Lecture 9

- Last time:
  - Drift current density ←
  - Ohm's and resistivity
- Today :
  - IC resistors
  - IC capacitors: metal-metal and pn junction

$J_p = q\mu_p \boxed{p} E$

$J_n = q\mu_n \boxed{n} E$

$p \approx \underbrace{N_a - N_d}_{N_{a,net}}$

$n \approx \underbrace{N_d - N_a}_{N_{d,net}}$

compensated.

$\sum_i N_{a_i} - \sum_j N_{d_j}$

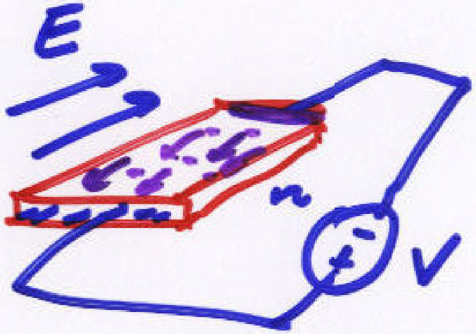
EE40.

$R_\square, R_{sq}$.

★

Resistivity

Bulk silicon: uniform doping concentration, away from surfaces



n-type example: in equilibrium, $\boxed{n_o = N_d}$.

When we apply an electric field, $n \stackrel{\sim}{=} N_d$.

no "o"

n-type.

$$J_n = q\mu_n nE = \underbrace{q\mu_n N_d}_{net} E$$

$(N_d - N_a)$

Conductivity $\sigma_n = (q\mu_n N_d)$

Resistivity $\rho_n = \boxed{\frac{1}{\sigma_n}} = \frac{1}{q\mu_n N_d}$ "Ω-cm"

$N_d = N_a = 0 \ldots \quad \rho_n =$

$n_o = p_o = 10^{10}\ \mathrm{cm}^{-3}$
$(N_a = N_d = 0)$

Ohm's Law

$V = IR.$ ↑

- Current I in terms of J_n
- Voltage V in terms of electric field

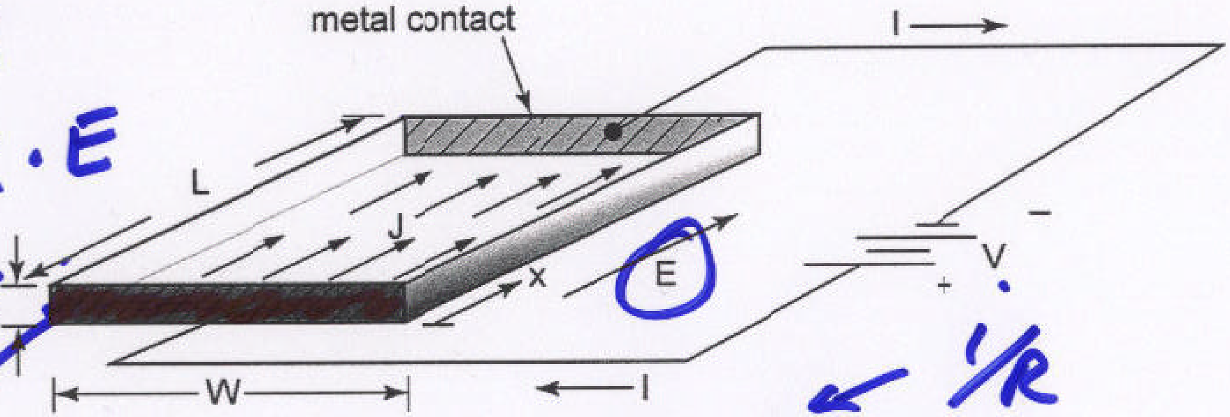
$I = J \cdot A$

$J = \sigma_n \cdot E$

$= A \sigma_n \cdot E$

$I = A \sigma_n \frac{V}{L}$

$A = wt$



- Result for R

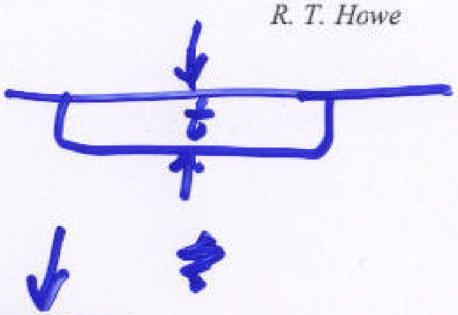
$I = \left(\frac{\sigma_n A}{L}\right) \cdot V$ ← $1/R$

$R = \frac{L}{\sigma_n A} = \rho_n \left(\frac{L}{A}\right)$ A ← $wt.$

$R = \rho_n \frac{L}{Wt}$

WE = I.C. CIRCUIT DESIGNERS

Sheet Resistance



- IC resistors have a specified thickness – not under the control of the *circuit* designer
- Eliminate *t* by absorbing it into a new parameter: the *sheet resistance*

[·]

Ω/□

Ω-cm

$$R = \frac{\rho L}{Wt} = \left(\frac{\rho}{t}\right)\left(\frac{L}{W}\right) = R_{sq}\left(\frac{L}{W}\right)$$

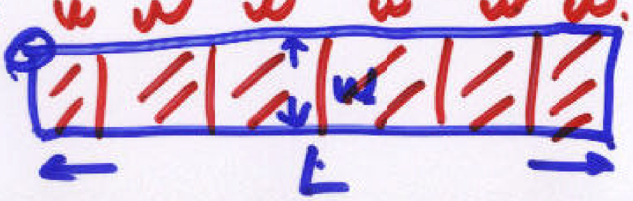
cm

□'s

squares.

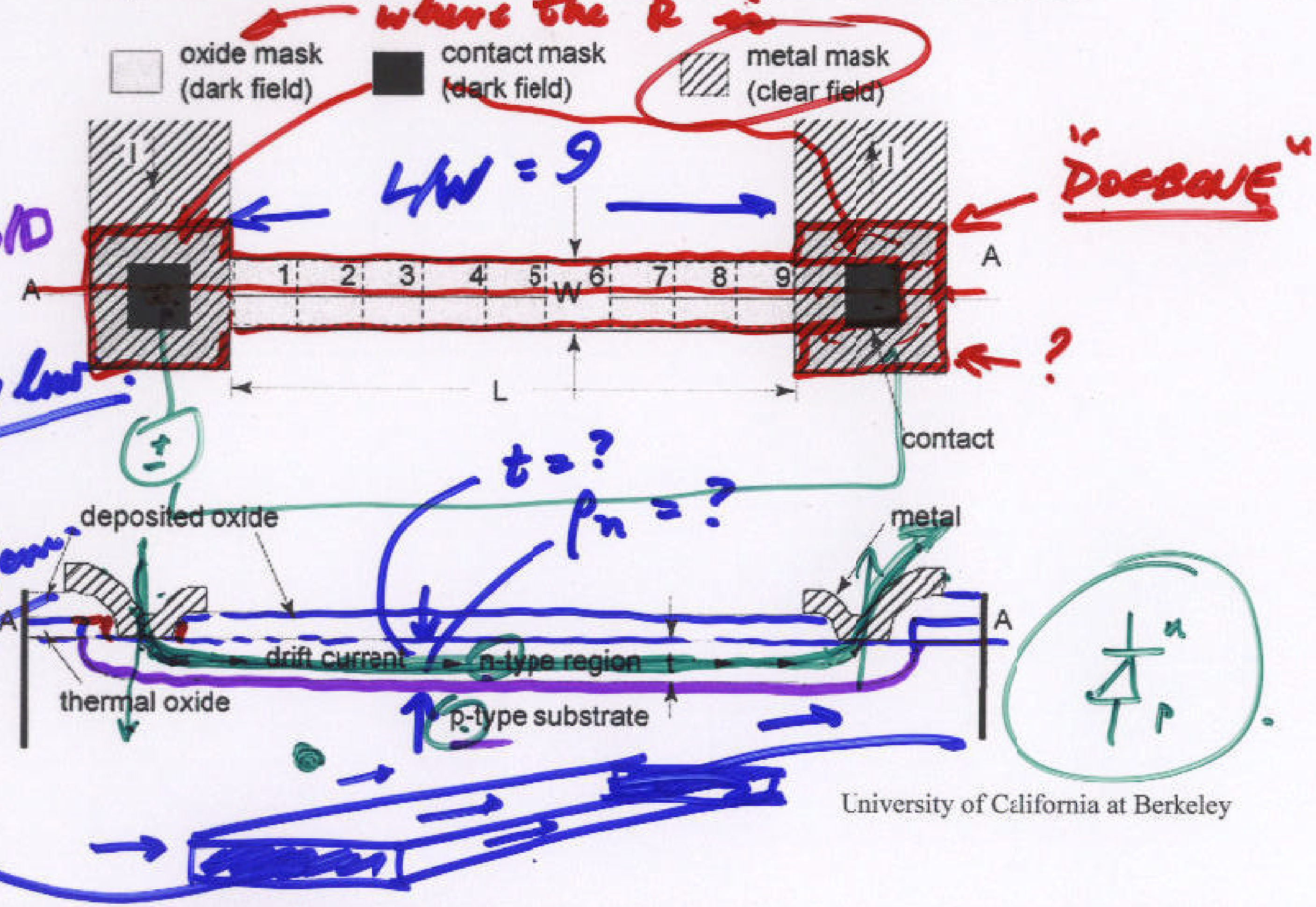
WE CONTROL!

$\frac{L}{W} = 6$



Using Sheet Resistance

- Ion-implanted (or "diffused") IC resistor

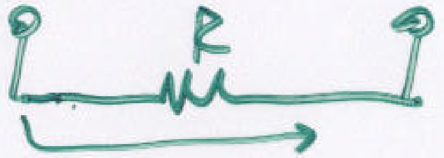


$R_{\square_{diff}}$ =

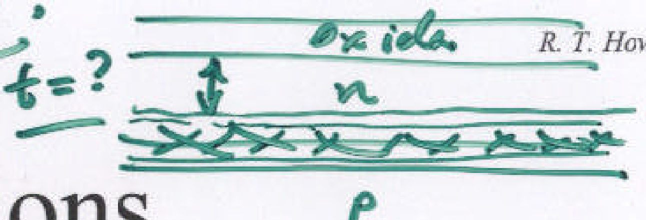
$R_{\square_{poly}} = 25\Omega/\square$

$R_{\square_{Al,Cu}}$ = very low.

$R_\square = 500\Omega/$[illegible]



EE 130:

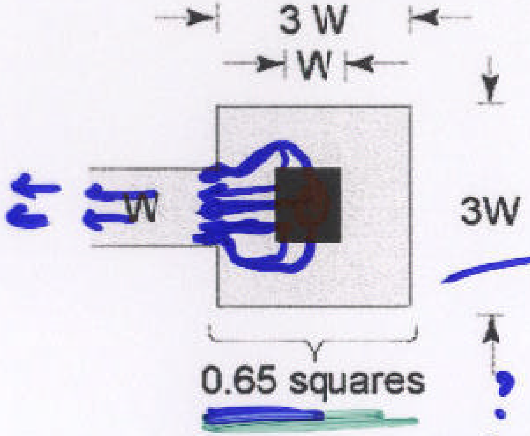


Idealizations

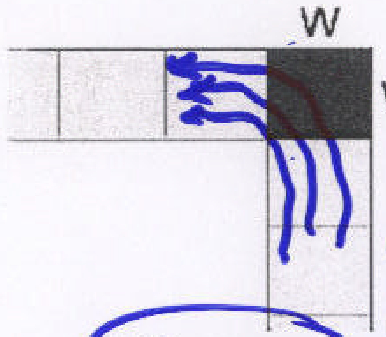
- ✓ Why does current density J_n "turn"? (LATER)
- ✓ What is the thickness of the resistor?
- What is the effect of the contact regions?

$\boxed{R_\square = R_\square(\text{zero bias})}$

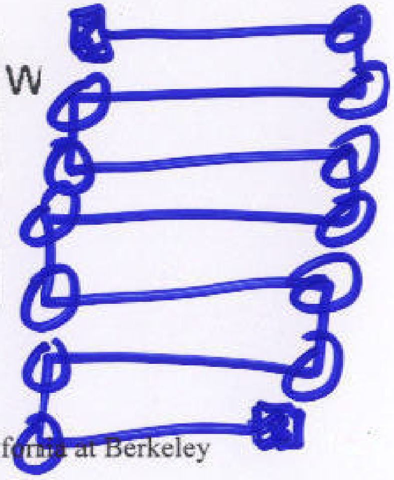
$R_\square = f(T)$



0.65 squares



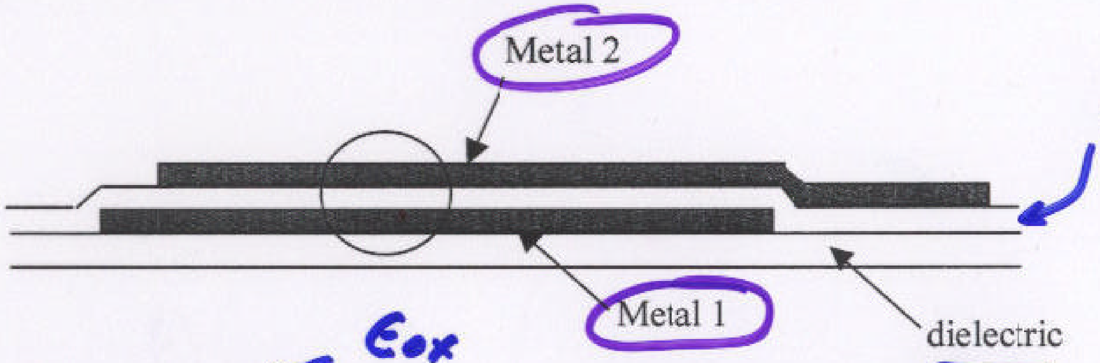
0.56 squares



$$R_{TOT} = R_\square\left(\overset{9}{\frac{L}{W}}\right) + 2(0.65)\cdot R_\square$$

IC Capacitors : GREAT CAPACITORS.

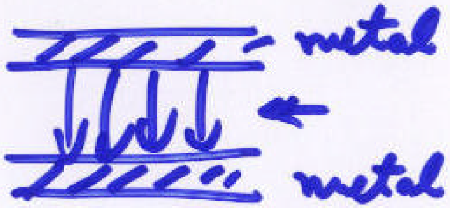
- Metal layers separated by insulators → get intentional (or parasitic) capacitor



SiO_2 = DIELECTRIC

ε_{ox}

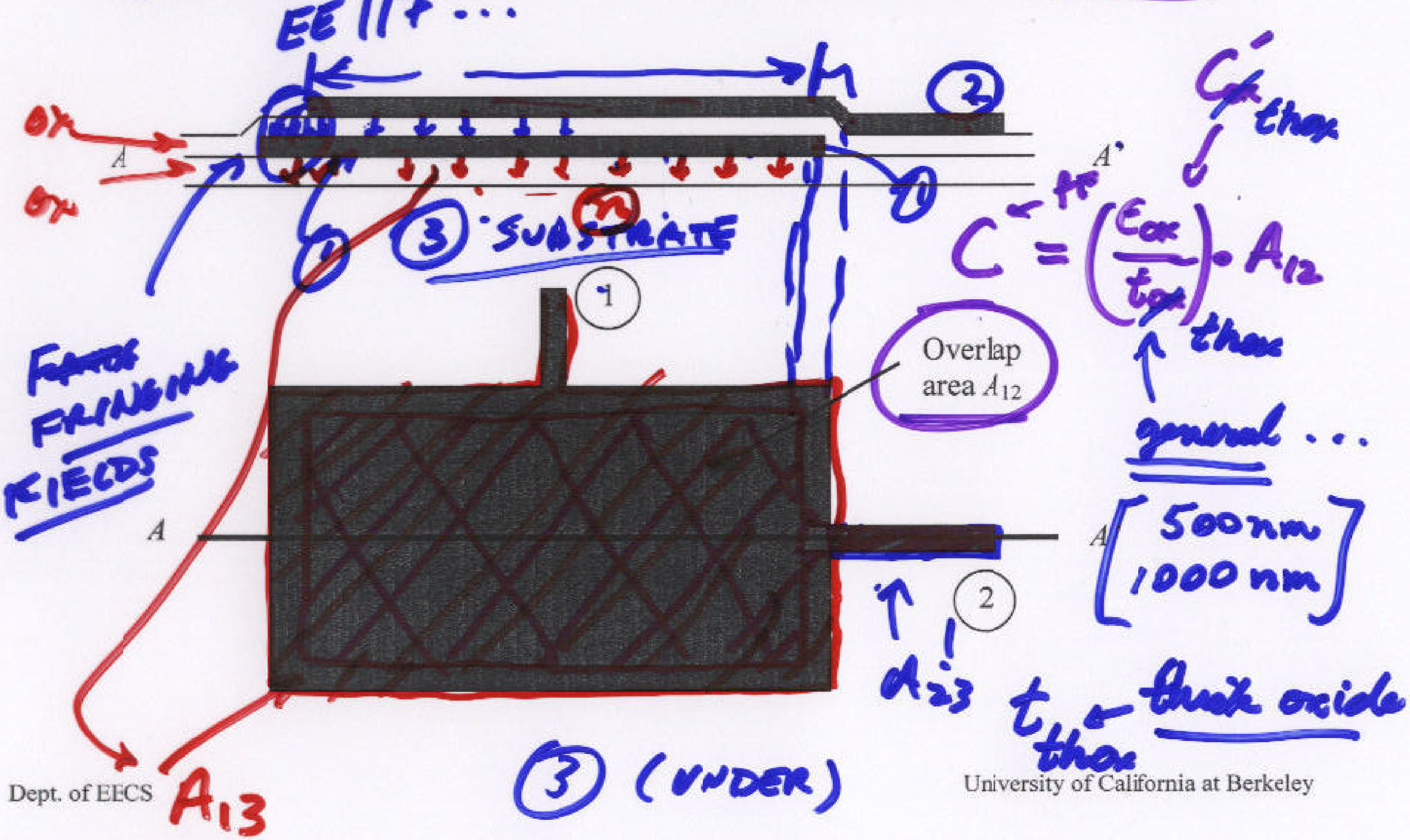
$$\boxed{C = \frac{\varepsilon_d}{t_d}}$$



cap./area $\frac{F}{cm^2} \Rightarrow \left(\frac{fF}{\mu m^2}\right)$ — $10^{-15} F$

$\mu m = 10^{-6} m.$

Metal-Metal Capacitor Layout



C'_{thox}

$C = \left(\frac{\epsilon_{ox}}{t_{ox}}\right) \cdot A_{12}$ ← thox

general ...

[500 nm
1000 nm]

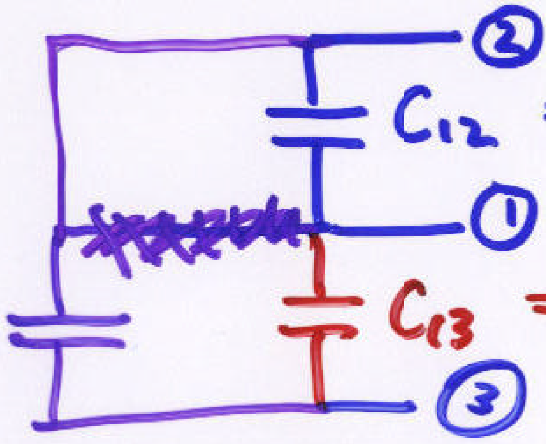
t_{thox} ← thick oxide

Circuit Model

- Capacitance between metal 1 and metal 2:

$$C_{12} = \left(\frac{\varepsilon_d}{t_d}\right) A_{12}$$

- Other capacitors: what is terminal 3?



$C_{12} = \left(\frac{\varepsilon_d}{t_{1-2}}\right) A_{12}$

$C_{13} = \left(\frac{\varepsilon_d}{t_{1-3}}\right) A_{13}$

LOWER ↓

$\left(\frac{\varepsilon_d}{t_{12} + t_{13}}\right) . A_{23} = C_{23}$

HARD TOPIC ... BUT YOU WILL GET LOTS OF PRACTICE

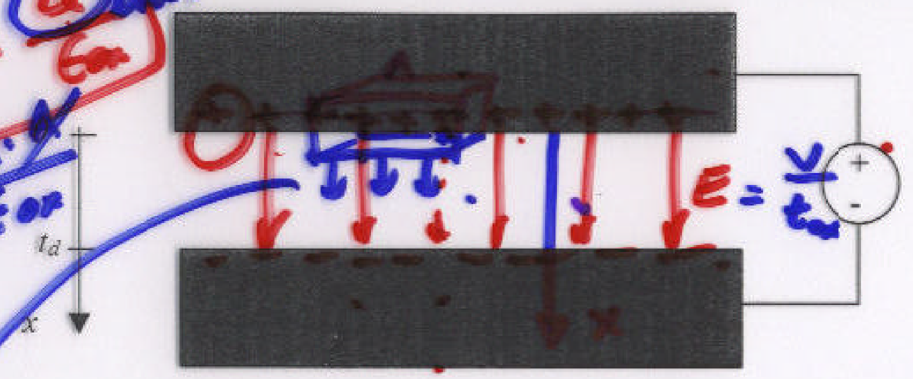
— PHYSICS 7B —

• Surface Charge and Electric Field

$$\oint \vec{E}\cdot d\vec{S} = \frac{Q_{enc.}}{\epsilon_{ox}}$$

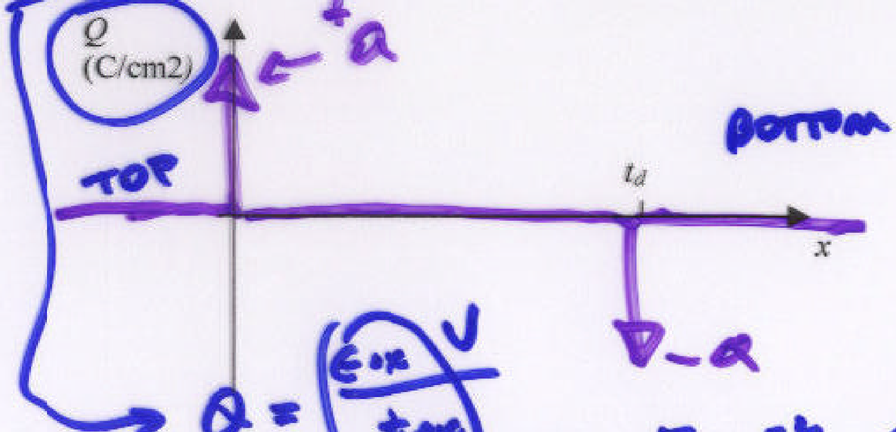
$$E.A = \frac{Q.A}{\epsilon_{ox}}$$

$$Q = \epsilon_{ox} E$$



$E = \frac{V}{t_{ox}}$

$V = \overset{+}{1}V$

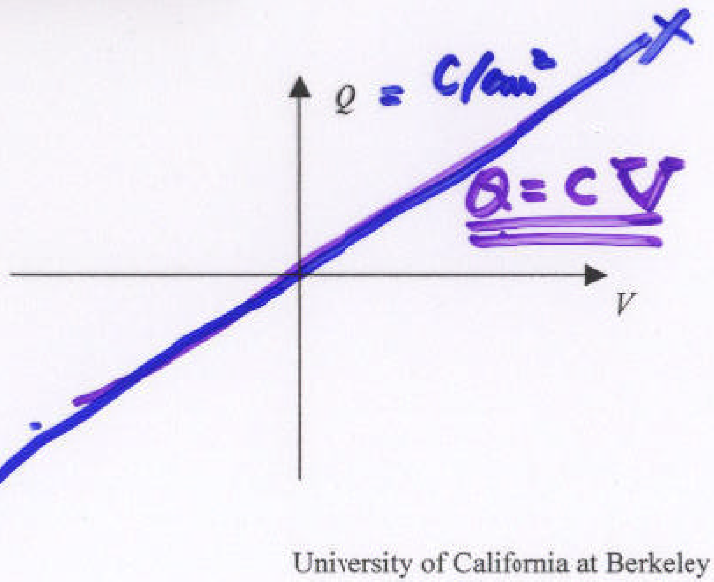


$$Q = \frac{\epsilon_{ox}}{t_{ox}} V$$

$F\,cm^{-2}$

$C\,cm^{-2}$

$$\boxed{Q = C.V.}$$



$Q = C/cm^2$

$Q = CV$