DIODES-02

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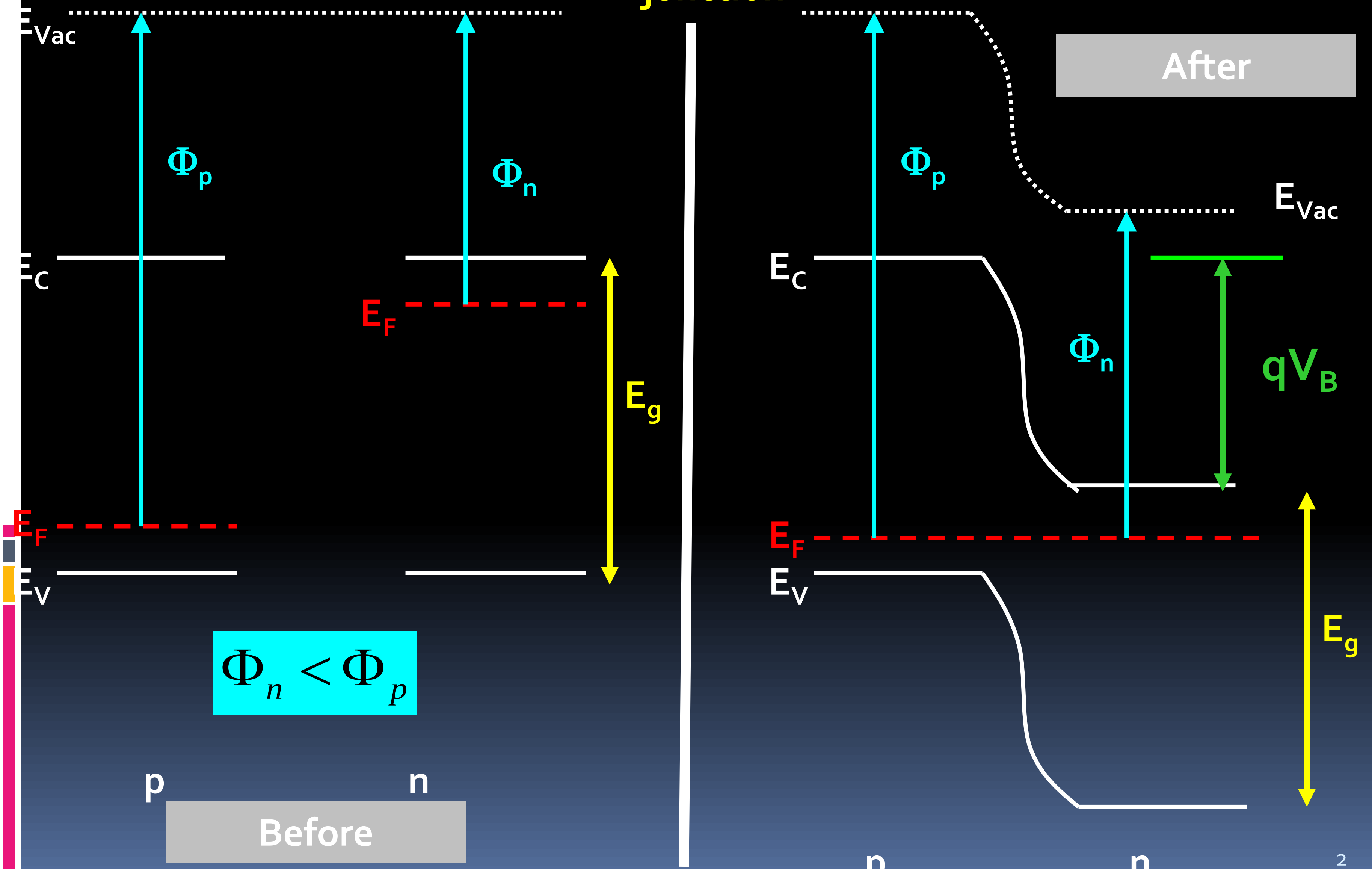
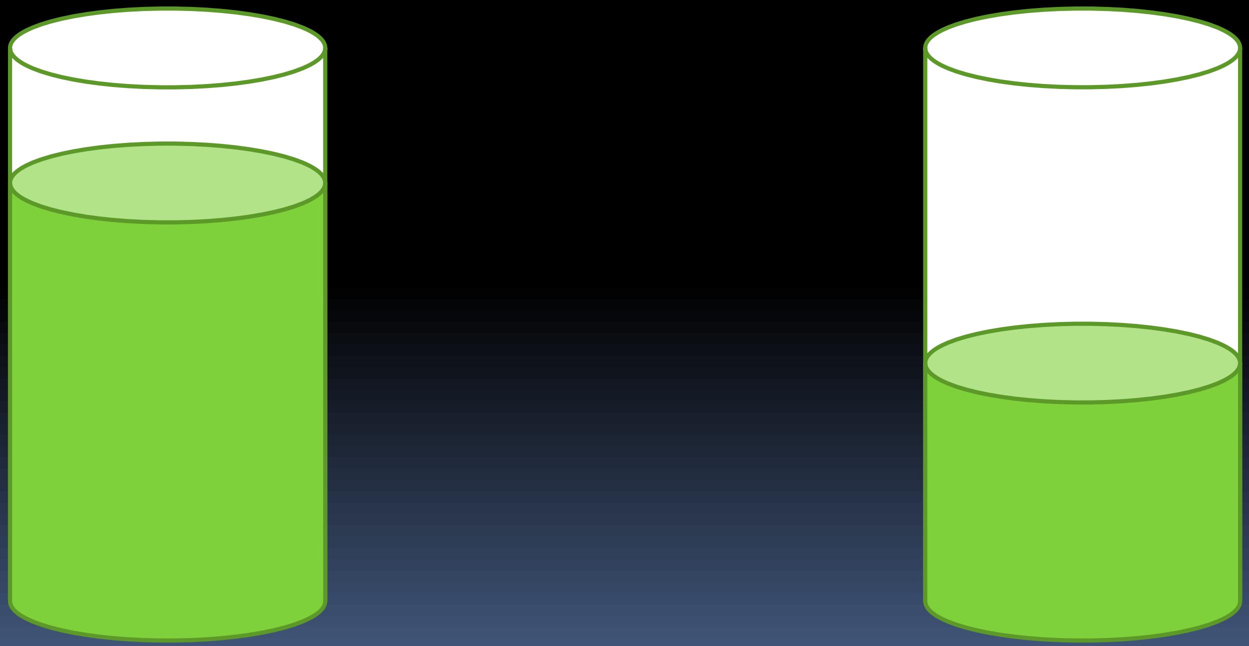
Electronics, PH3144
IISER-Pune

RECAPITULATION

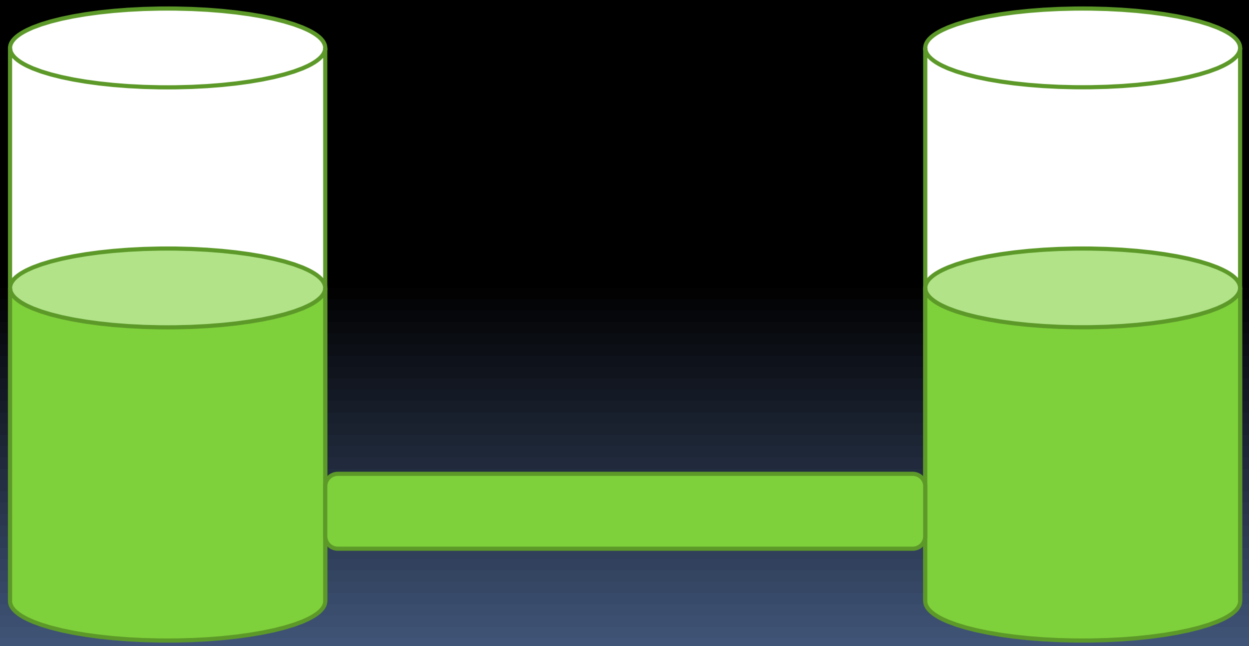
Spatial Variation of Potential Energy ≡ Presence of an electric Field at the junction



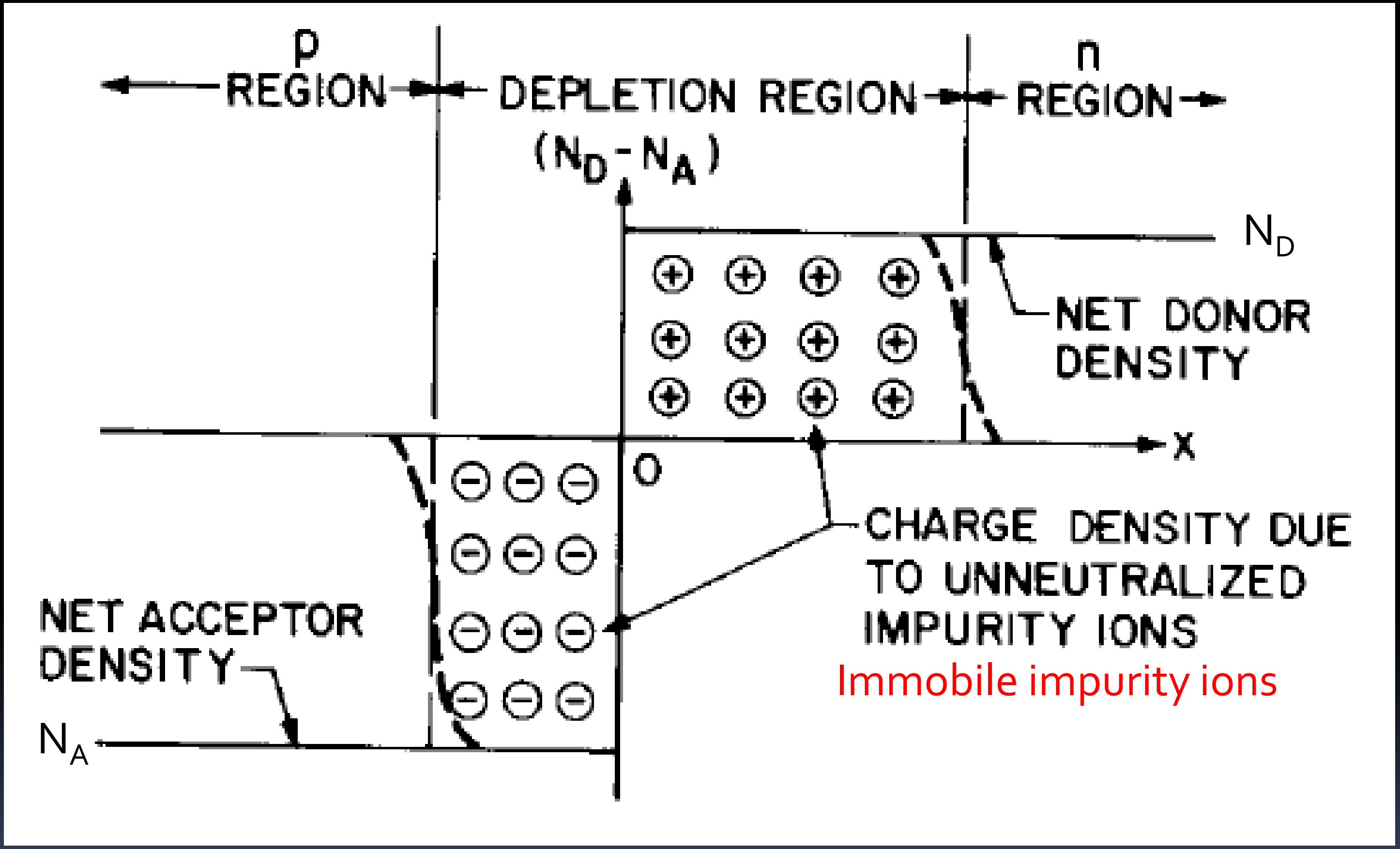
REMEMBER
THE ANALOGY OF WATER LEVELS IN TWO BEAKERS



REMEMBER
THE ANALOGY OF WATER LEVELS IN TWO BEAKERS AT EQUILIBRIUM AFTER THEY ARE JOINED TOGETHER.



RECAPITULATION



Depletion Region : Depleted of Free Mobile Charge Carriers
(either e or h)

RECAPITULATION

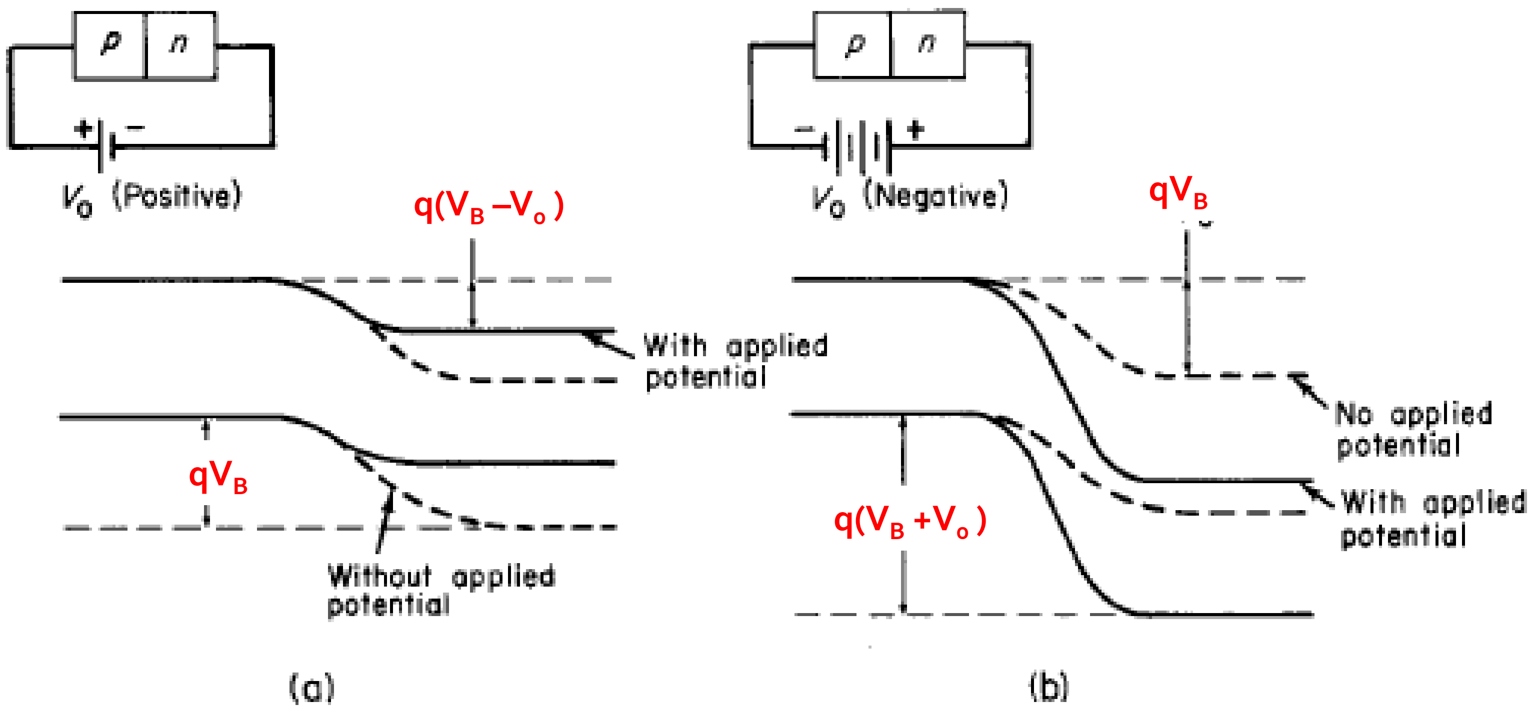


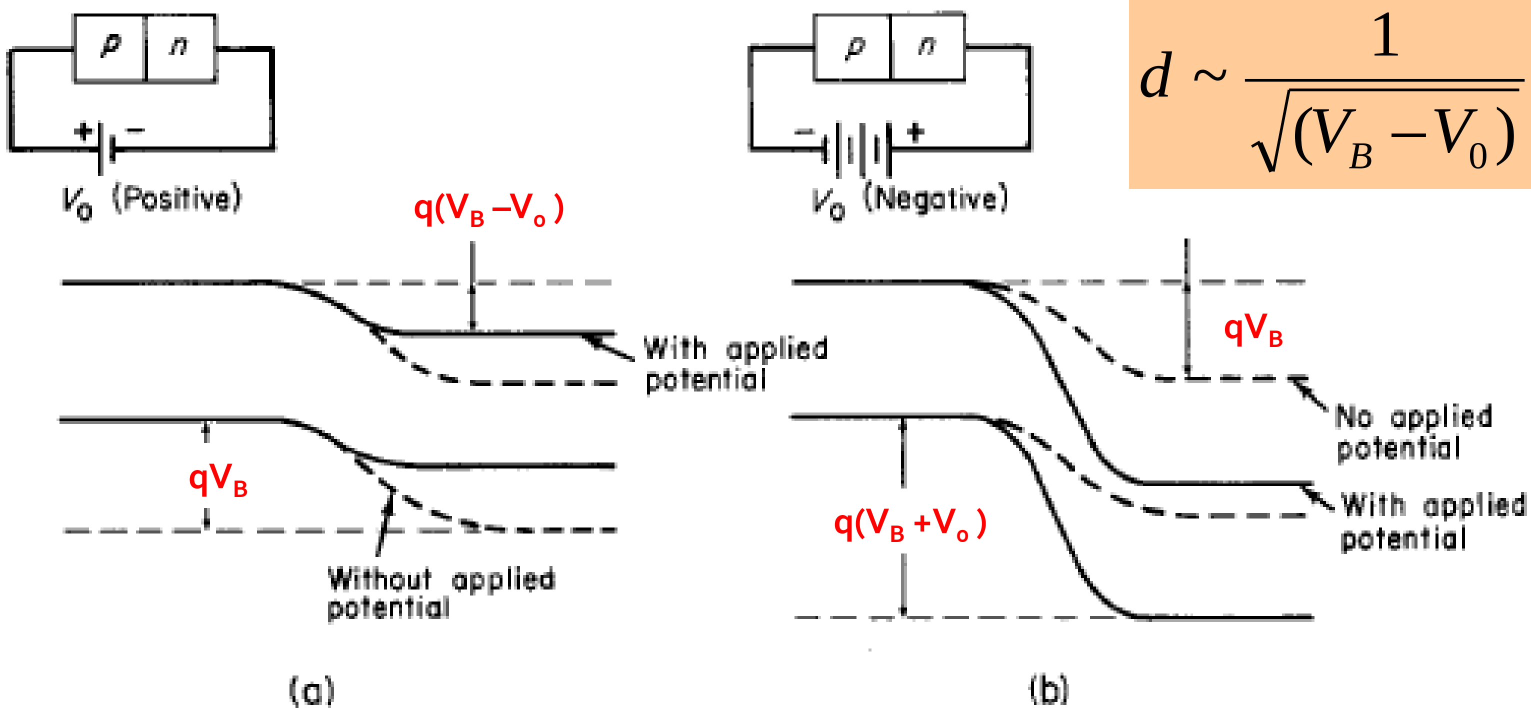
FIGURE 12.4. Potential energy diagrams showing the effect of (a) forward bias and (b) reverse bias voltage upon the energy band configuration at a *p-n* junction.

Barrier Height decreases under forward bias $\Rightarrow$ More current

Barrier Height increases under reverse bias $\Rightarrow$ Less Current

McKelvey, Solid State and Semiconductor Physics

RECAPITULATION



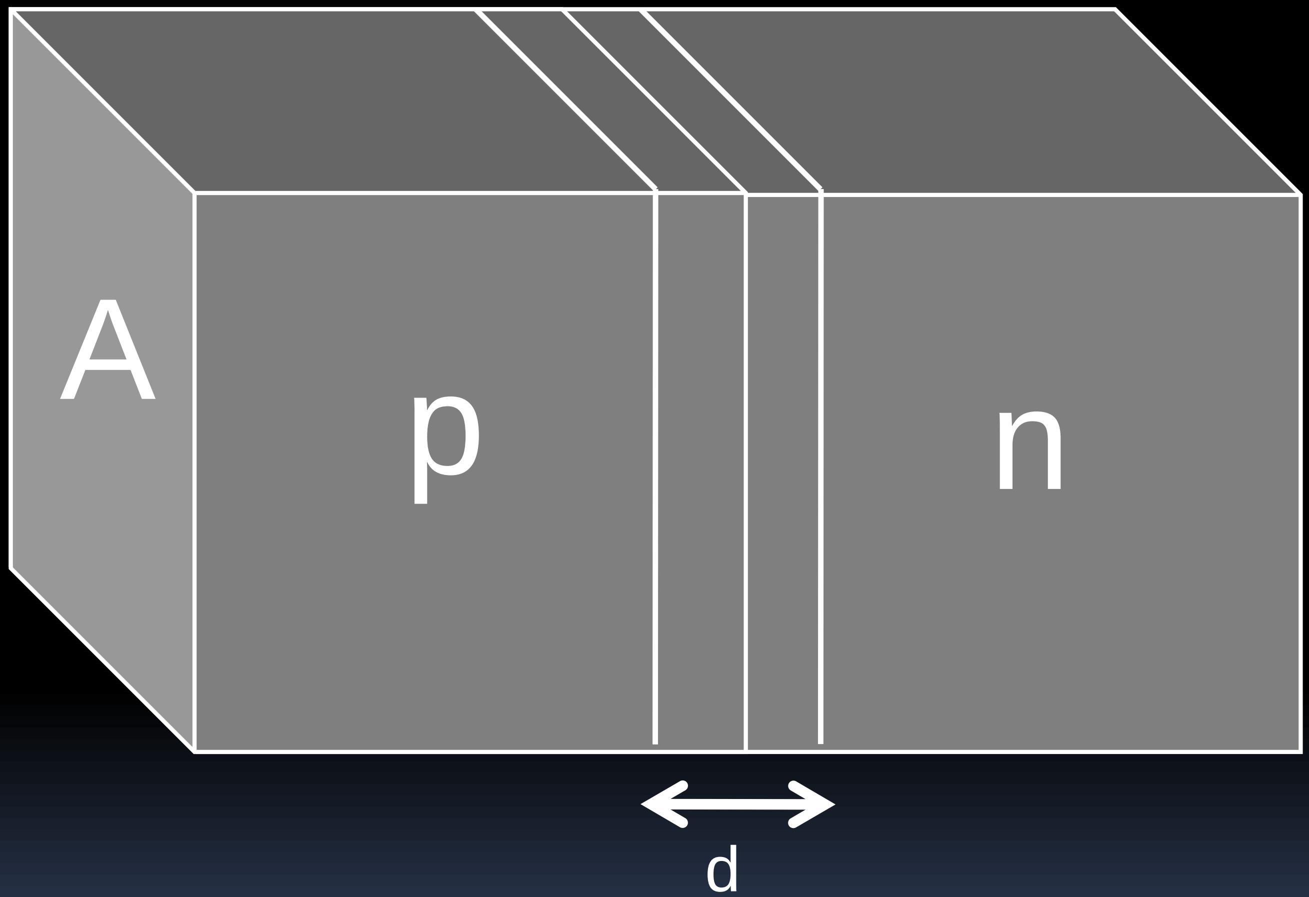
$$d \sim \frac{1}{\sqrt{(V_B - V_0)}}$$

FIGURE 12.4. Potential energy diagrams showing the effect of (a) forward bias and (b) reverse bias voltage upon the energy band configuration at a *p-n* junction.

Width of the depletion region decreases under forward bias
Width of the depletion region increases under reverse bias

(Figure is not to scale !!) McKelvey, Solid State and Semiconductor Physics

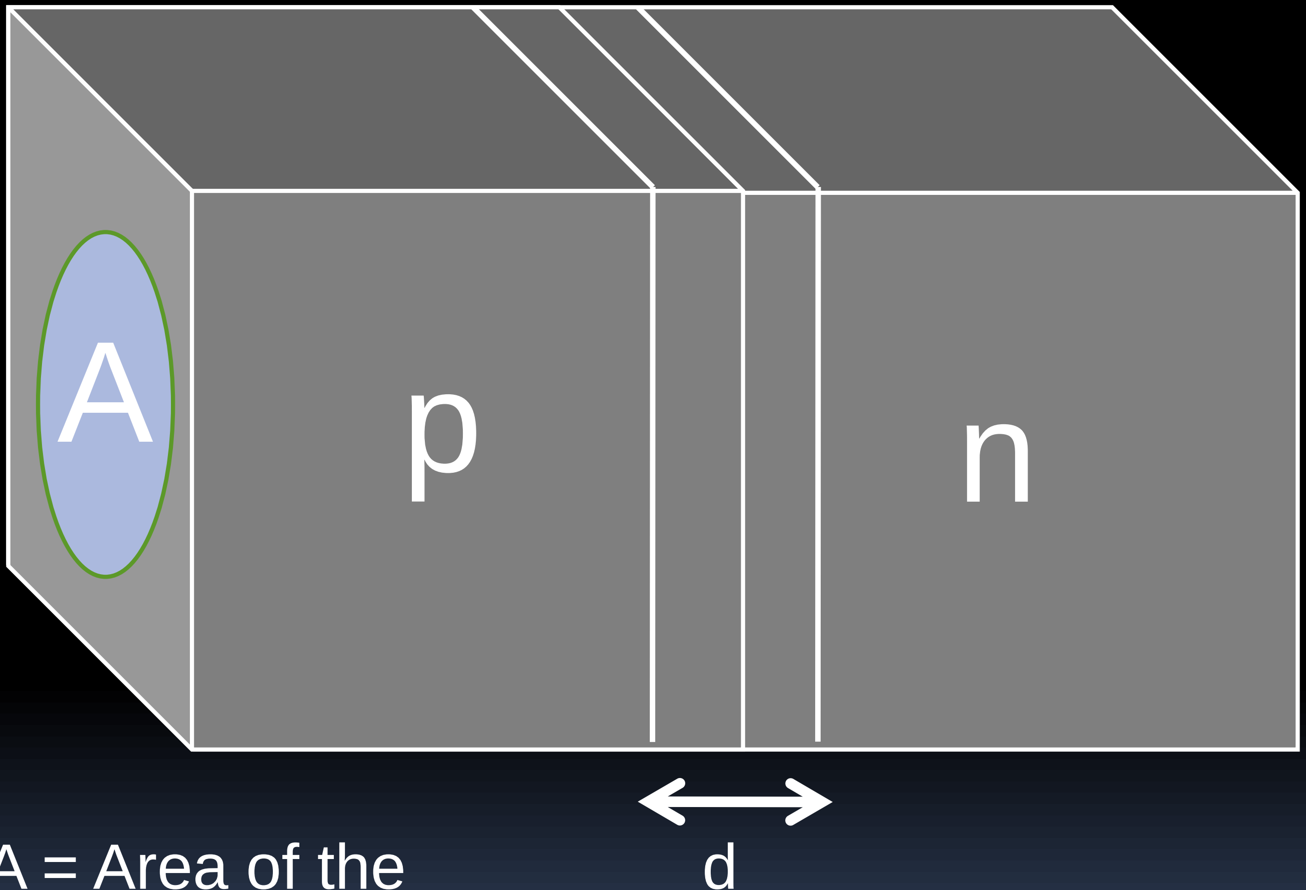
DEPLETION CAPACITANCE



$$C_J = \frac{\varepsilon\varepsilon_0 A}{d}$$

Fig 3.1, Milman & Halkias, Integrated Electronics

DEPLETION CAPACITANCE



$$C_J = \frac{\varepsilon \varepsilon_0 A}{d}$$

A = Area of the Metal Dot

C is not constant, it depends upon applied voltage, therefore it is defined as dQ/dV.

Fig 3.1, Milman & Halkias, Integrated Electronics

DEPLETION CAPACITANCE

$$C_J = \frac{dQ}{dV} = \frac{\varepsilon \varepsilon_0 A}{d}$$

$$C_J = \frac{1}{\sqrt{V_B - V}}$$

C is not constant, it depends upon applied voltage, therefore it is defined as dQ/dV.

Fig 3.1, Milman & Halkias, Integrated Electronics

DEPLETION CAPACITANCE UNDER FORWARD BIAS

Under Forward bias the capacitance is larger than the static value

The width (d) of the depletion region decrease under forward bias

$$C_J = \frac{\varepsilon \varepsilon_0 A}{d}$$

DEPLETION CAPACITANCE UNDER REVERSE BIAS

Under Reverse bias the width (d) of the depletion region increase

Under Reverse bias the capacitance is much smaller than the unbiased static value

$$C_J = \frac{\varepsilon \varepsilon_0 A}{d}$$

DIFFUSION (DYNAMIC) CAPACITANCE UNDER FORWARD BIAS

Under Forward bias the capacitance is much larger (million times !) than the static Depletion Capacitance

Additional Contribution from he accumulation of injected minority carriers near the junction

In case of Reverse Bias C_d is negligible compared to depletion capacitance.

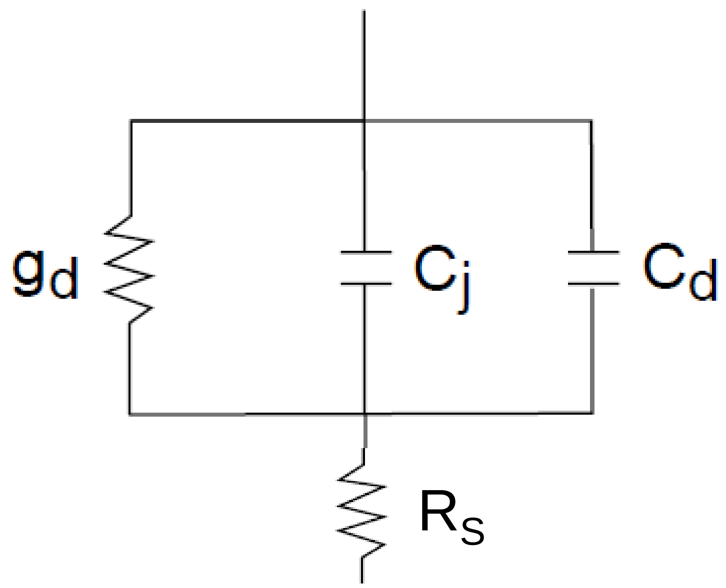
$$C_d \approx e^{\frac{qV}{\eta k_B T}} \approx I$$

C_d (~ $1/\omega^{1/2}$) is appreciable at Low Frequencies under forward bias.

Milman & Halkias, Integrated Electronics

EQUIVALENT CIRCUIT OF A P-N JUNCTION DIODE

Complete small-signal equivalent circuit model for diode:



Milman & Halkias, Integrated Electronics

RECAPITULATION

Depletion Capacitance (C_j) increases under forward bias
Depletion Capacitance (C_j) decreases under reverse bias

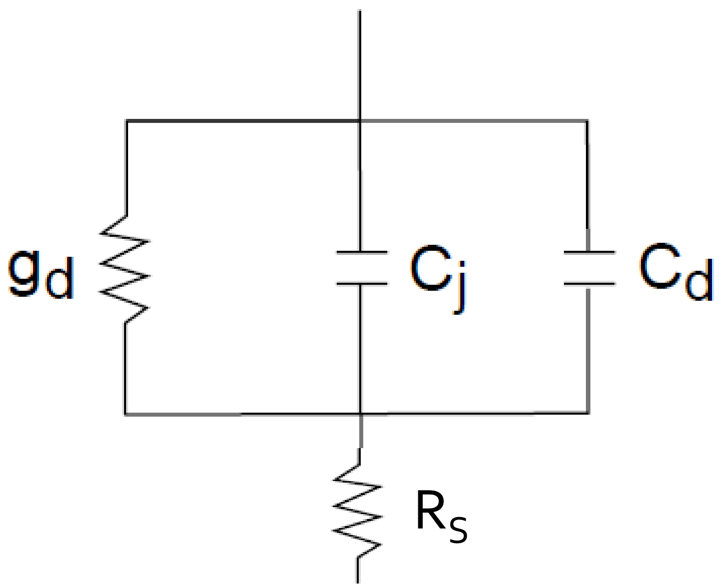
Diffusion Capacitance (C_d) increases significantly under forward bias
Diffusion Capacitance (C_d) is negligible under reverse bias

Incremental conductance (g_d) increases significantly under forward bias
Incremental conductance (g_d) is negligible under reverse bias

McKelvey, Solid State and Semiconductor Physics

RECAPITULATION

Complete small-signal equivalent circuit model for diode:



“DIODE RECTIFY ANY AC SIGNALS”

“DIODE RECTIFY ANY AC SIGNALS”

ARE YOU SURE ??

HOW DIODES RECTIFY AC SIGNALS ?

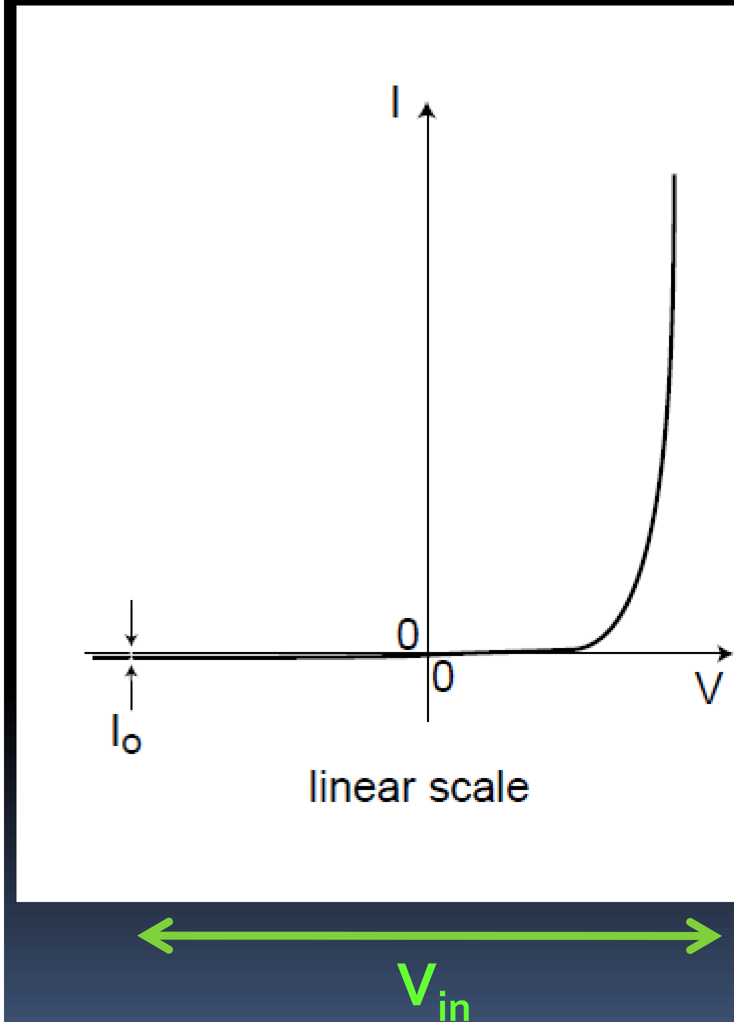
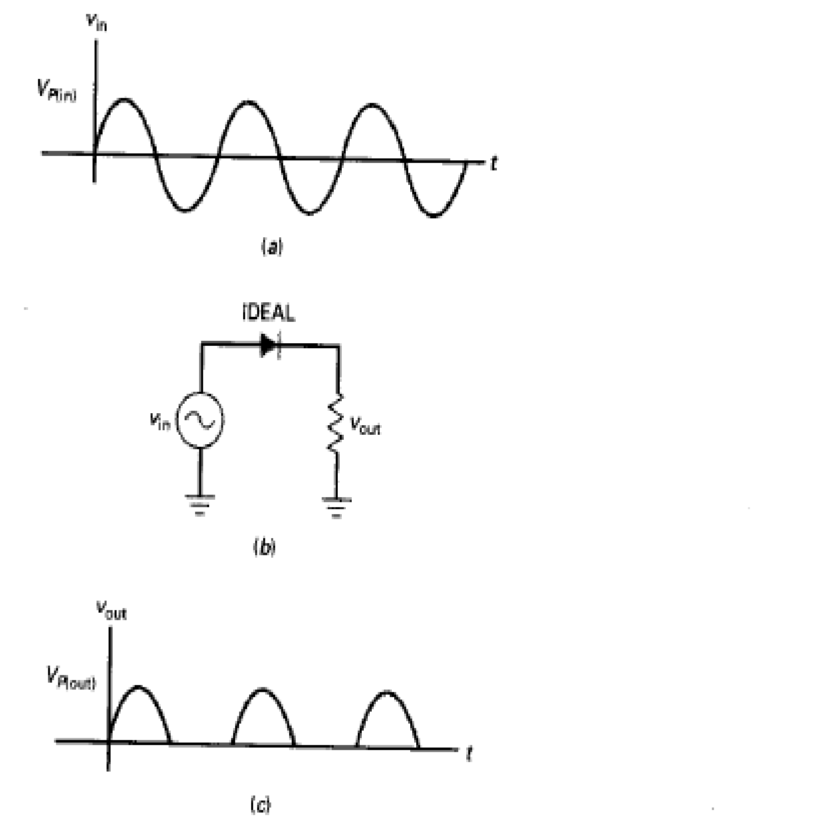


Figure 4-2 (a) Input to half-wave rectifier; (b) circuit; (c) output of half-wave rectifier.



Malvino & Bates, Electronic Principles

IT DOES NOT RECTIFY A SMALL SIGNAL AC AT LARGE REVERSE BIAS

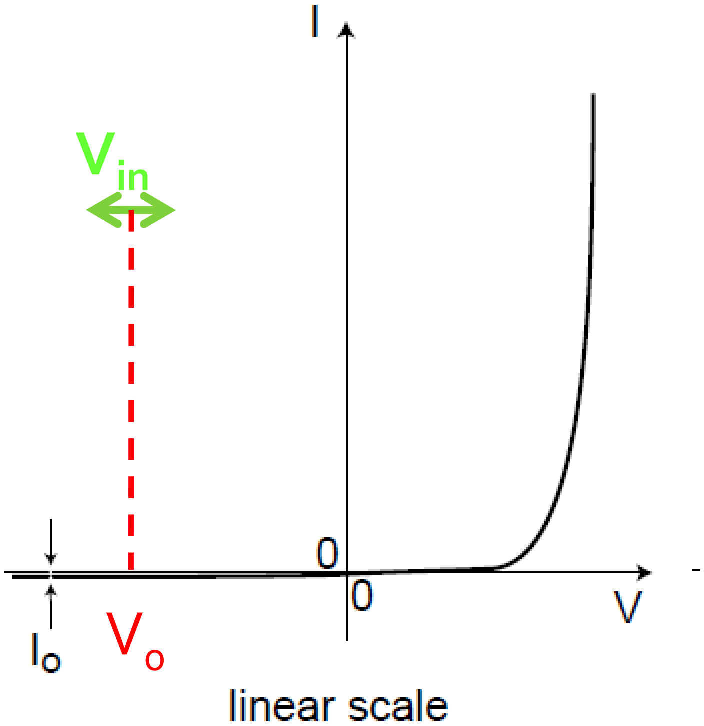
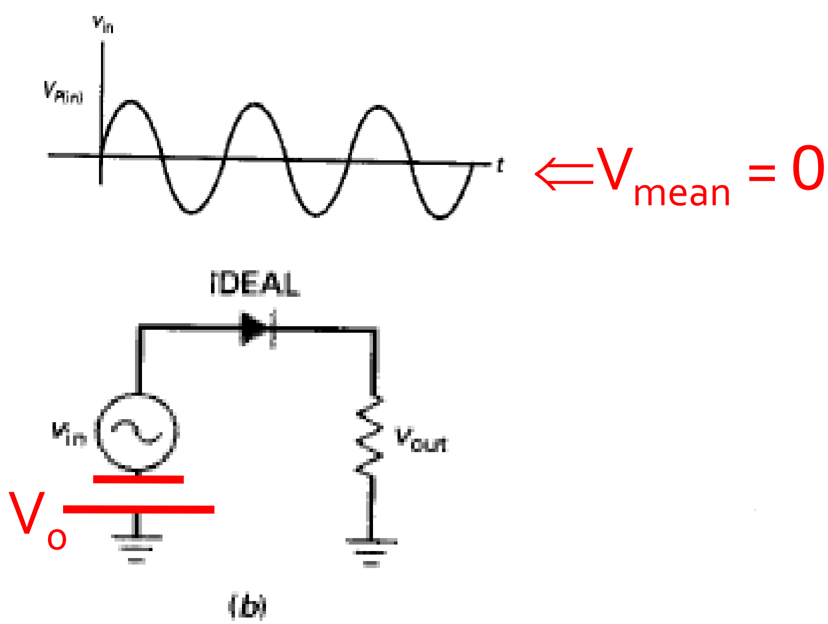


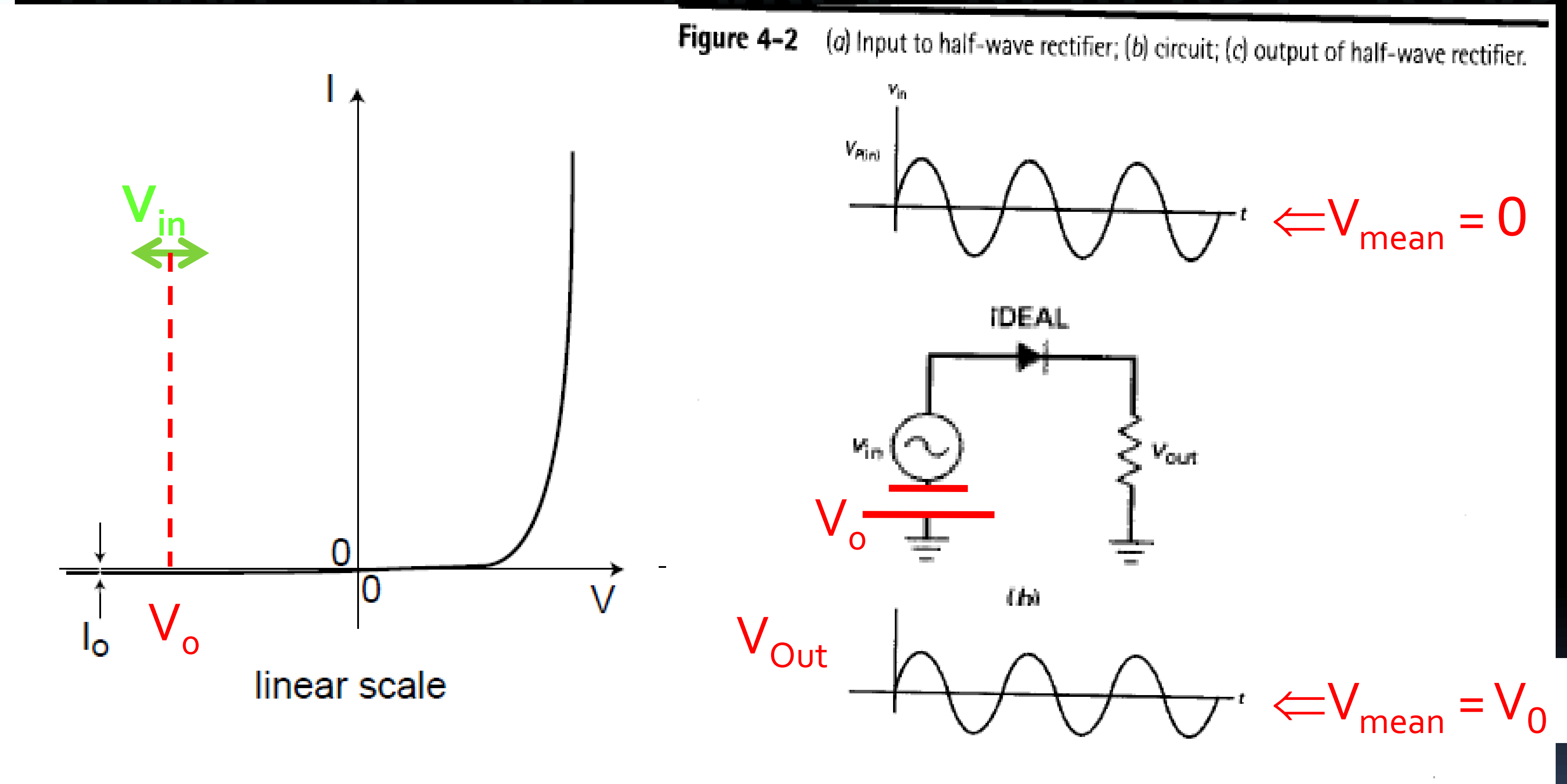
Figure 4-2 (a) Input to half-wave rectifier; (b) circuit; (c) output of half-wave rectifier.



$V_{Out} = ??$

$V_{Out} = V_o + V_{in} = V_o + V_{pp}\sin(\omega t);$ Assumption $V_{pp} << V_o$

IT DOES NOT RECTIFY A SMALL SIGNAL AC AT LARGE REVERSE BIAS



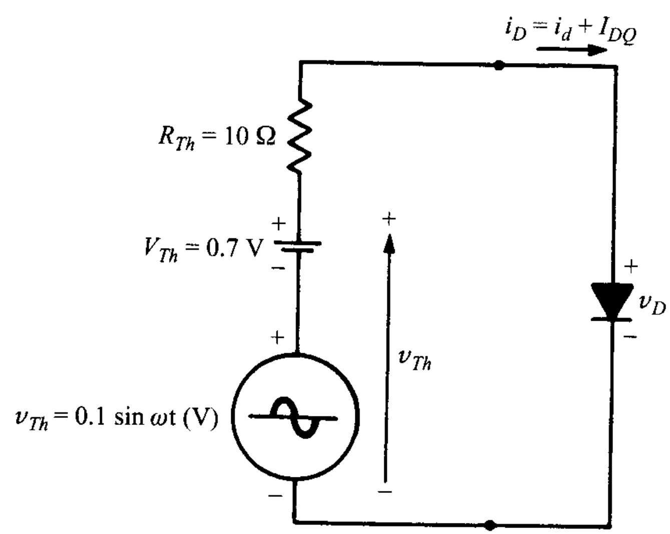
$V_{Out} = V_o + V_{in} = V_o + V_{pp}\sin(\omega t);$ Assumption $V_{pp} << V_o$

Malvino & Bates, Electronic Principles

DOES NOT RECTIFY A SMALL SIGNAL AC AT LARGE FORWARD BIAS EITHER

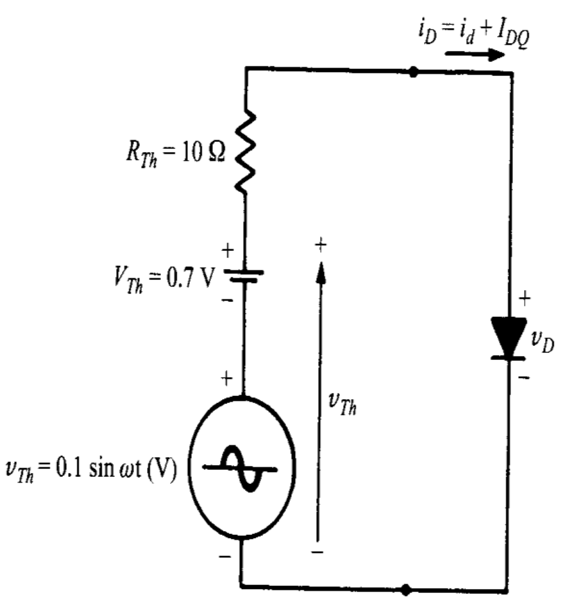
Example 2.7. If both dc and time-varying sources are present in the original linear portion of a network, then v_{Th} is a series combination of a dc and a time-varying source. Suppose that the Thévenin source for a particular network combines a 0.7-V battery and a 0.1-V-peak sinusoidal source, as in Fig. 2-10(a). Find i_D and v_D for the network.

We lay out a scaled plot of v_{Th}, with the v_{Th} axis parallel to the v_D axis of the diode characteristic curve. We then consider v_{Th}, the ac component of v_{Th}, to be momentarily at zero ($t = 0$), and we plot a load line for this instant



(a)

DOES NOT RECTIFY A SMALL SIGNAL AC AT LARGE FORWARD BIAS EITHER



(a)

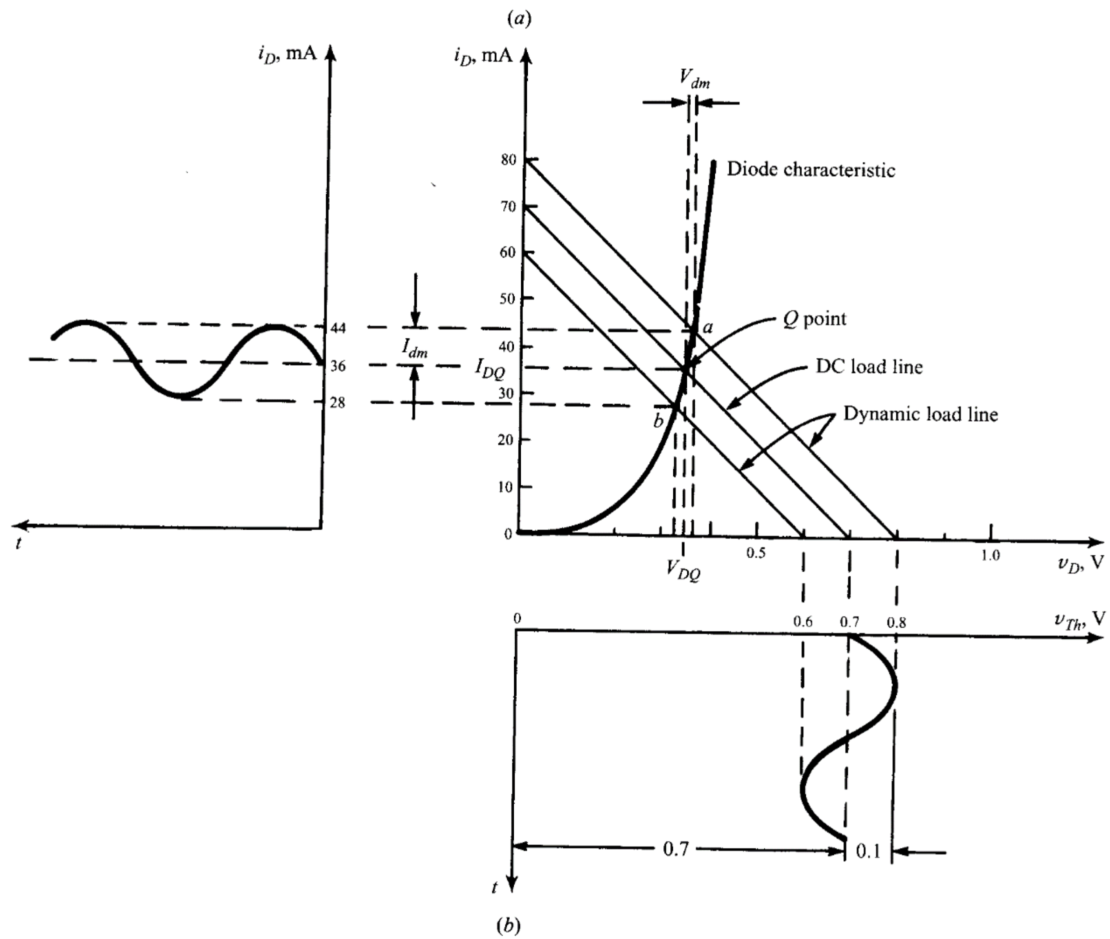
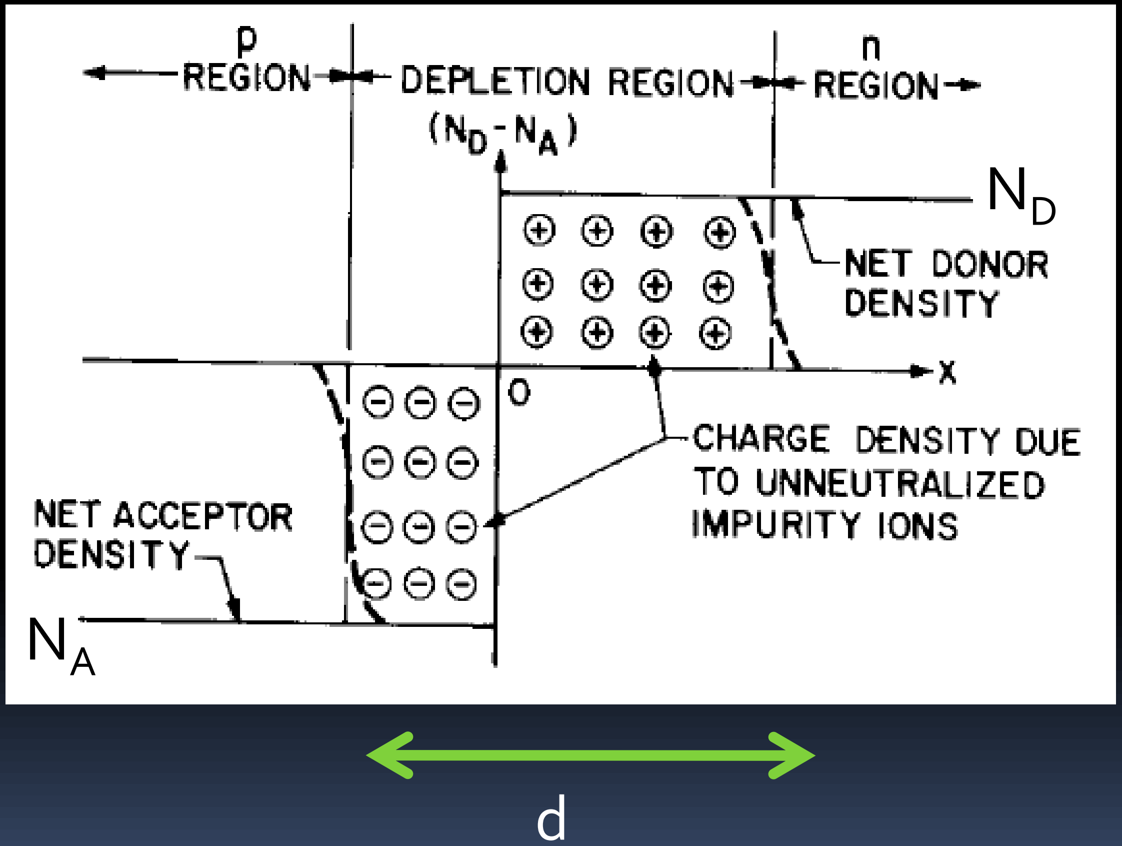


Fig. 2-10

DEPLETION (JUNCTION) CAPACITANCE

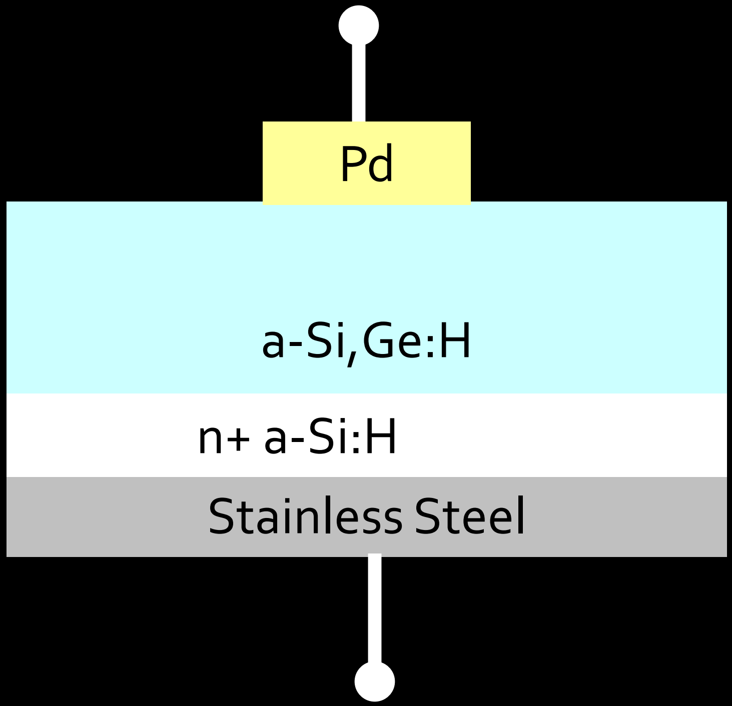


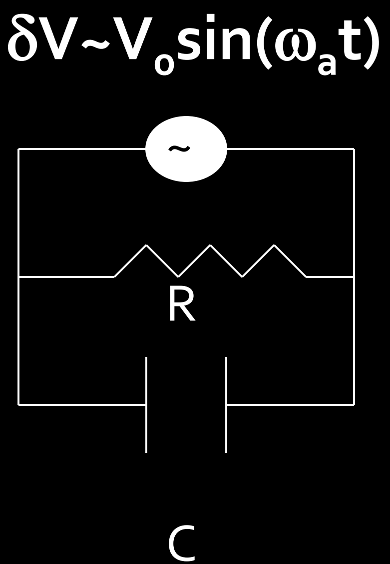
$$C_J = \frac{\varepsilon \varepsilon_0 A}{d}$$

Capacitance : The Space Charge or the depletion region stores charge

Fig 3.1, Milman & Halkias, Integrated Electronics

Admittance Measurements



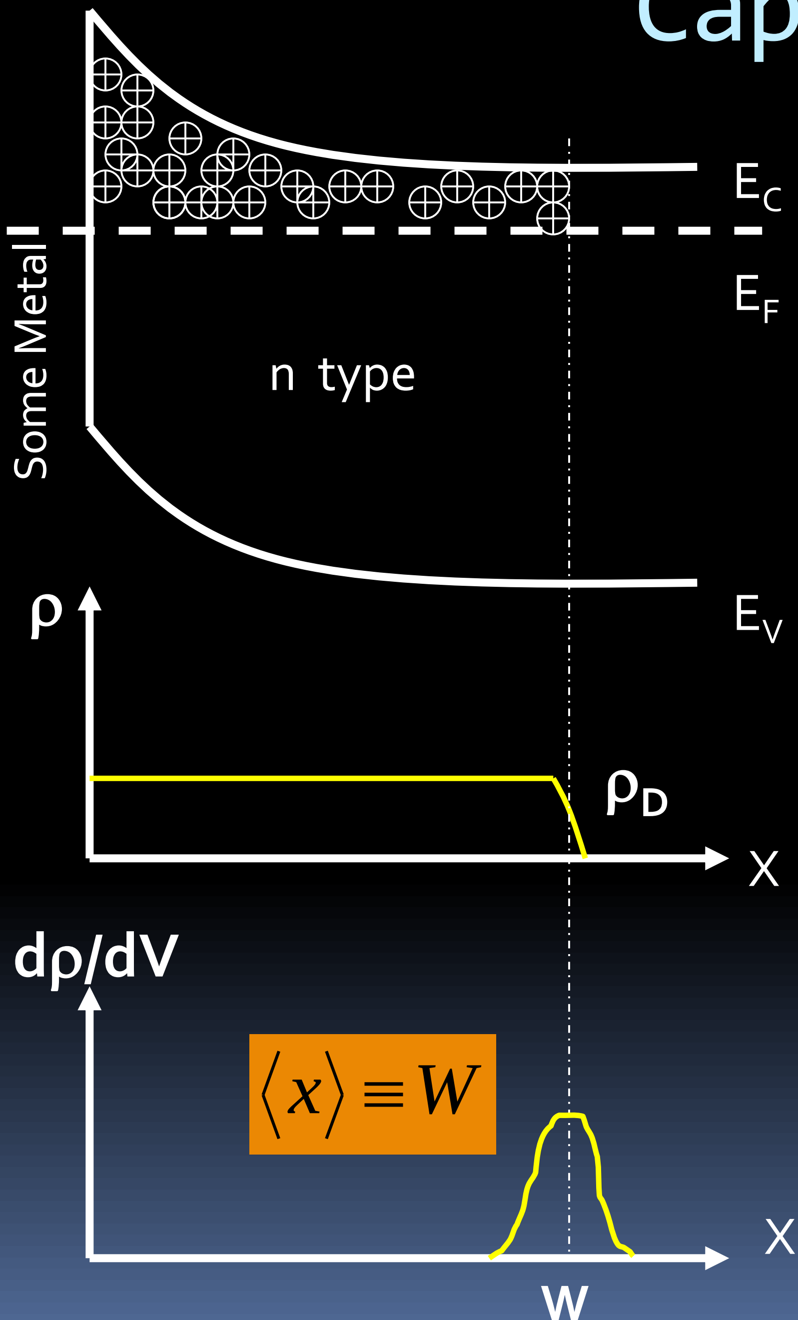


$$\frac{1}{Z_{eq}} = \frac{1}{R} + i\omega_a C = G + i\omega_a C$$

$$i = \frac{dq}{dt} = \left(\frac{dq}{dV}\right) \times \frac{dV}{dt} = C\frac{dV}{dt}$$

Capacitance is estimated by measuring the ac current 90° out of phase with the 'small signal' voltage excitation.

Capacitance

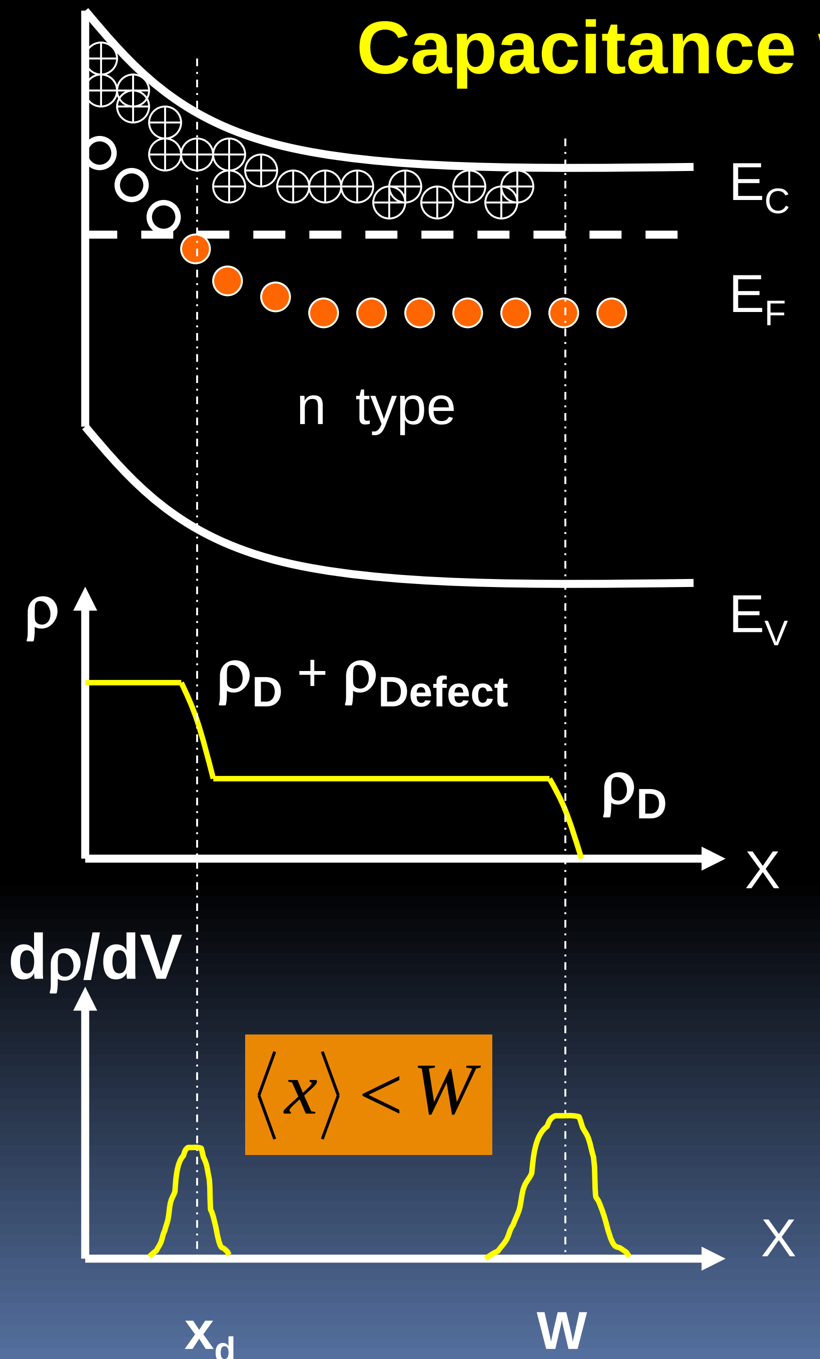


$$C = \frac{dq}{dV} = \frac{\varepsilon A \int_0^{\propto} \delta\rho(x)dx}{\int_0^{\propto} x\delta\rho(x)dx} = \frac{\varepsilon A}{\langle x \rangle}$$

Capacitance is a measure of the mean position of the displaced charge distribution.

H. Kroemer et.al, Sol. State. Electron 24, 655, 1981; David Cohen et.al J. Appl. Phys. 95,1000 (1995)

Capacitance with Defect States



$$C = \frac{dq}{dV} = \frac{\varepsilon A \int_0^{\infty} \delta\rho(x)dx}{\int_0^{\infty} x\delta\rho(x)dx} = \frac{\varepsilon A}{\langle x \rangle}$$

Capacitance is a measure of the mean position of the displaced charge distribution.

H. Kroemer et.al, Sol. State. Electron 24, 655, 1981; David Cohen et.al J. Appl. Phys. 95,1000 (1995)

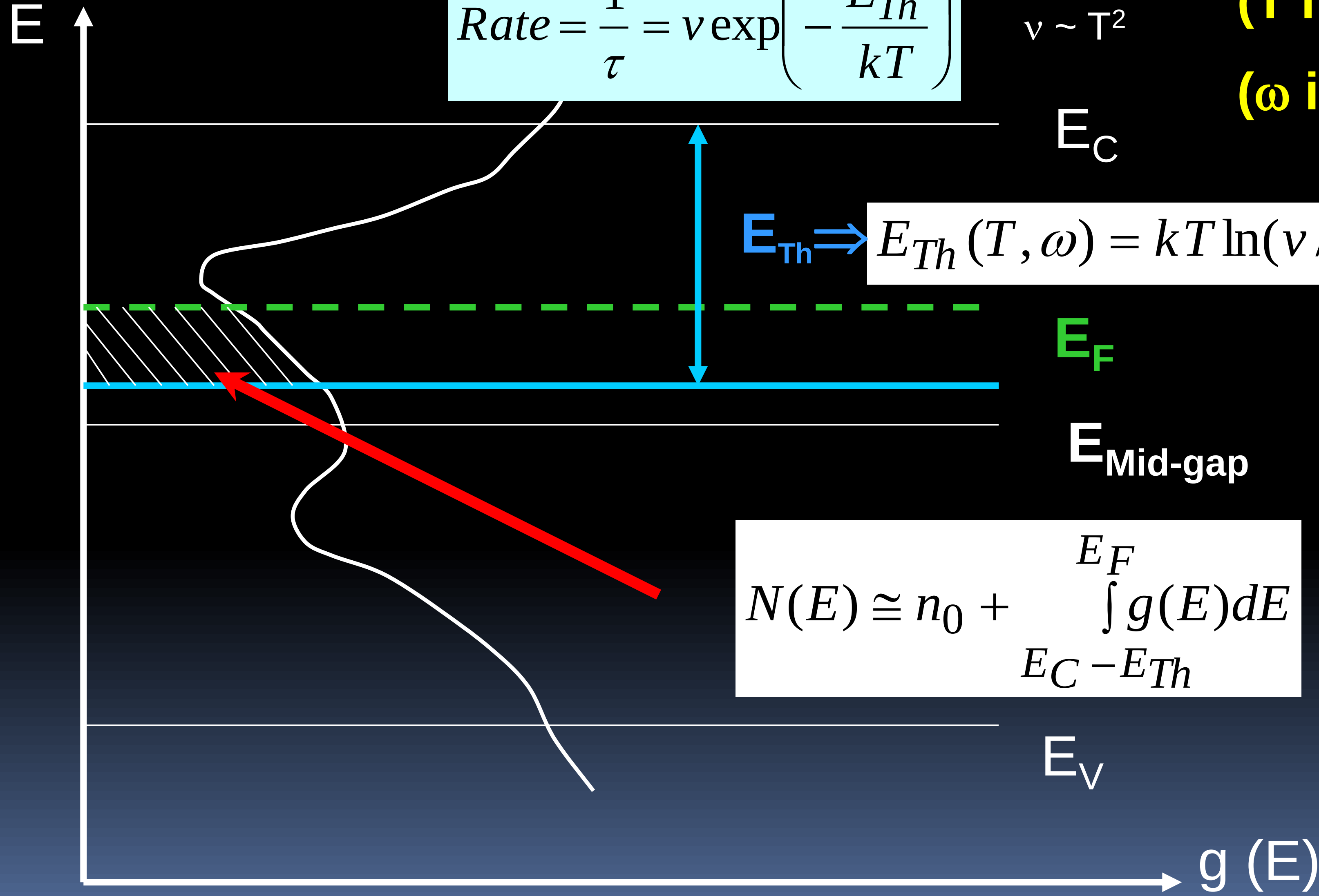
Temperature and Frequency Dependence of Thermally Activated Processes

$$Rate = \frac{1}{\tau} = \nu \exp\left(-\frac{E_{Th}}{kT}\right)$$

$\nu \sim T^2$

(T in K)

(ω in Hz)

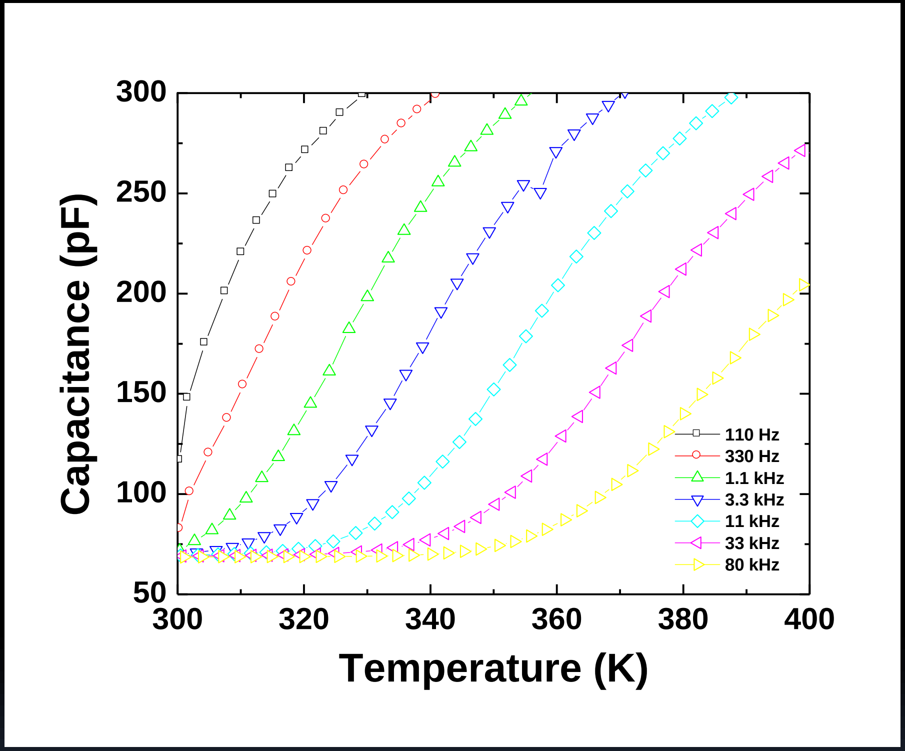


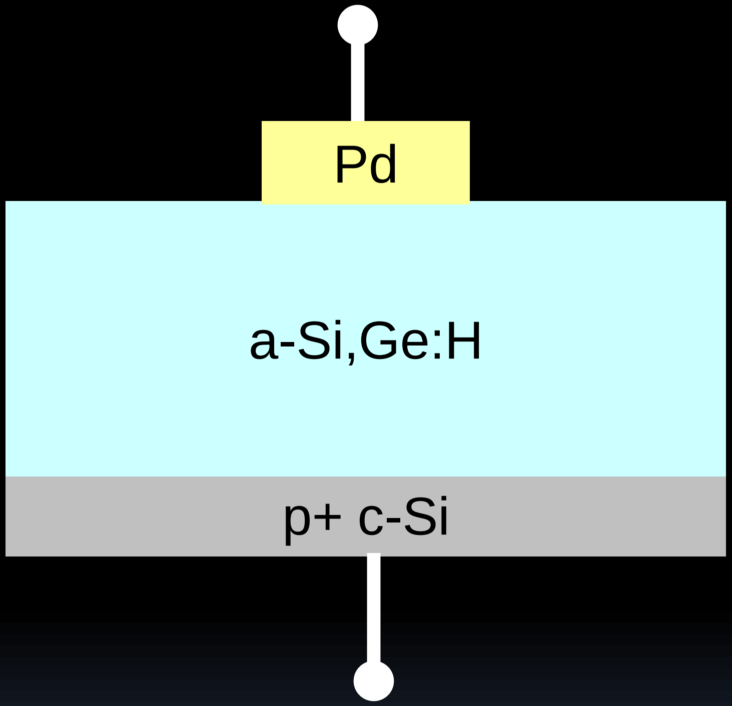
$$E_{Th}(T,\omega) = kT \ln(\nu/\omega)$$

$$N(E) \cong n_0 + \int_{E_C - E_{Th}}^{E_F} g(E)\,dE$$

Admittance Measurements

HWCVD a-Si,Ge;H with 30%Ge and >10^{20}/cm^3 O_2 on p^+ c-Si





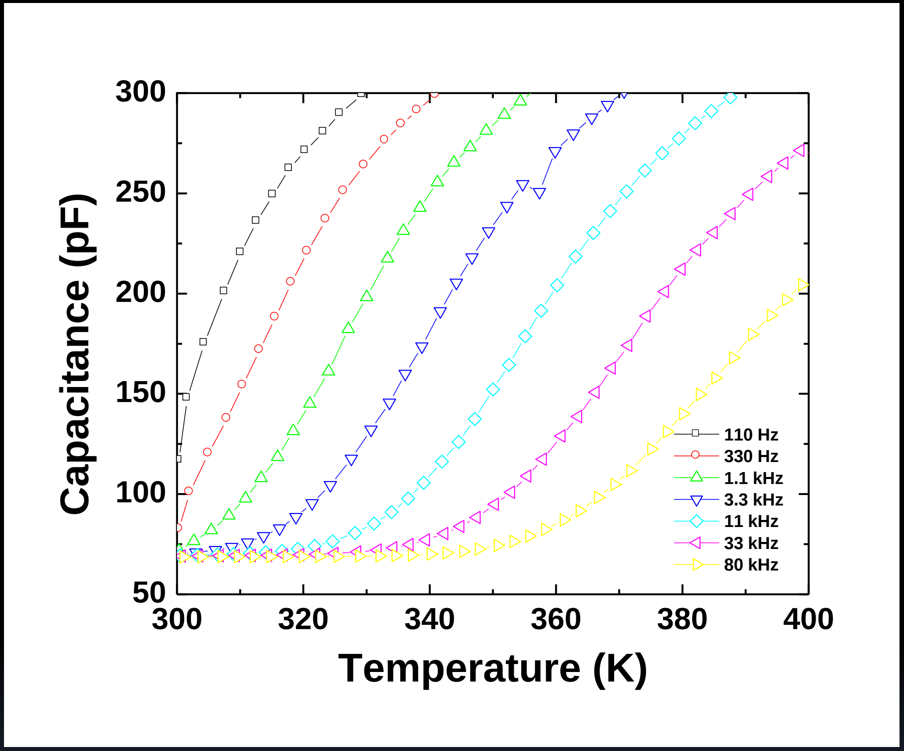
$$C = \frac{\varepsilon A}{t} \Rightarrow \frac{\varepsilon A}{\langle x \rangle}$$

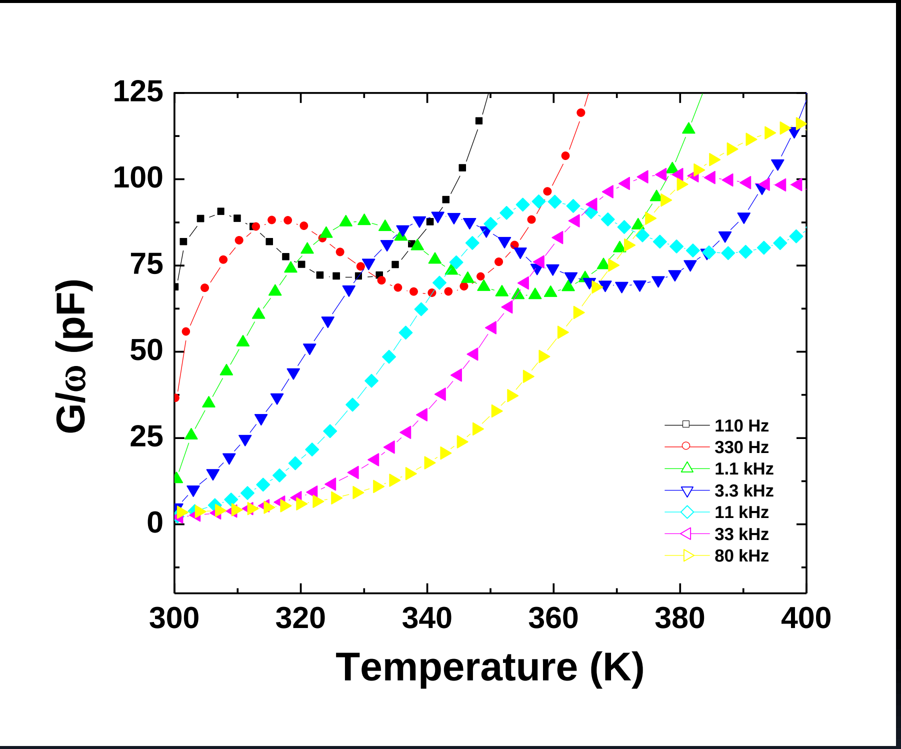
Thickness of the Film (t) > Effective Depletion Width (<x>)

'A' is the area of the top semi-transparent Pd dot

Admittance Measurements

HWCVD a-Si,Ge;H with 30%Ge and $>10^{20}/cm^3\ O_2$ on p^+ c-Si

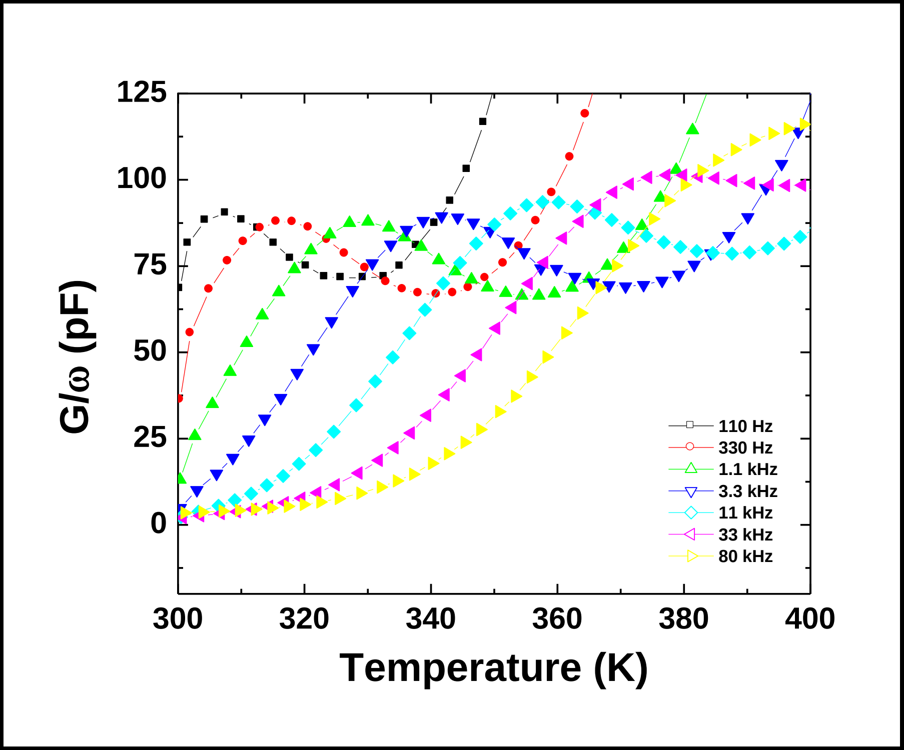




Conductance Peaks $\Rightarrow$ $E_{Th}(T,\omega) \equiv E_F$

$$E_{Th}(T,\omega) = kT\ln(\nu/\omega)$$

Activation of Conduction



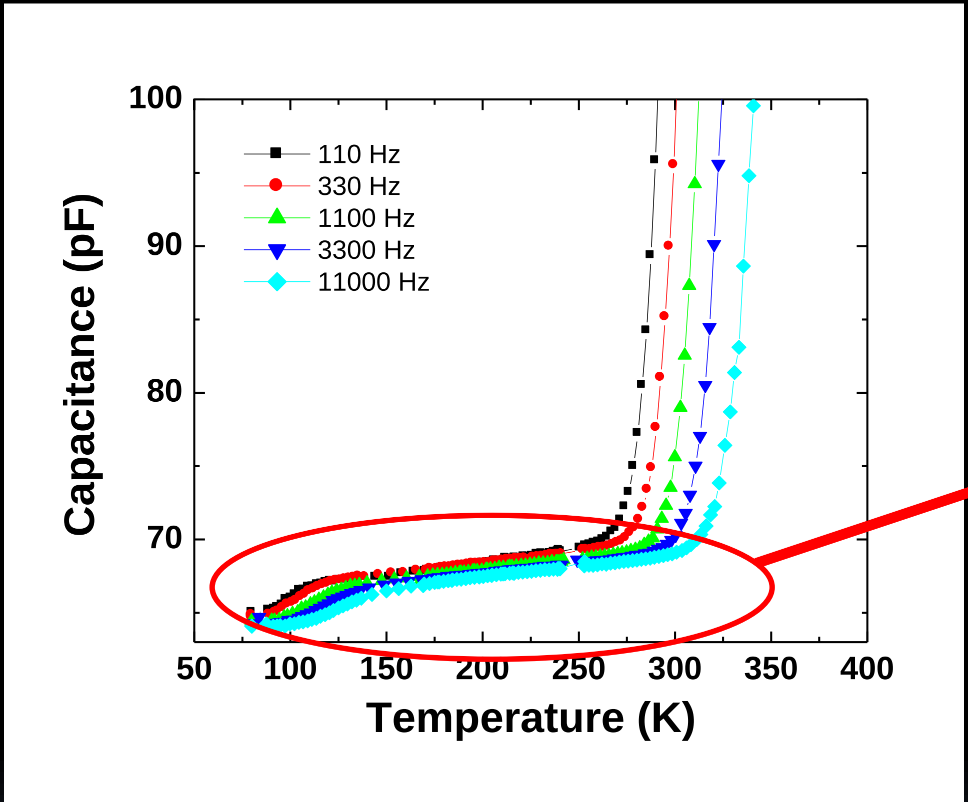
G ⇒ Conductance (Ohm^{-1})

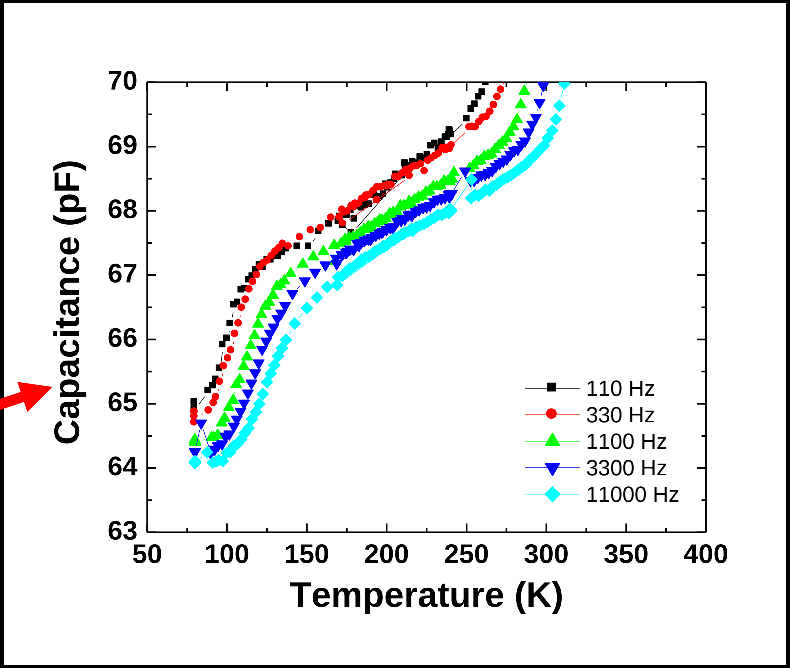
k_B ⇒ Boltzmann Constant (8.617 343 x 10-5 eV K^{-1})

ω ⇒ Frequency of Measurement (Hz)

E_a ⇒ Activation Energy (eV)

Signature of Doping – Activation of Shallow States





$$C_{Low\ \ Temp} = \frac{\varepsilon A}{t}; \quad t = Film\ Thickness$$

2006 HWCVD a-Si,Ge:H with 30% Ge / n^+ a-Si:H / Stainless Steel