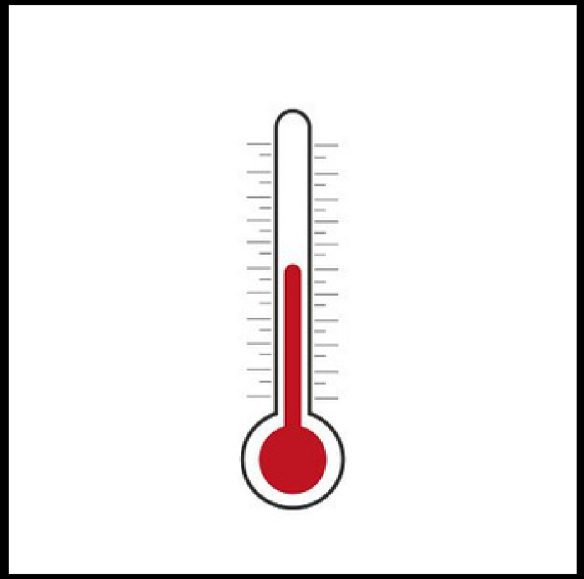




3.TEMPERATURE

3.TEMPERATURE

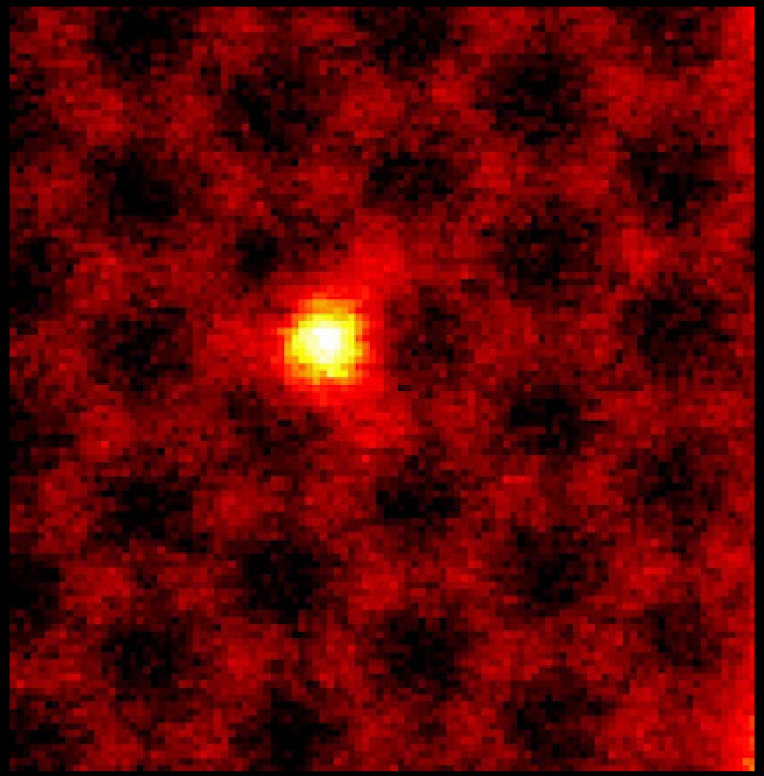
- Higher temperature increases the random thermal motion.
- This means the molecules are less closely aligned with one another, which reduces the orientational polarization and lowers the dielectric constant.



4.IMPURITIES

4.IMPURITIES

- Impurities affect the properties of dielectrics.
- If there are impurities in a material with electronic states inside the gap.
- Transitions from or into the impurity states are now possible, increasing the leakage current.
- Impurities make dielectrics conductive.



5.HIGH ELECTRIC FIELD

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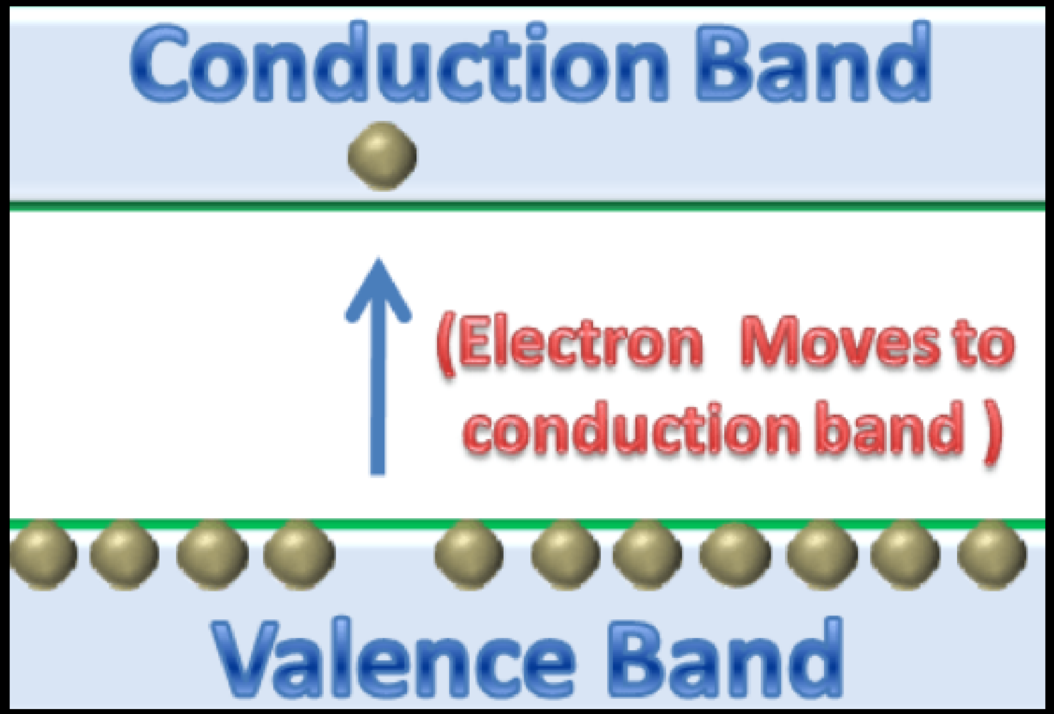
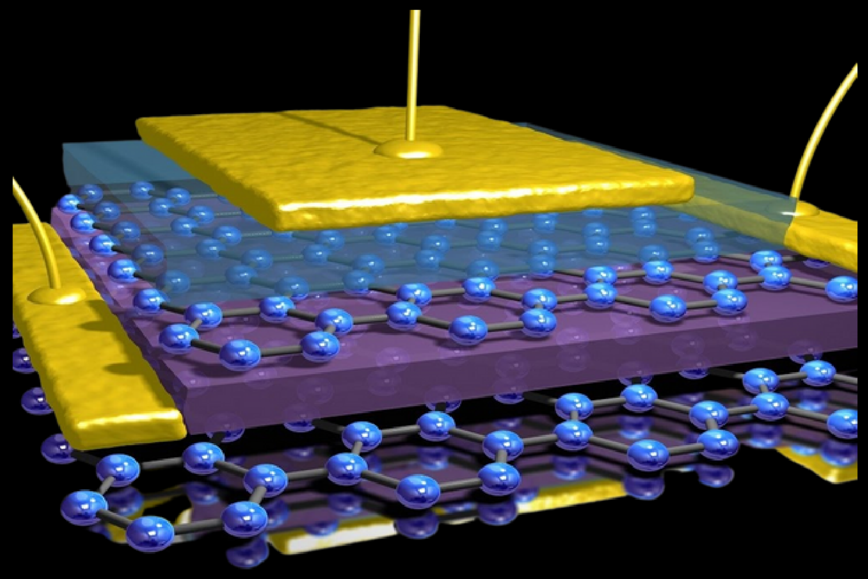
The very high electric field can supply enough energy to promote many electrons to the conduction band, the material now conducts charge rather than storing it. This is referred to as dielectric breakdown.



MOHAMMED MAHMOUD

High-k Dielectric Materials

1. Definition
2. Need for High-k Materials.
3. properties of High-k Materials
   - 3.1 High permittivity
   - 3.2 Reducing leakage current
   - 3.3 Lowering power consumption



1-Definition

- Materials with high dielectric constant (K) as compared to silicon dioxide .

High dielectric are used in semiconductor manufacturing processes to reduce a silicon dioxide gate dielectric thickness or another device dielectric layer.

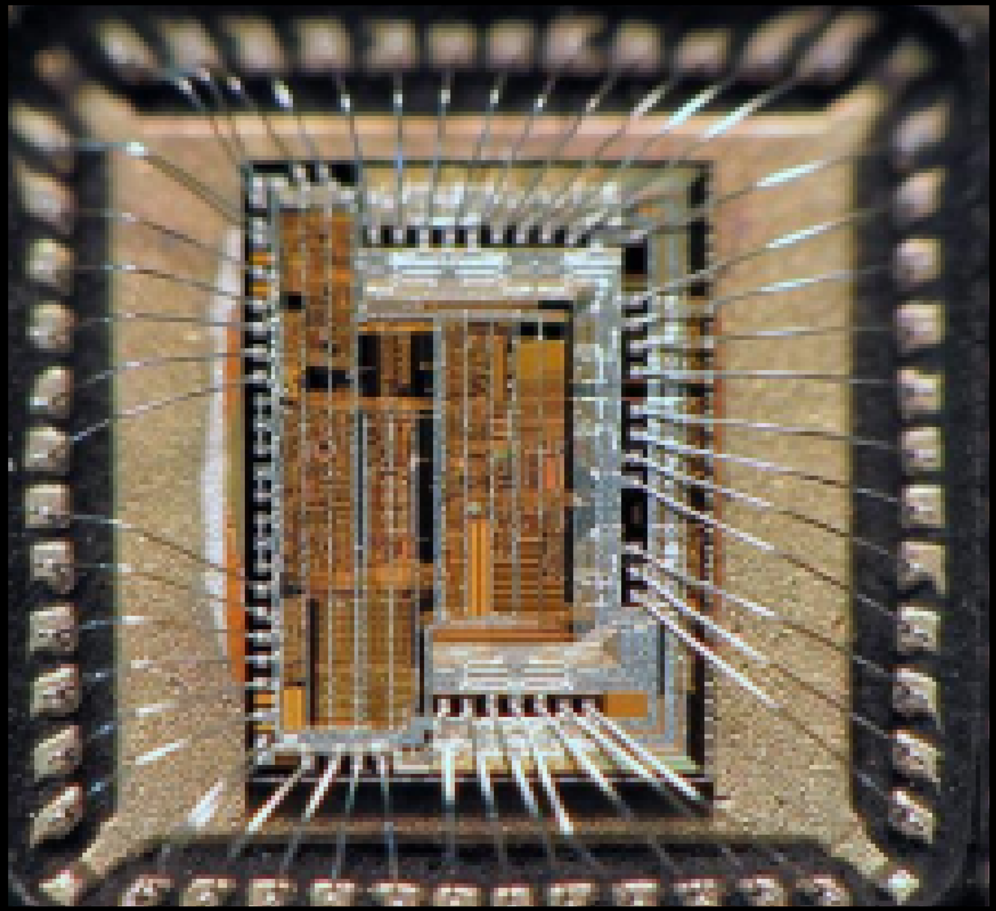
- K or (Kay) represents relative permittivity of material

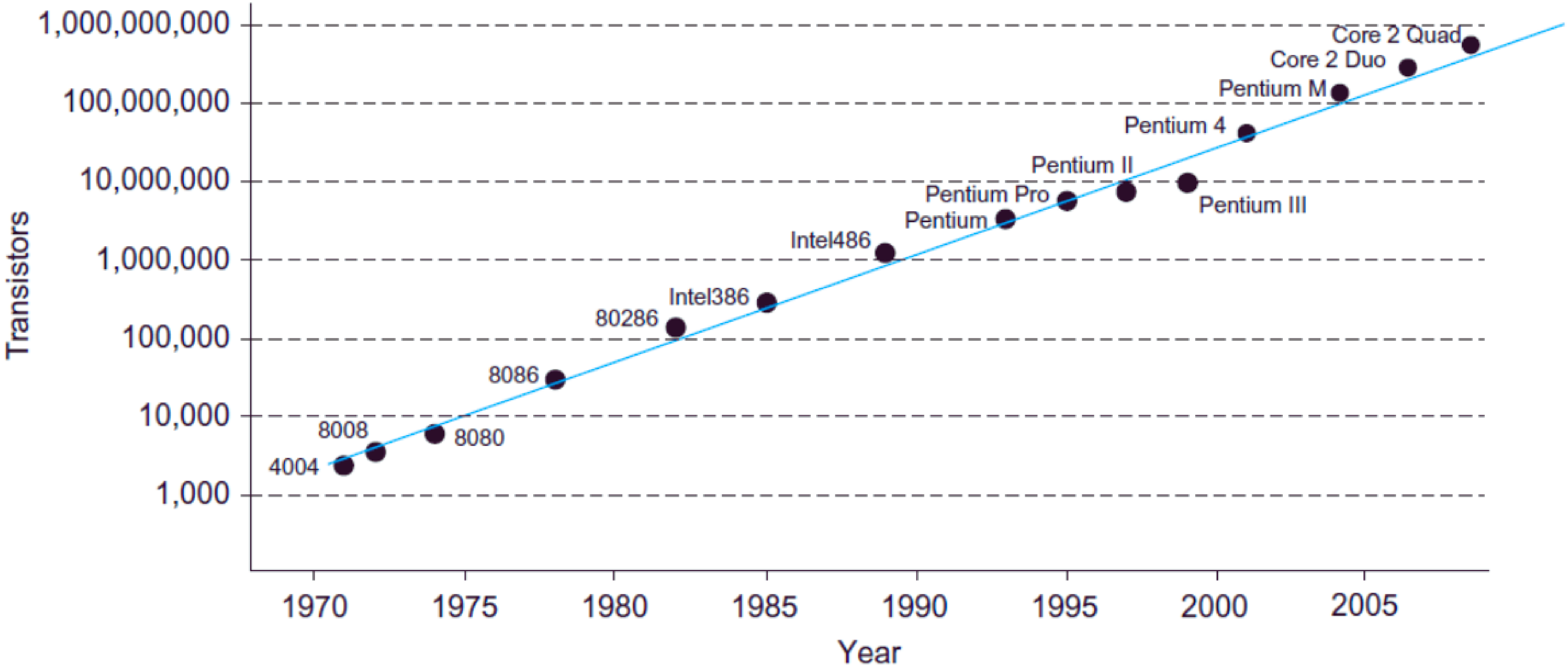
But Why are we interested in High-k??

Need for High_k materials

Moore`s Law

- ❑ Moore’s law [1965]: Transistor count doubles every year
- ❑ Practically: It doubled every 2-3 years since the 4004 [1970s]
- ❑ At the end of the day: It is exponential !



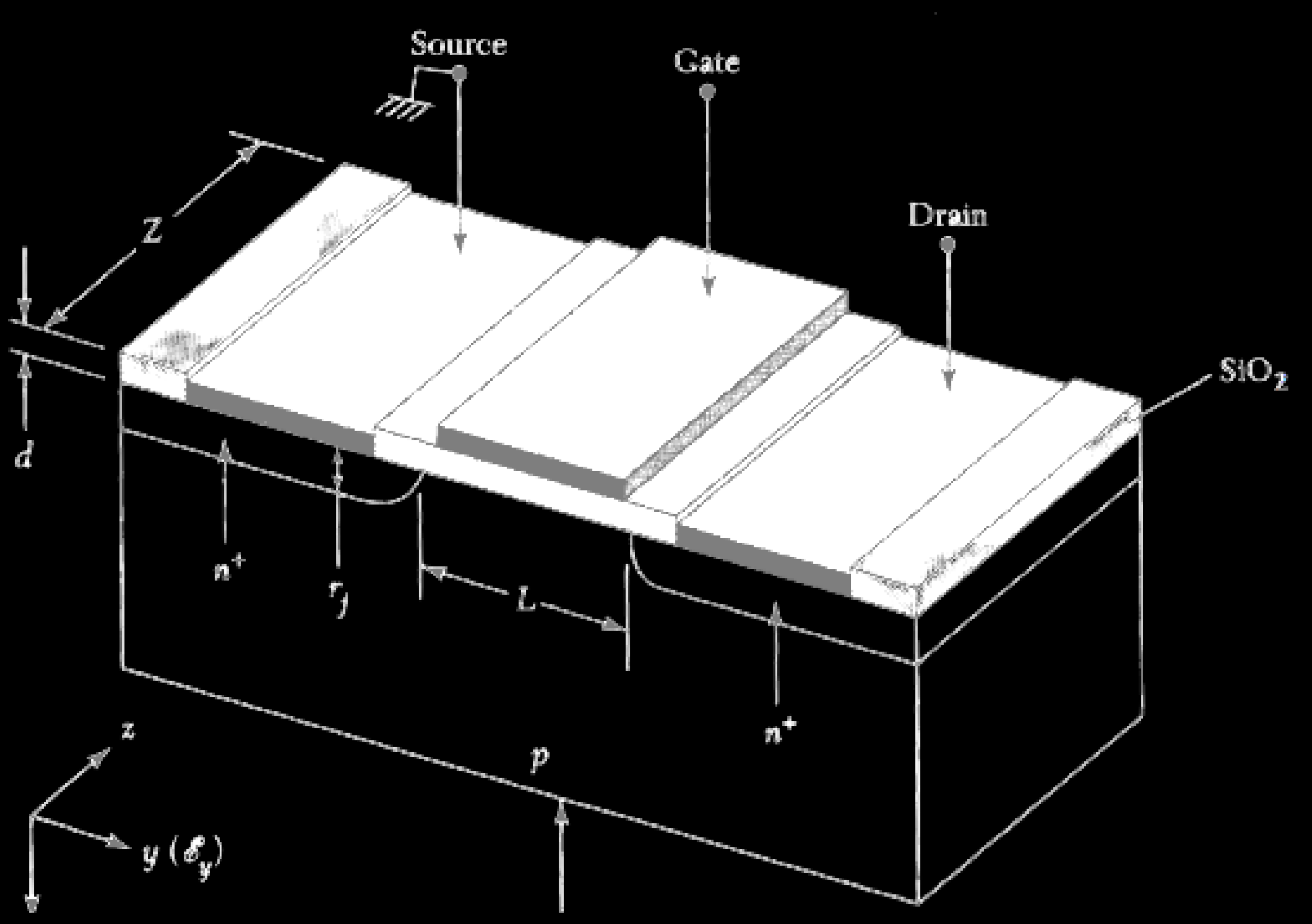


[Weste and Harris, 2010]

Properties of High-k Materials

1- High permittivity

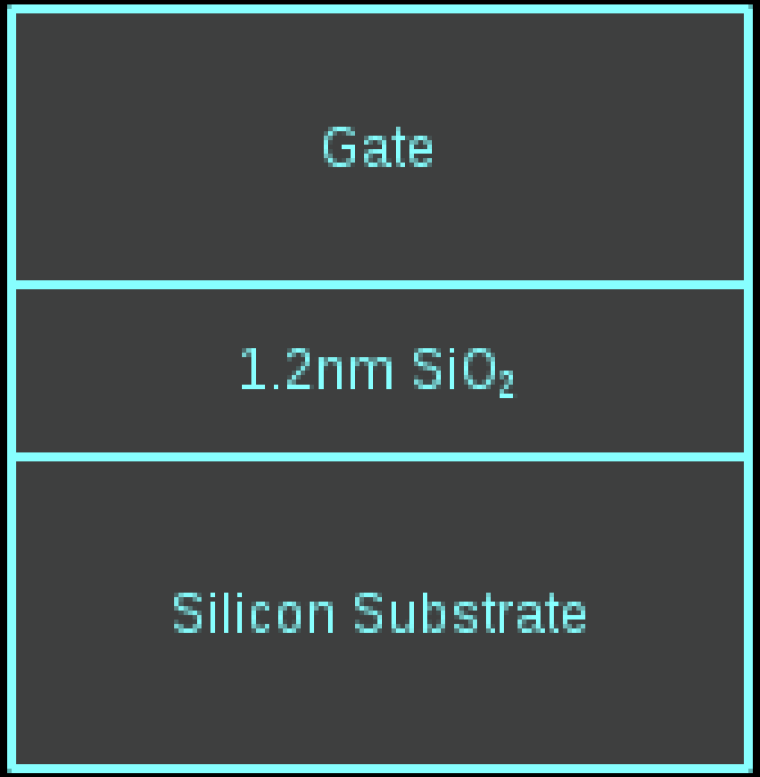
(SiO2, = 3.9), silicon nitride (Si3N4, = 7.55), aluminum oxide (Al2O3, = 9), and zirconium dioxide (HfO2, = 25)



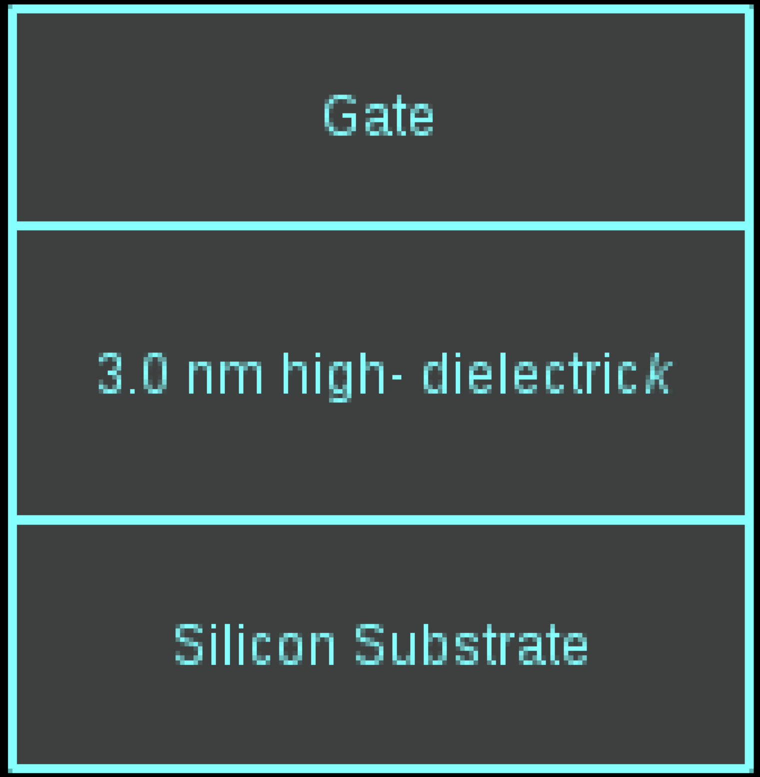
$$C = \frac{\kappa \epsilon_0 A}{d}$$

$$I_D = \begin{cases} \bar{\mu}_n C_{ox.} \left(\frac{Z}{L}\right) \left[(V_G - V_T)V_D - \frac{1}{2}V_D^2\right], & V_D < V_G - V_T \\ \frac{1}{2}\bar{\mu}_n C_{ox.} \left(\frac{Z}{L}\right) (V_G - V_T)^2, & V_D \geq V_G - V_T \end{cases}$$

2- Reducing Leakage Current



Existing 90nm Process
Capacitance = 1x
Leakage Current = 1x



A potential high- process*k*
Capacitance = 1.6x
Leakage Current = 0.01x

3-Lowering Power Consumption

On the other hand

What are the challenges that will face us?

MOMEN MAGDY

HIGH-K DIELECTRIC MATERIALS CHALLENGES

Low compatibility with Si MOSFET compared to SiO_2

01 Thermal Instability

02 Carrier Mobility Degradation

03 Charge Trapping and Threshold Voltage Shift

HfO_2 is given as an example to demonstrate such challenges

THERMAL INSTABILITY

Cause

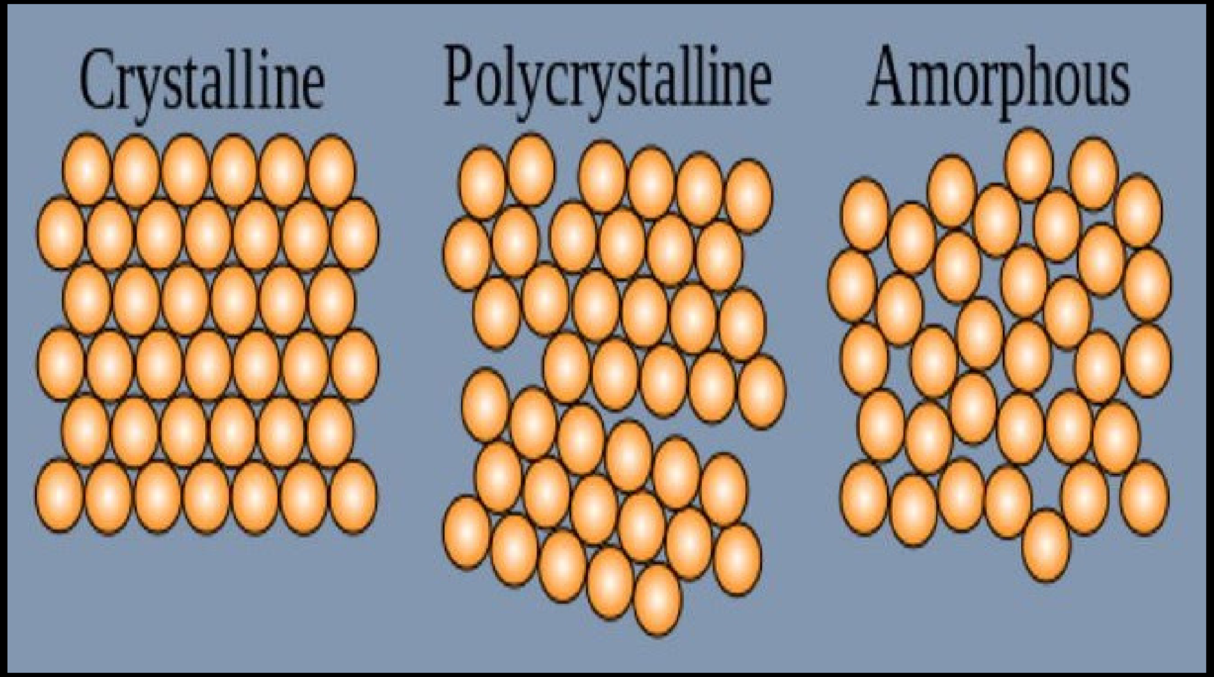
The predominance of the poly-Si gate electrode in industry.

- Requires annealing at temperatures above 1000°C for dopants activation

Result

- The transformation of HfO_2 from its amorphous state to a poly-crystalline state losing its insulation characteristic.

- The formation of a SiO_2 layer between 5 and 10 Å, losing the high-k oxide replacement.



THERMAL INSTABILITY

Solution

Addition of 30% Al to HfO_2

- Raises the temperature at which the crystallization occur by 400-500 °C

Addition of 20% Si to HfO_2

- Can prevent the crystallization at the activation temperature used for the poly-gate.

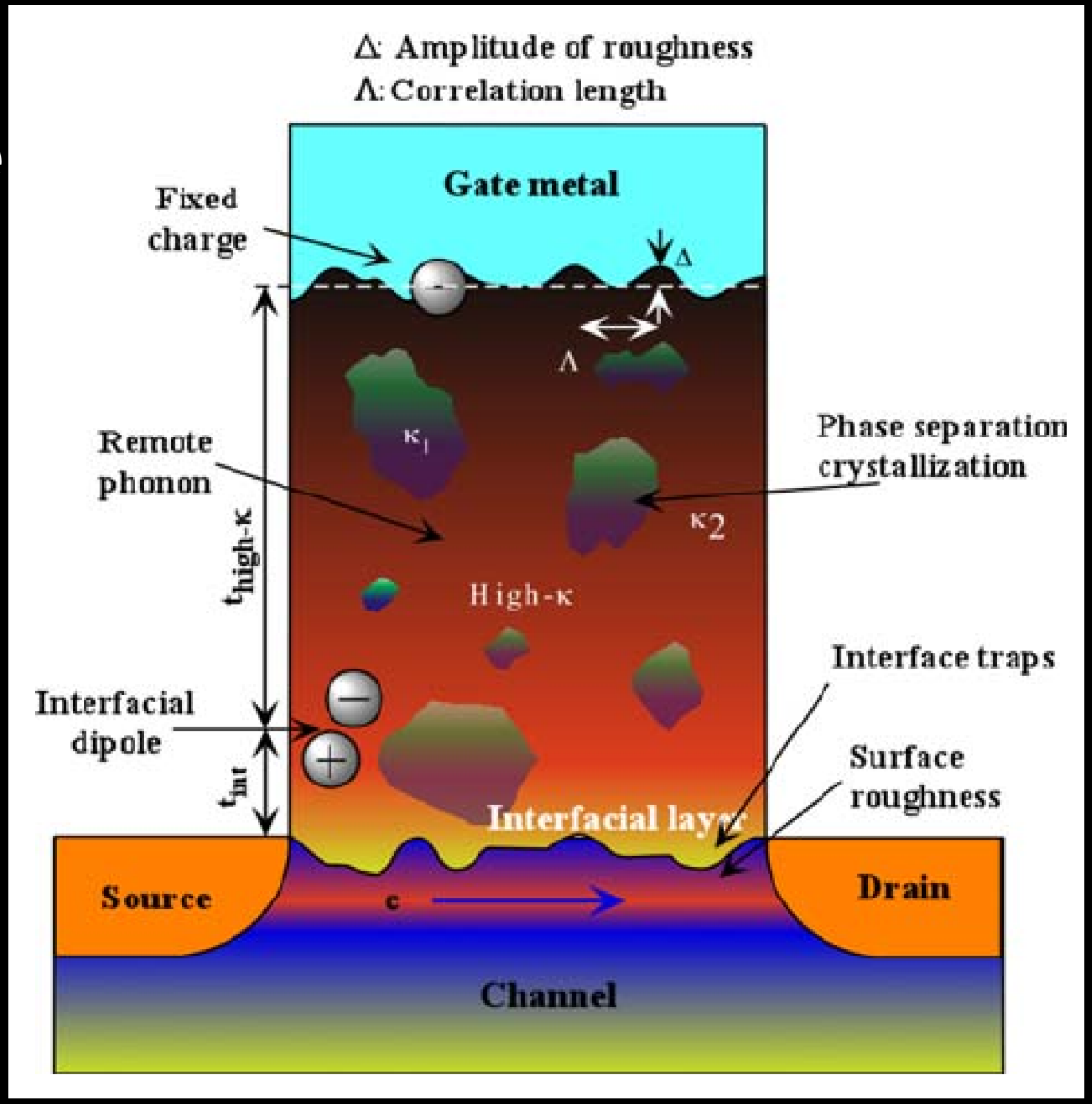
CARRIER MOBILITY DEGRADATION

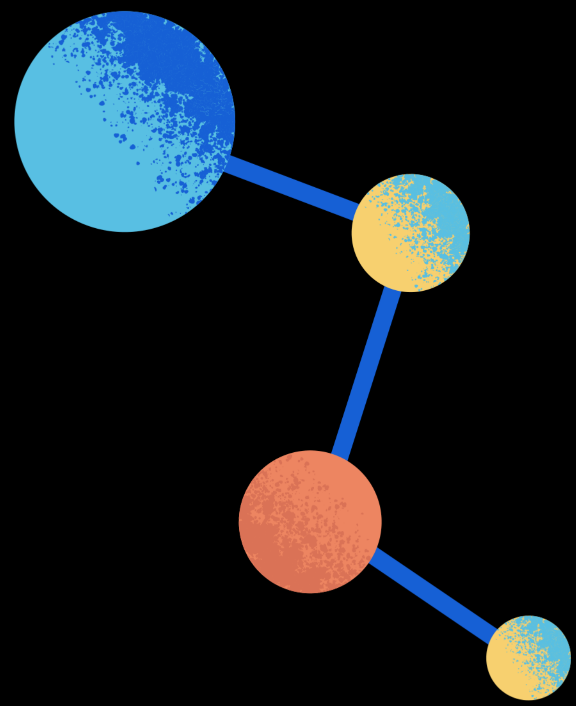
Cause

Softer optical phonons than the SiO2 gate, and the long-range dipole associated with the interface excitations.

Result

- Reduce the effective electron mobility in the Si substrate's inversion layer.
- Scattering and degrading mechanism affects the mobility of the inversion channel carriers.



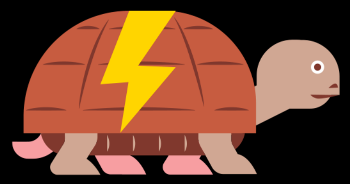


CARRIER MOBILITY DEGRADATION

Solution

Addition of Si to HfO_2

- Increases mobility, which is thought to be caused by a decrease in remote phonon scattering.



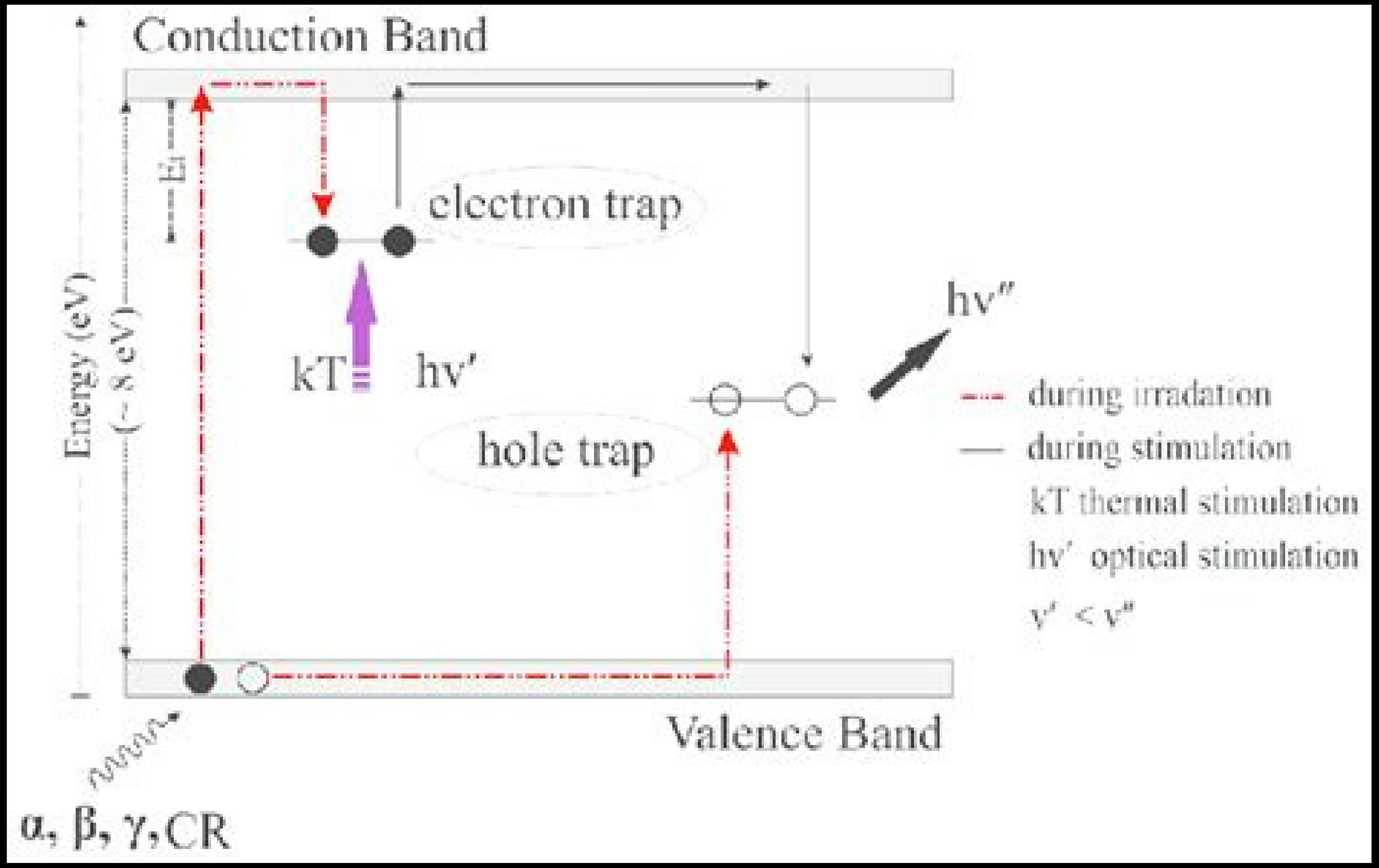
CHARGE TRAPPING & THRESHOLD VOLTAGE SHIFT

Cause

The Fermi-level pinning at the interface, which in turn has been attributed to the interfacial Si–Hf and Si–O–Al bonds of the HfO2 layer as well as the oxygen vacancies at the poly-silicon/HfO2 interface.

Result

- The interface states partially screen the electric field from the gate electrode, preventing it from modulating the channel fully. Therefore, the efficacy of the gate-induced tuning of the channel carriers is somewhat hindered.



CHARGE TRAPPING & THRESHOLD VOLTAGE SHIFT

Solution

Addition of Al_2O_3 or AlN layer on top the oxide layer

- Prevent the threshold voltage shift and obtained shift values as low as 0.2 V.

La_2O_3 has been used to passivate HfSiO on N-MOS-FET

- Was attained to reduce the threshold voltage by as much as 0.25V.

A 0.5–2nm Dy_2O_3 cap layer mixed with HfSiO dielectric layer

- Showed a reduction of 0.2V in the threshold voltage.

MOMEN MEDHAT

High K dielectrics Applications

1- High-k dielectrics for DRAM MIMCap

2- High-k dielectrics for flash applications

General Requirements for any application

1-Low price

2-scalling the size

3- low power consumption

Effect of High-k dielectrics on the applications

Scaling of the equivalent oxide thickness specially in DRAM

Decrease the leckage of current

A solution for the charge trapping specially in flash appl.

1- High-k dielectrics for DRAM MIMCap

EOT challenges

For better EOT => MIMcap use metal with high WF

pt electrodes => 👎
RU-based => 👎
while STO and HfTiO4 👍

2- High-k dielectrics for flash applications

Charge trapping challenge

Idea of the flash memory is based on the charge trapping

so High-K are introduced as charge trap device to block the charges

AL2o3=> BO=>CT device

THANK YOU

See you at the Final!