ELECTRICAL CHARACTERIZATION OF THIN-FILM FIELD-EFFECT TRANSISTORS

"Electronics 101"

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The Algarve

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Faro, Portugal

Inspiration

"Perfection is reached not when there is nothing left to add, but when there is nothing left to take away"

Saint-Exupéry 1900-1944

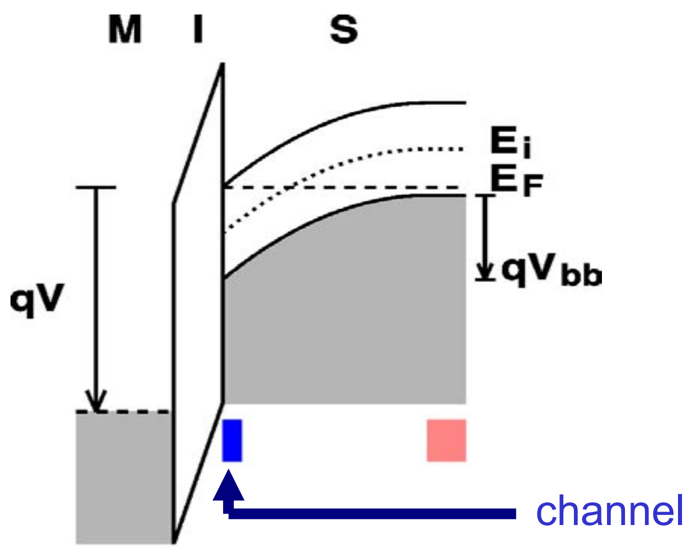
"One should not increase, beyond what is necessary, the number of entities required to explain anything"

William of Occam, 1288-1348

The MOS-FET model

The MOS-FET model is the *de facto* standard for modeling TFTs

The gate field induces band bending in the semiconductor. This moves the electronic levels relative to the Fermi level.

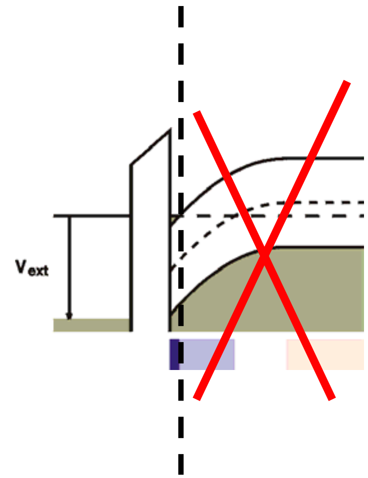


When the Fermi level at interface is resonant with conduction band, a large density of charge is induced. This is the so-called "channel"

The MOS-FET model

Why a TFT is not a MOS-FET?

1. A TFT is made of a **thin** film and cannot accommodate band bendings.



2. A TFT normally works in **accumulation** and thus cannot store the immobile charge needed for band bendings (there are no electronic states, N_A^-).

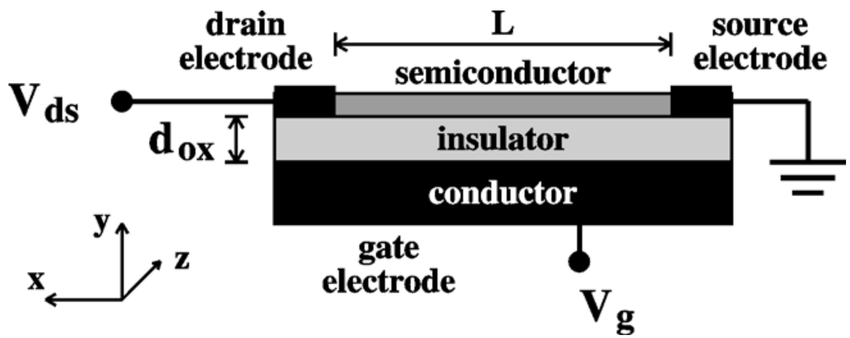
There **are** no band bendings!

Not even in thick film transistors! Not even at contacts!

The Algarve TFT model

1: At any place in the device, the charge is related to the local potential (the device is a simple capacitor):

$$\rho(x) = -C_{ox}[V_g\text{-}V(x)]$$

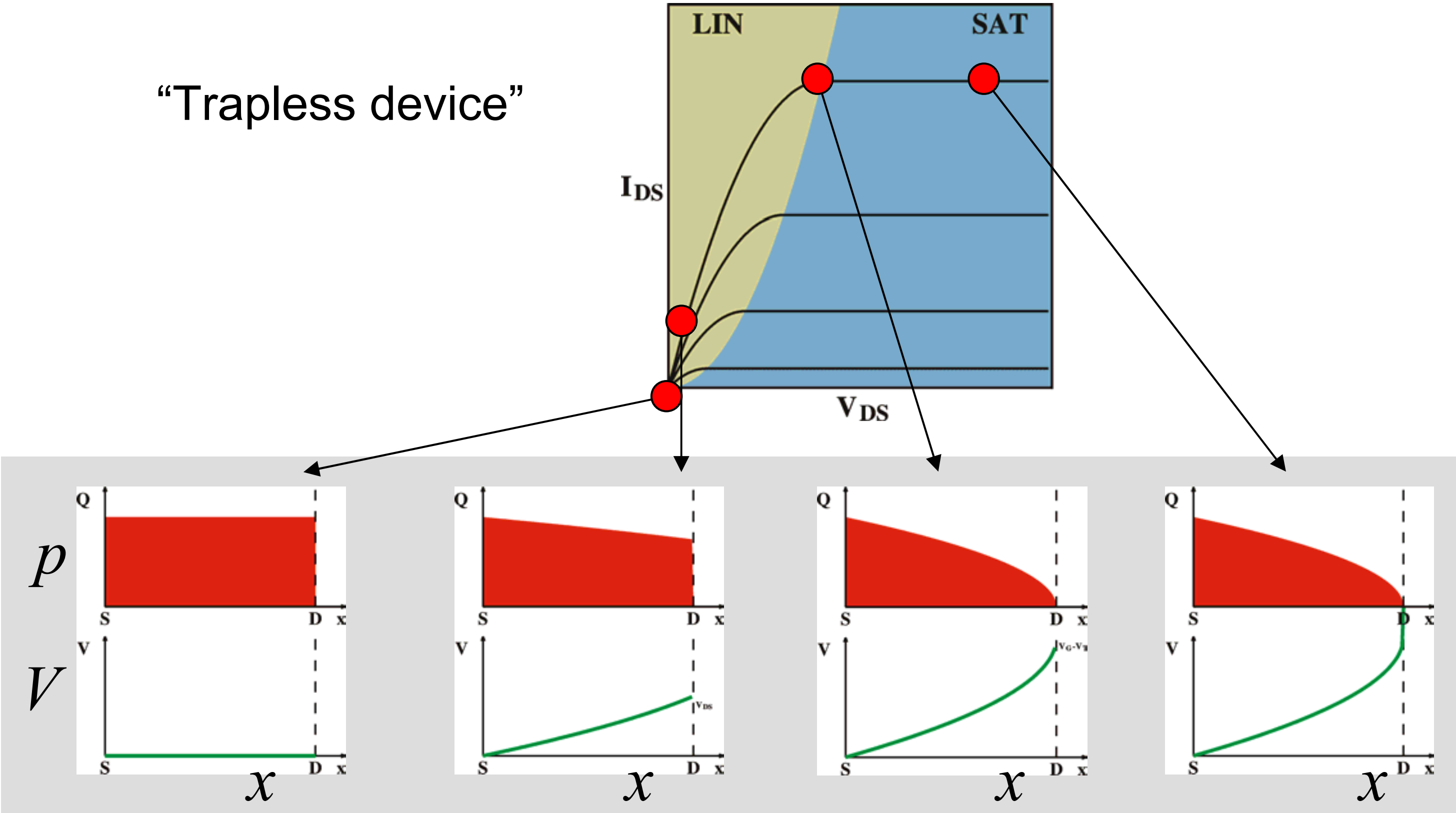


2: At any place in the device, the current is proportional to the local field and charge density:

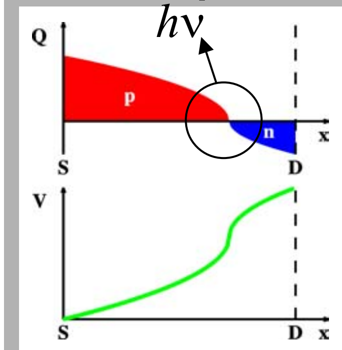
$$I(x) = \mu\ \rho(x)\ \mathrm{d}V(x)/\mathrm{d}x$$

The Algarve TFT model

"Trapless device"



ambipolar:



LE-FET

At small V_{ds},
homogeneous device

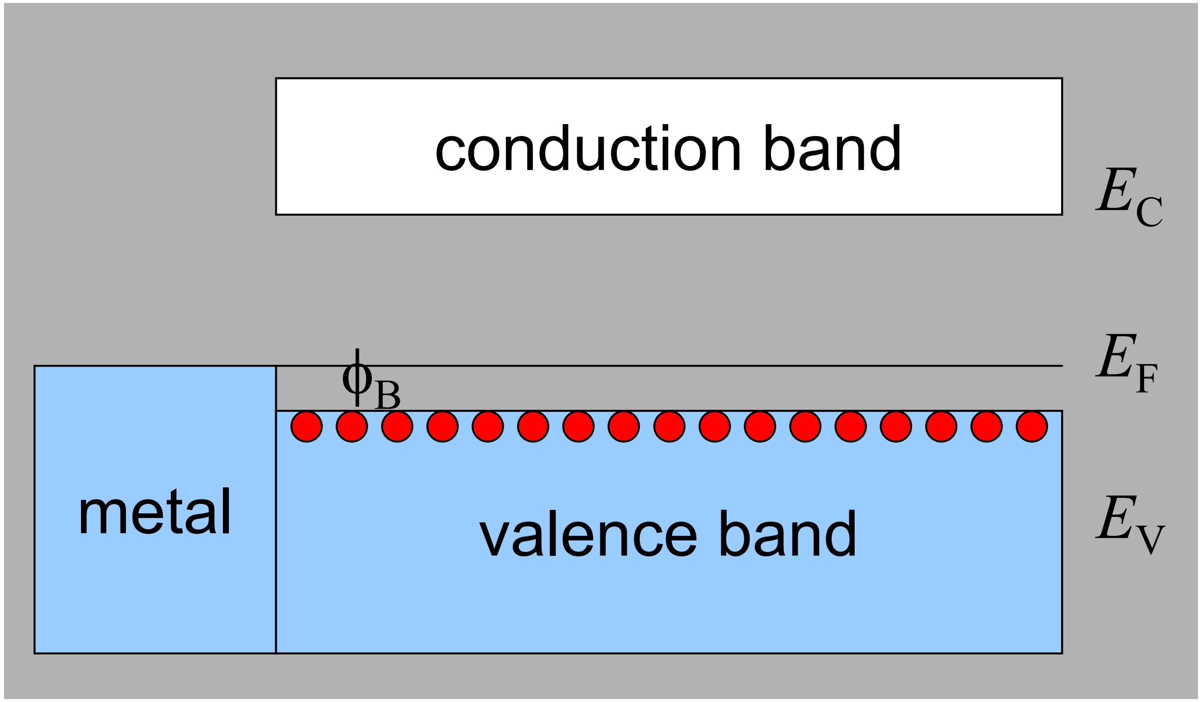
$$\boxed{I_{\mathrm{ds}}(V_{\mathrm{g}}) \sim p(V_{\mathrm{g}})}$$

Calculate p as a function of V_{g} will yield mobility μ_{FET}

The Algarve TFT model

The **are** no “contact effects” !!

$$I \longrightarrow p \longrightarrow E_F - E_V \longrightarrow \phi_B$$



measurable current? ⟶ barrier is less than 100 meV!

The Algarve TFT model

1: All charge is directly at interface

2: Charge can be free charge (h) or trapped charge (T^+)

3: Sum of them is depending on local bias ($p + N_T^+ \sim V_g$-$V(x)$)

4: Relative densities (can) depend on temperature and bias (Fermi-Dirac distribution $f(E)$)

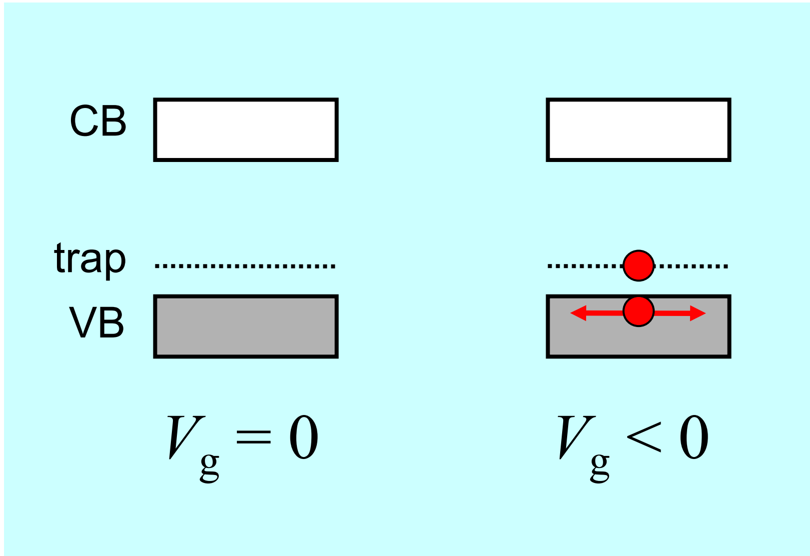
5: Thermal equilibrium reached instantaneously

6: Currents are proportional to free charge only ($I_{ds} \sim p$)

7: Mobility is defined via derivative of transfer curve in linear region ($\mu_{FET} \sim dI_{ds}/dV_g$)

No parameters. No N_A, V_T, V_{FB}, ε, E_g, etc.

Traps



$$\boxed{p(V_g) + N_T^{+}(V_g) = -C_{ox}V_g/q}$$

Traps

p and N_T^+ can depend on temperature and bias in a different way, thus the mobility can depend on temperature and bias

$$\mu_{FET}(V_g, T)$$

a: trap-free
b: abundant discrete trap
c: exponential trap
d: exponential trap and VB

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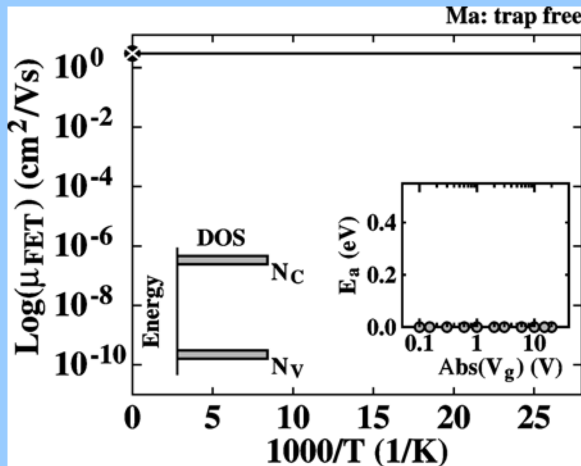
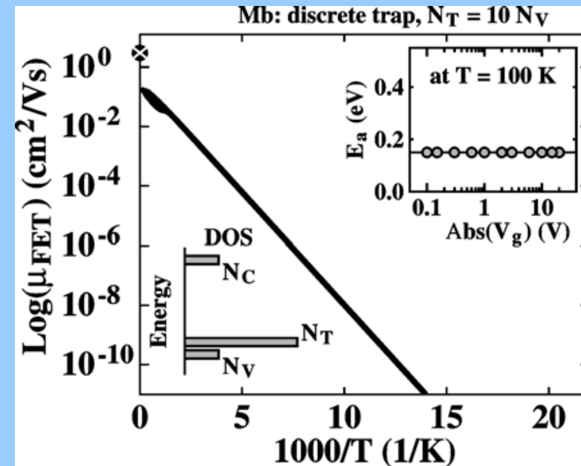
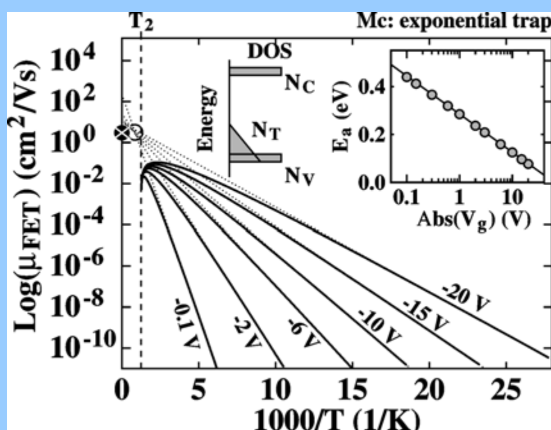
Traps, Arrhenius plots



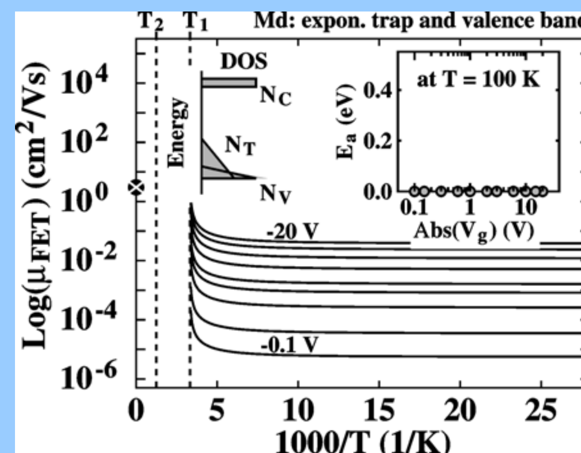
Trap free: “Standard MOS-FET”



Abundant trap: “Poole-Frenkel”, $\mu = \mu(T)$



Expon. trap: Meyer-Neldel Rule

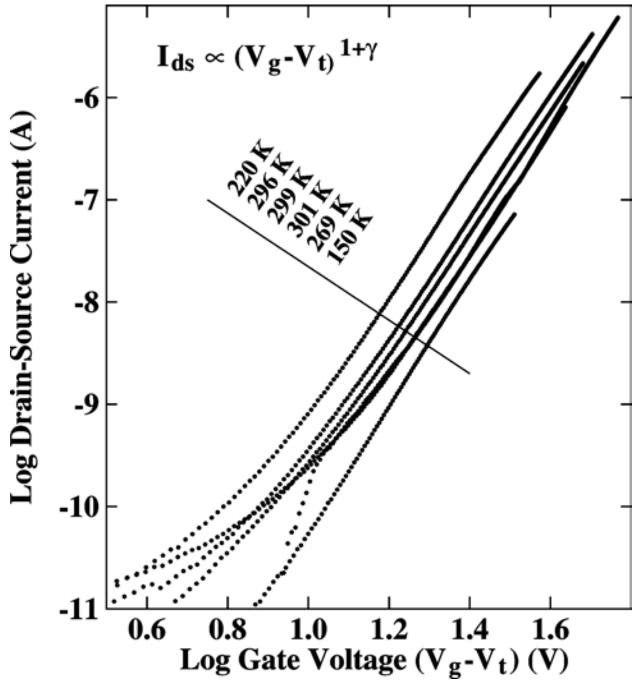


Expon. trap & VB: $\mu = \mu(V_g)$

Summary, Arrhenius plots

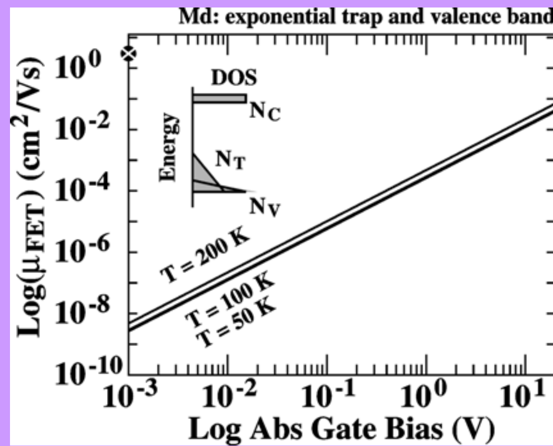
The only model that explains our experimental data

experiment:



Stallinga et al., JAP **96**, 5277 (2004)

theory:



Expon. trap & VB: $\mu = \mu(V_g)$

Conclusions

Conduction states (N_V)	Trap states (N_T)	Temperature dependent mobility	Bias dependent mobility
discrete	-	no	no
discrete	discrete	yes	no
discrete	exponential	yes	yes
exponential	exponential	no	yes

Algarve TFT model

Is very, very simple

Can explain mobilities in wide range (10^{-8} – 10^{2} cm^2/Vs) …
… without change in conduction mechanism.

Can explain bias-dependent mobility (!)

Can explain temperature-dependent mobility

Can explain bias-and-temperature-dependent mobility (Meyer-Neldel Rule)

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Related publications: Organic Electronics, Synthetic Metals (2006)

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