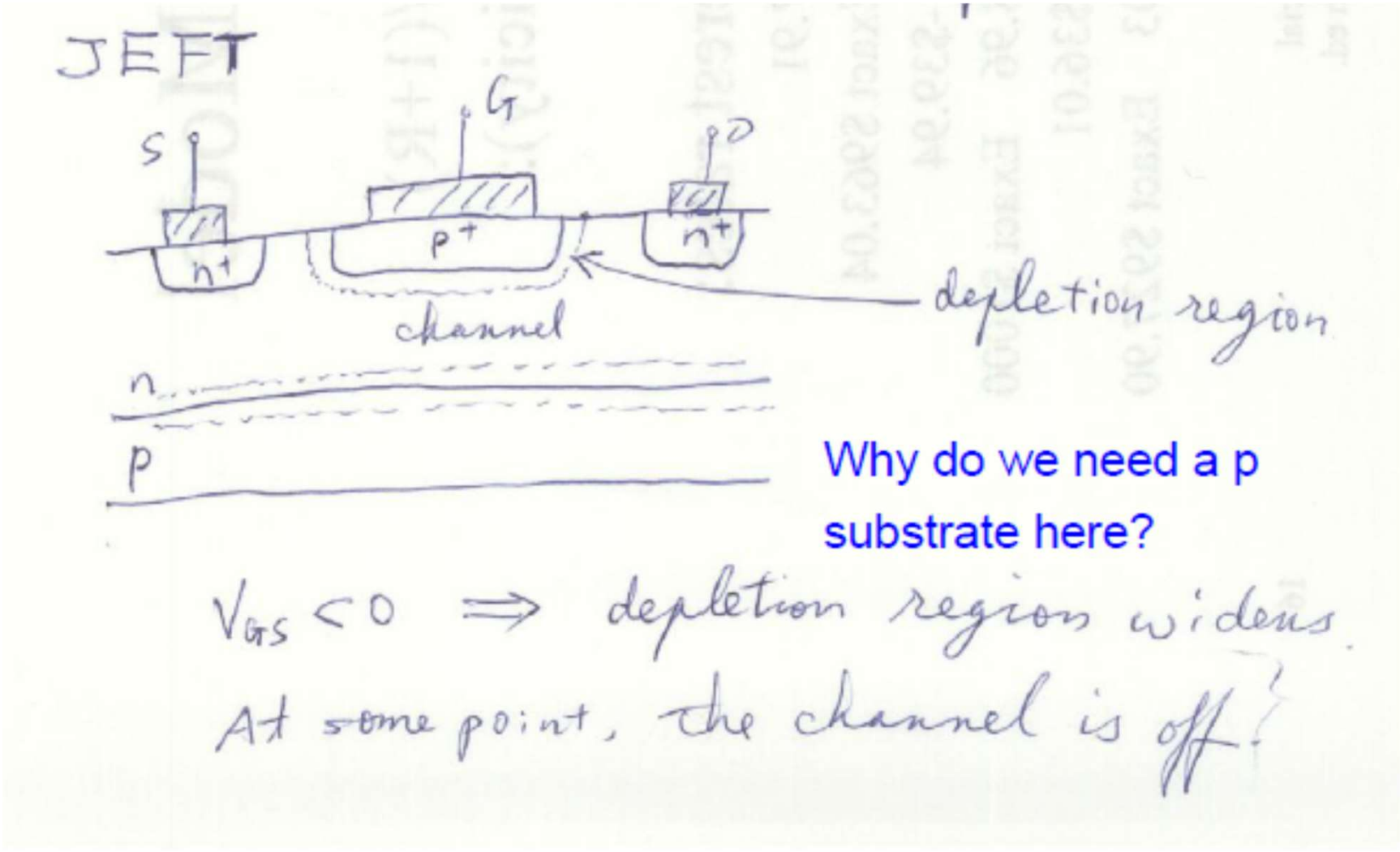
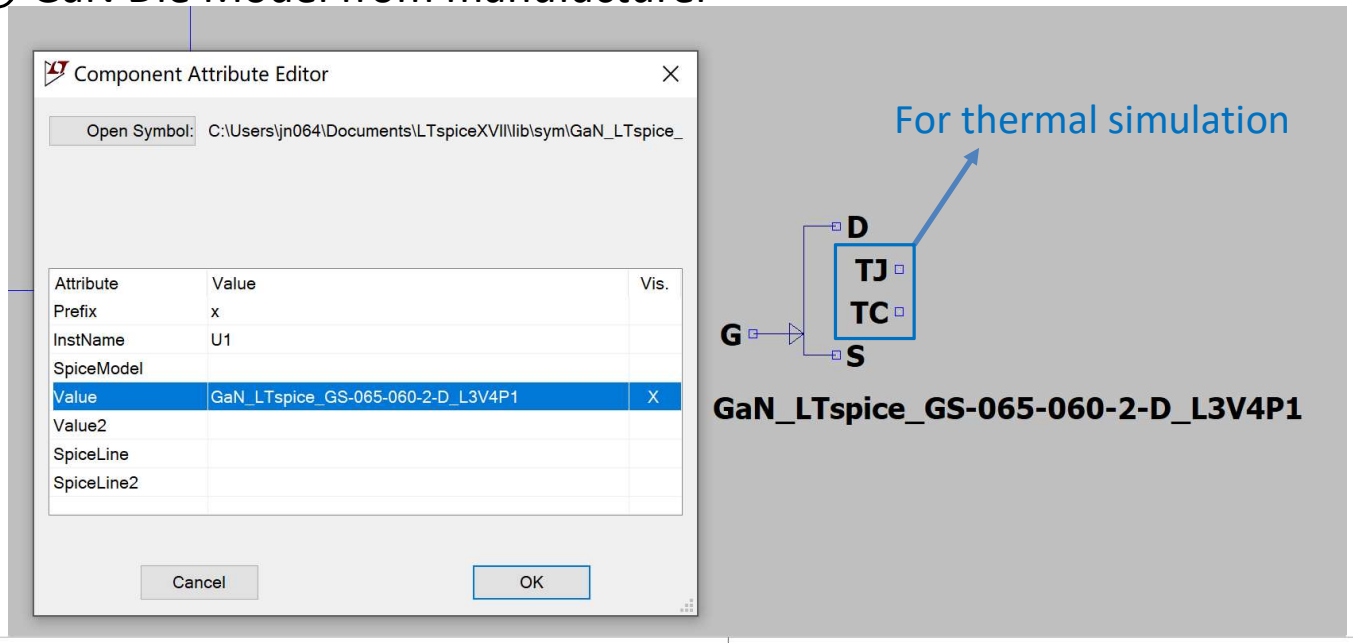
Other types of FETs

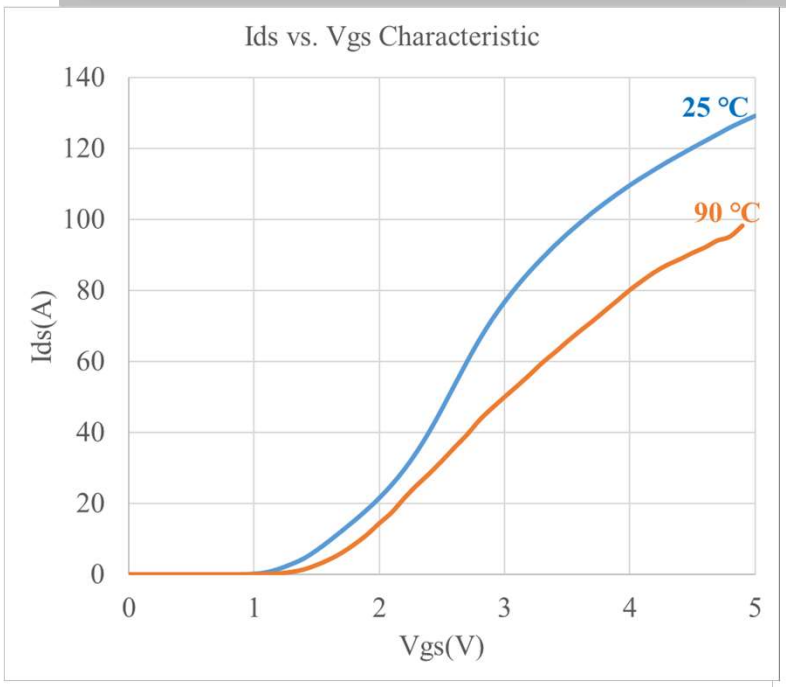
- Si is the dominant semiconductor just because of the excellent Si/SiO_2 interface. So far. This is the best semiconductor/dielectric interface.
- But Si is inferior to many other semiconductors (e.g. GaAs, InSb, etc) in terms of μ, v_{sat}.
- RF, microwave, millimeter wave applications need faster transistors.
- But MOSFETs are not that good w/ those materials due to the lack of a good semiconductor/dielectric interface.



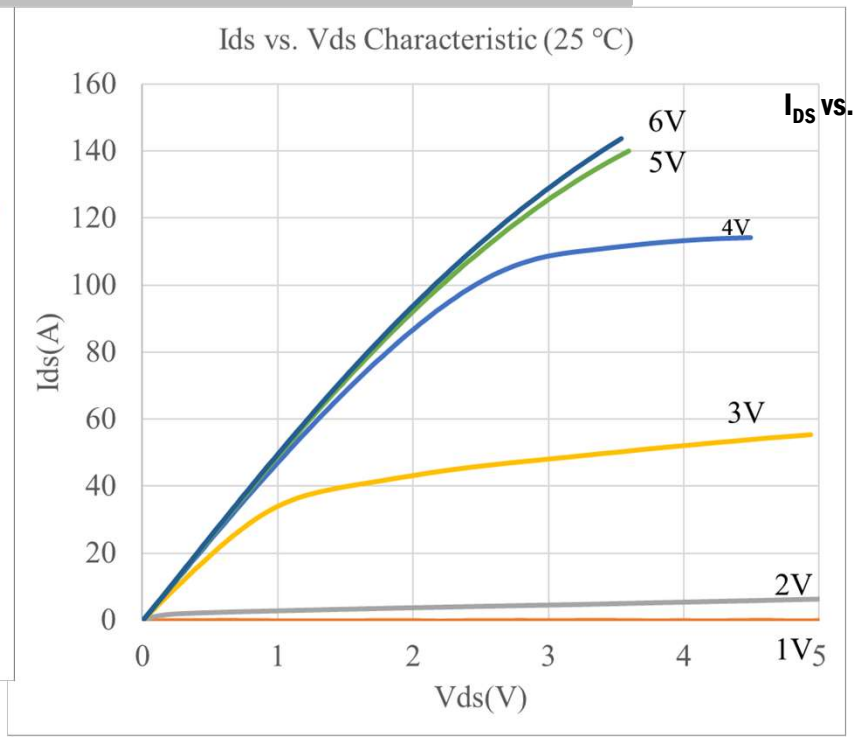
JFETs usually work in depletion mode (normally on).
Enhancement mode (normally off) devices are desired for switches.

⊙ GaN Die Model from manufacturer



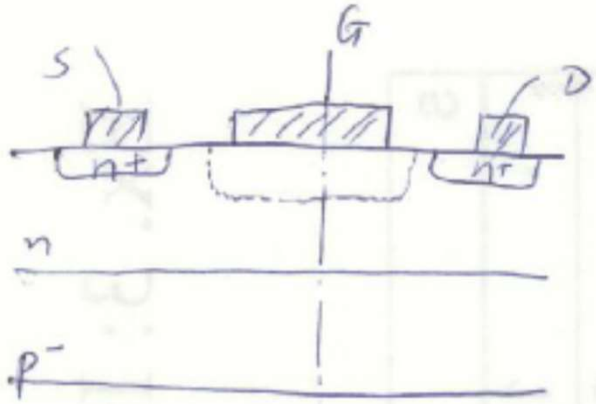


I_{DS} vs. V_{GS} @ T_J = 25 °C/ 90 °C



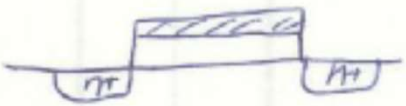
I_{DS} vs. V_{DS} @ T_J = 25 °C

MESFET

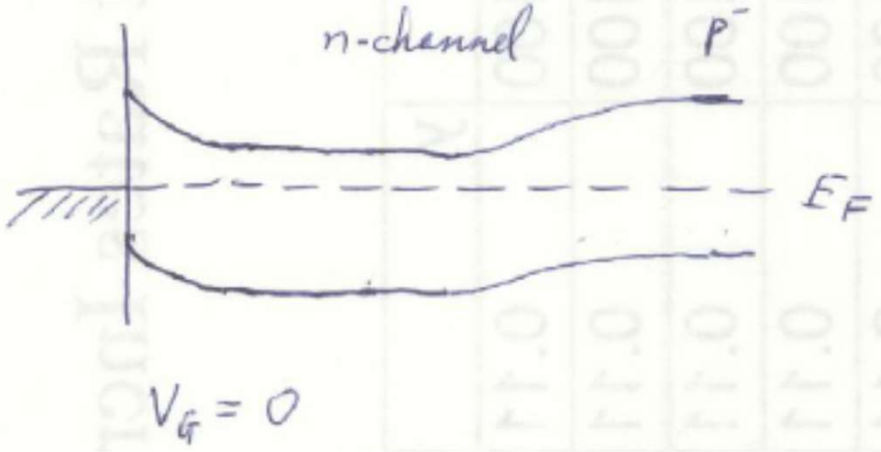


compare to MOSFET.

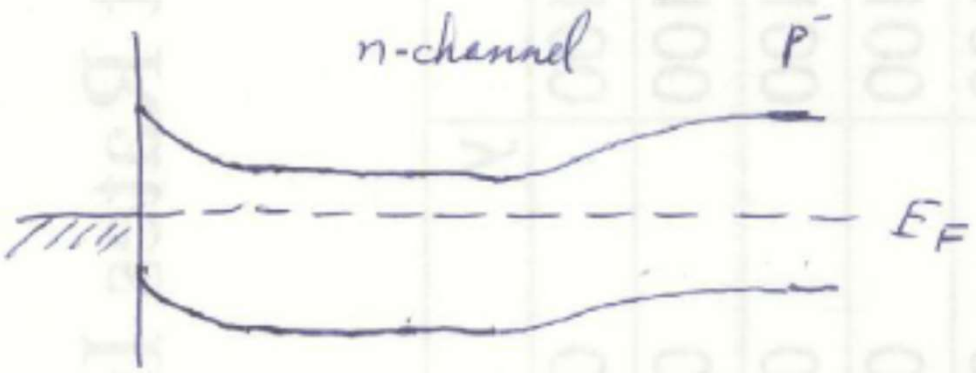
no self alignment



↓ band diagram



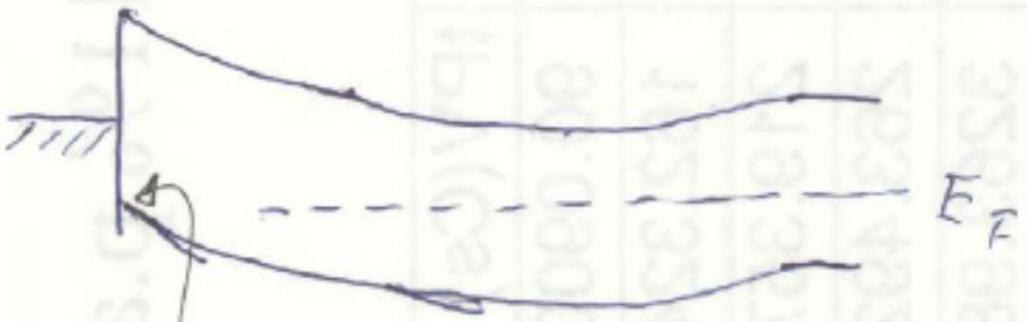
$V_G = 0$



$V_G = 0$

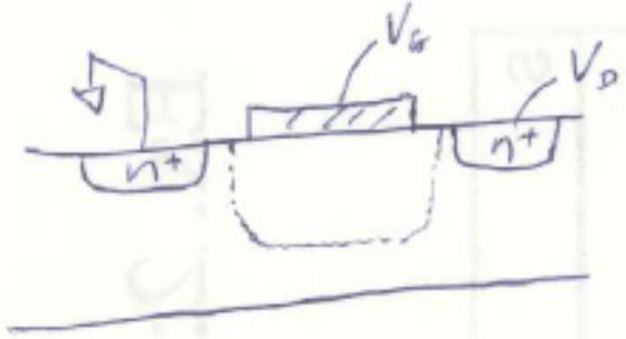
↓

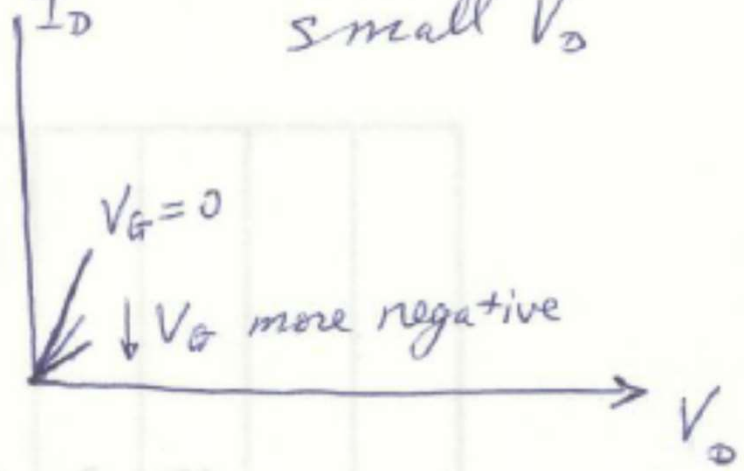
$V_G < 0$

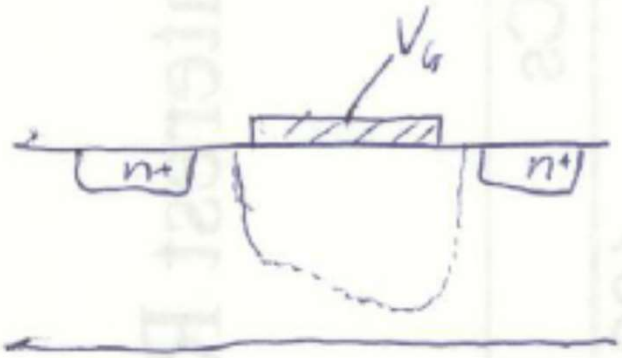


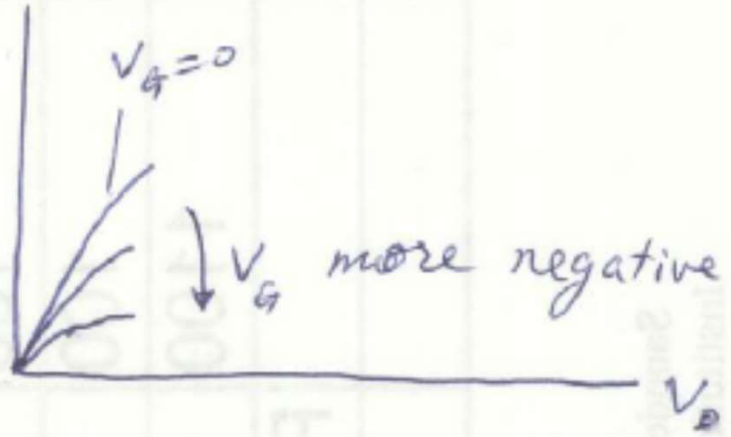
Will you have an inversion layer here?

I-V Characteristics

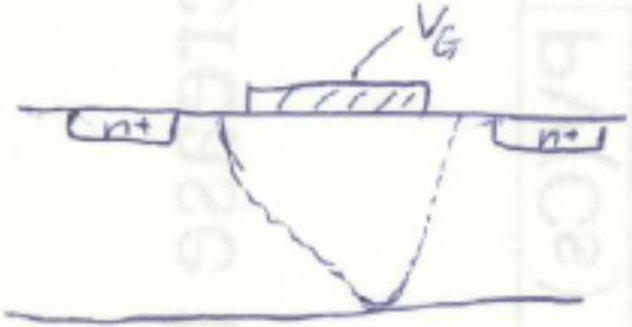






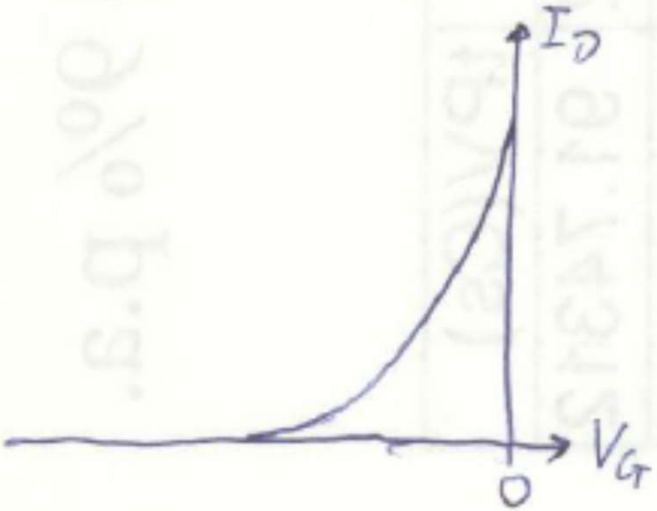


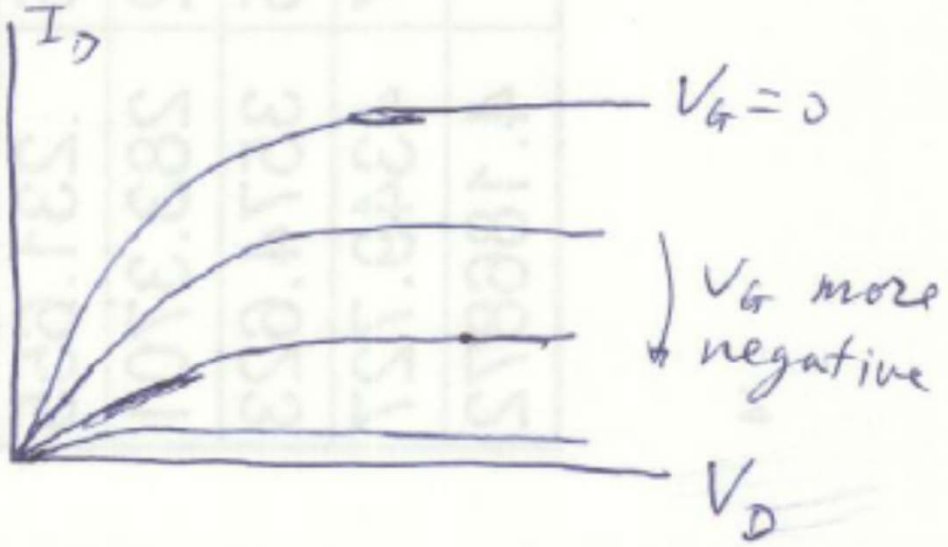
For larger (more positive) V_D, V_{GD} more negative than V_{GS} $\Rightarrow$ depletion region wider on the D side.



High V_D, pinch-off.

saturation





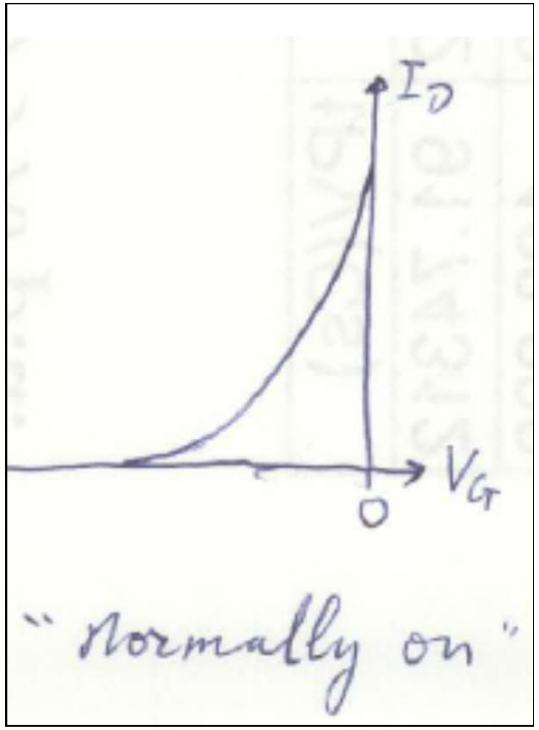
"normally on"

JFETs & MESFETs are "normally on".

Channels are doped.

Turn them off by depleting them.

Dopants scatter carriers.



We want μ & V_{sat} as high as possible.

(what's the mobility of a typical Si MOSFET?)

Solution: MODFET

many names. HEMT, HFET

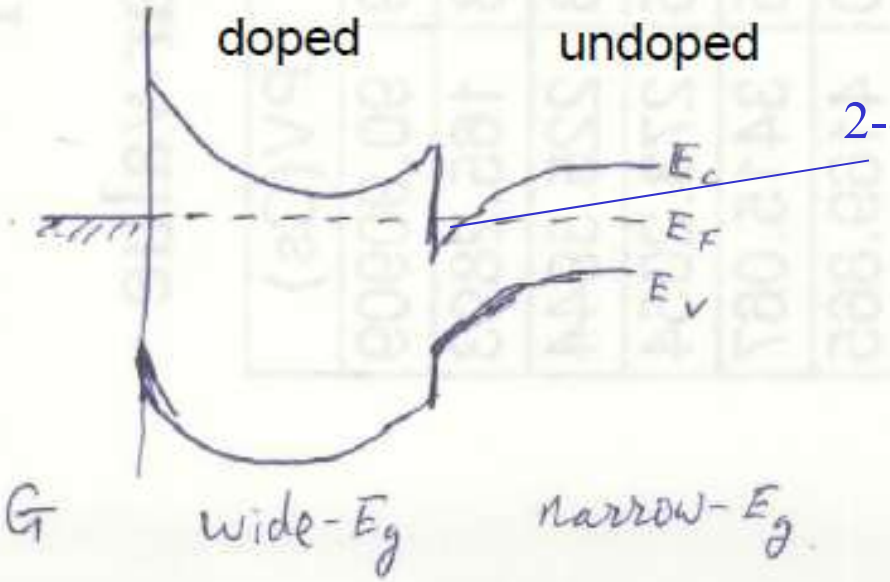
Solution: MODFET

many names. HEMT. HFET

Want electrons (n). but not dopants (N_D).

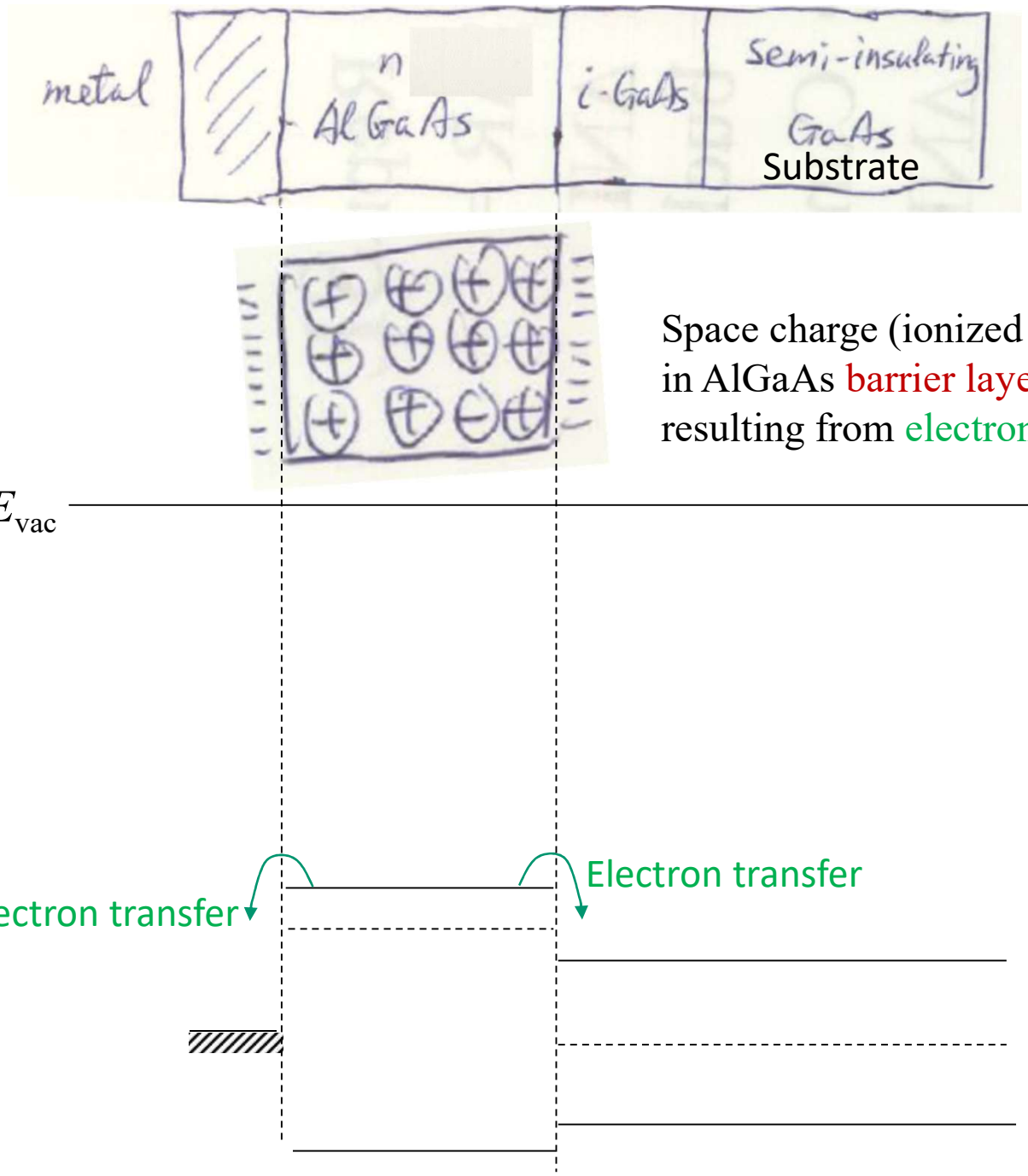
The idea: have N_D in one layer.

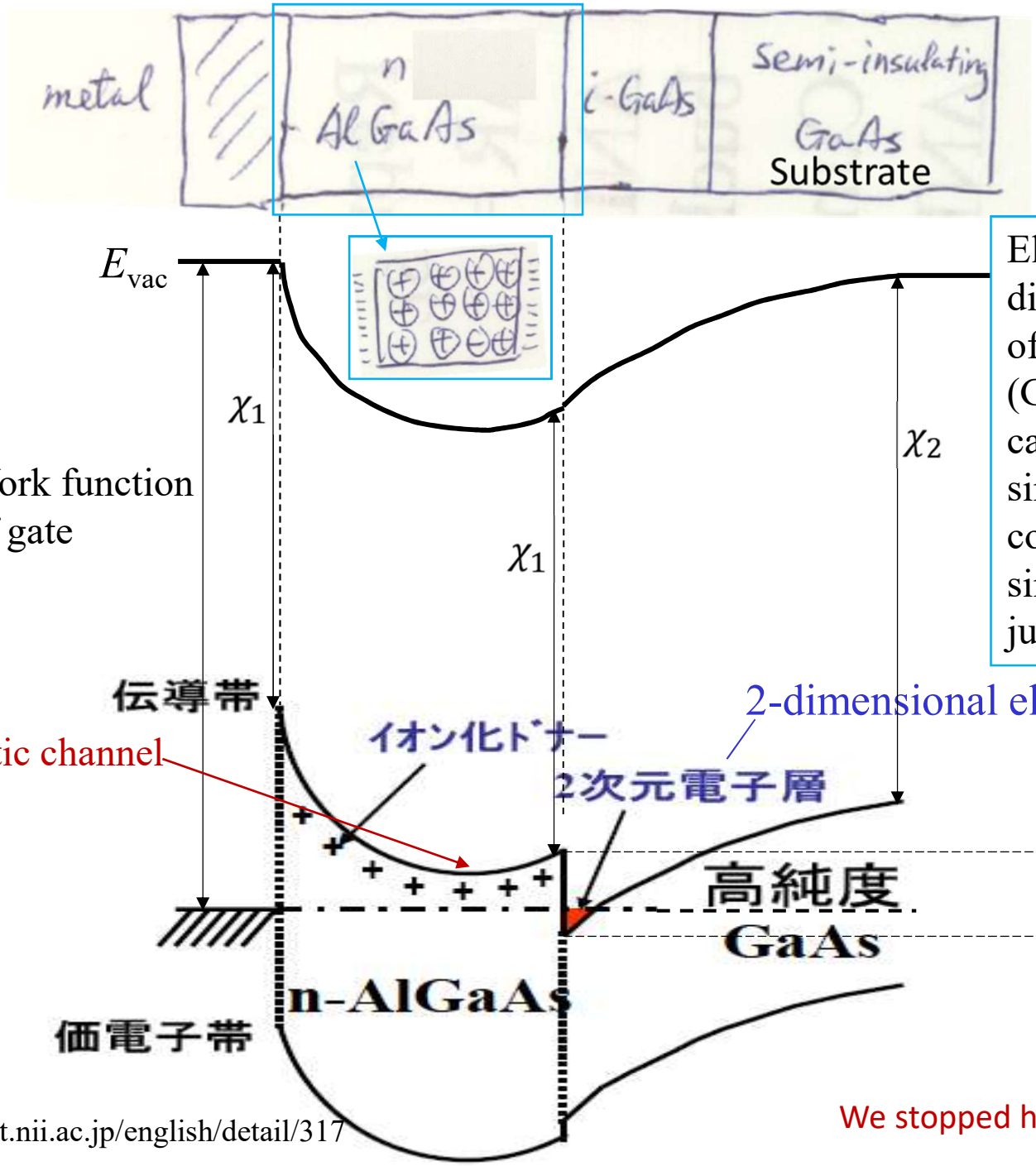
but get n in another.



2-dimensional electron gas (2DEG)

Recommended reading: Umesh & Singh, *Semiconductor Device Physics & Design*, p. 375 - 388


metal
n
AlGaAs
i-GaAs
Semi-insulating
GaAs
Substrate
Space charge (ionized donors)
in AlGaAs barrier layer
resulting from electron transfer
E_{vac}
Electron transfer
Electron transfer

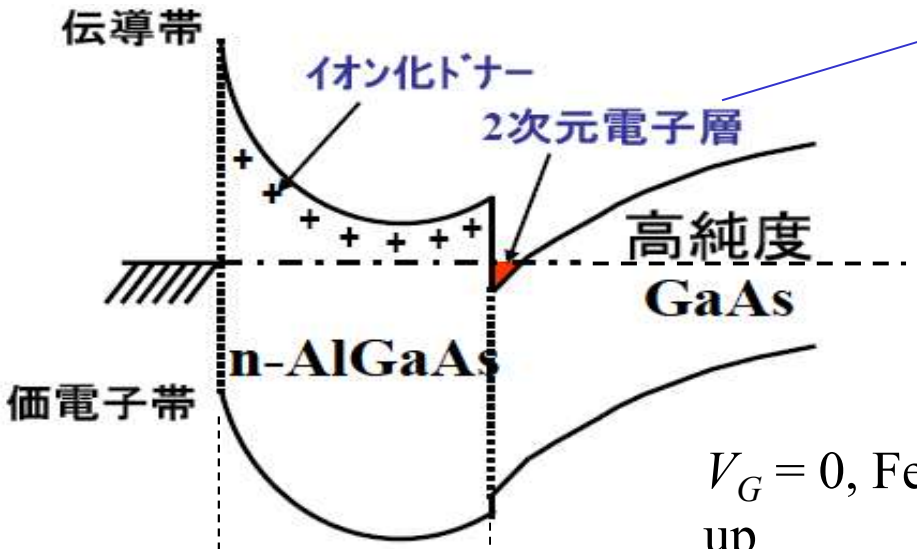


Electrostatic potential distribution as a result of Poisson's equation (Gauss's law) and carrier statistics, similar to (but more complicated than in a simple Schottky or junction)

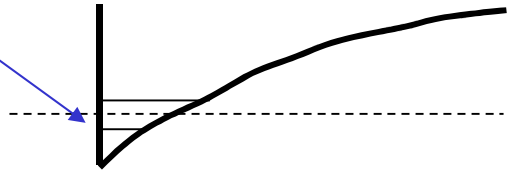
2-dimensional electron gas (2DEG)

https://dbnst.nii.ac.jp/english/detail/317

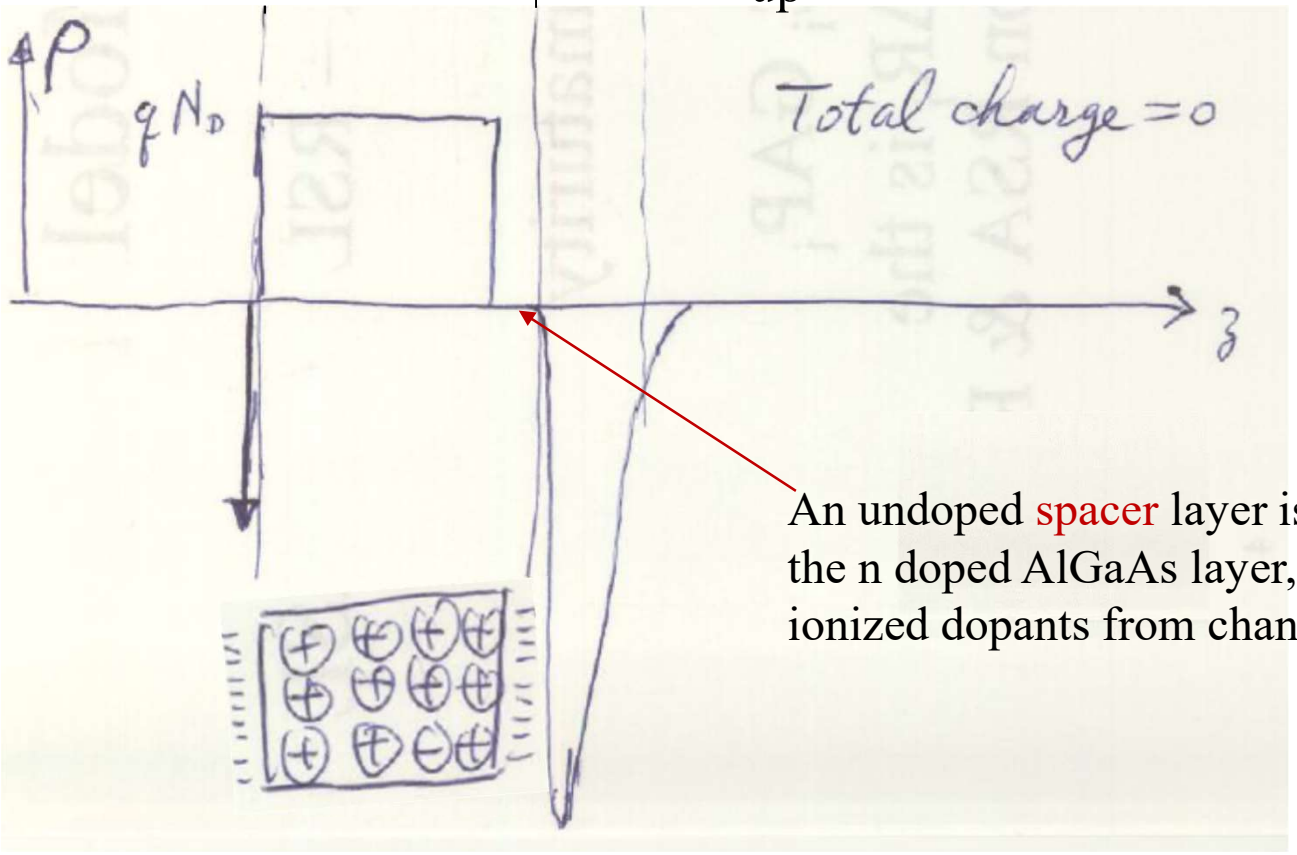
We stopped here on Tue 10/12/2021



2-dimensional electron gas (2DEG)

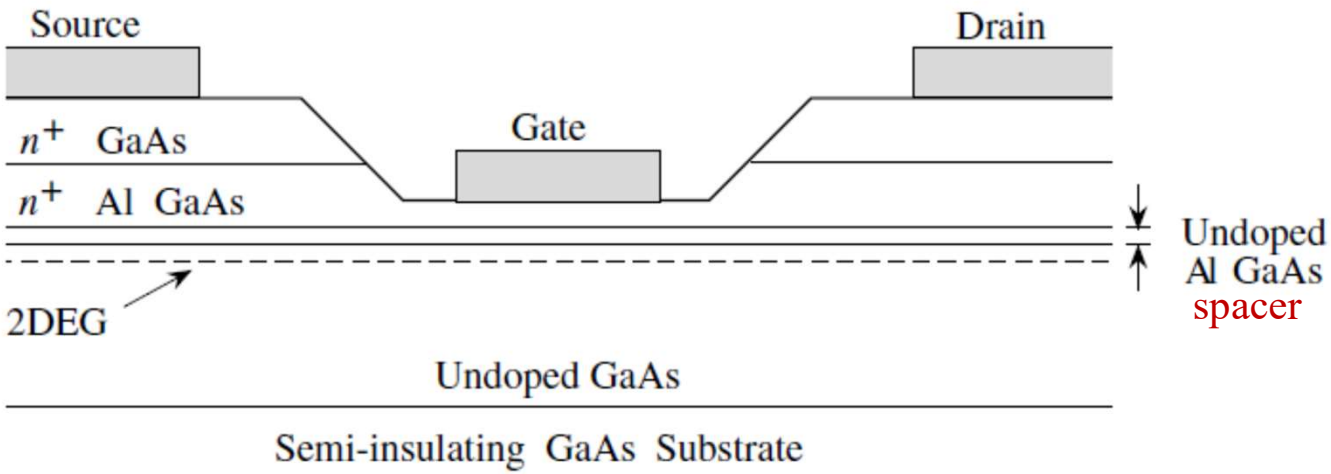


$V_G = 0$, Fermi levels line up



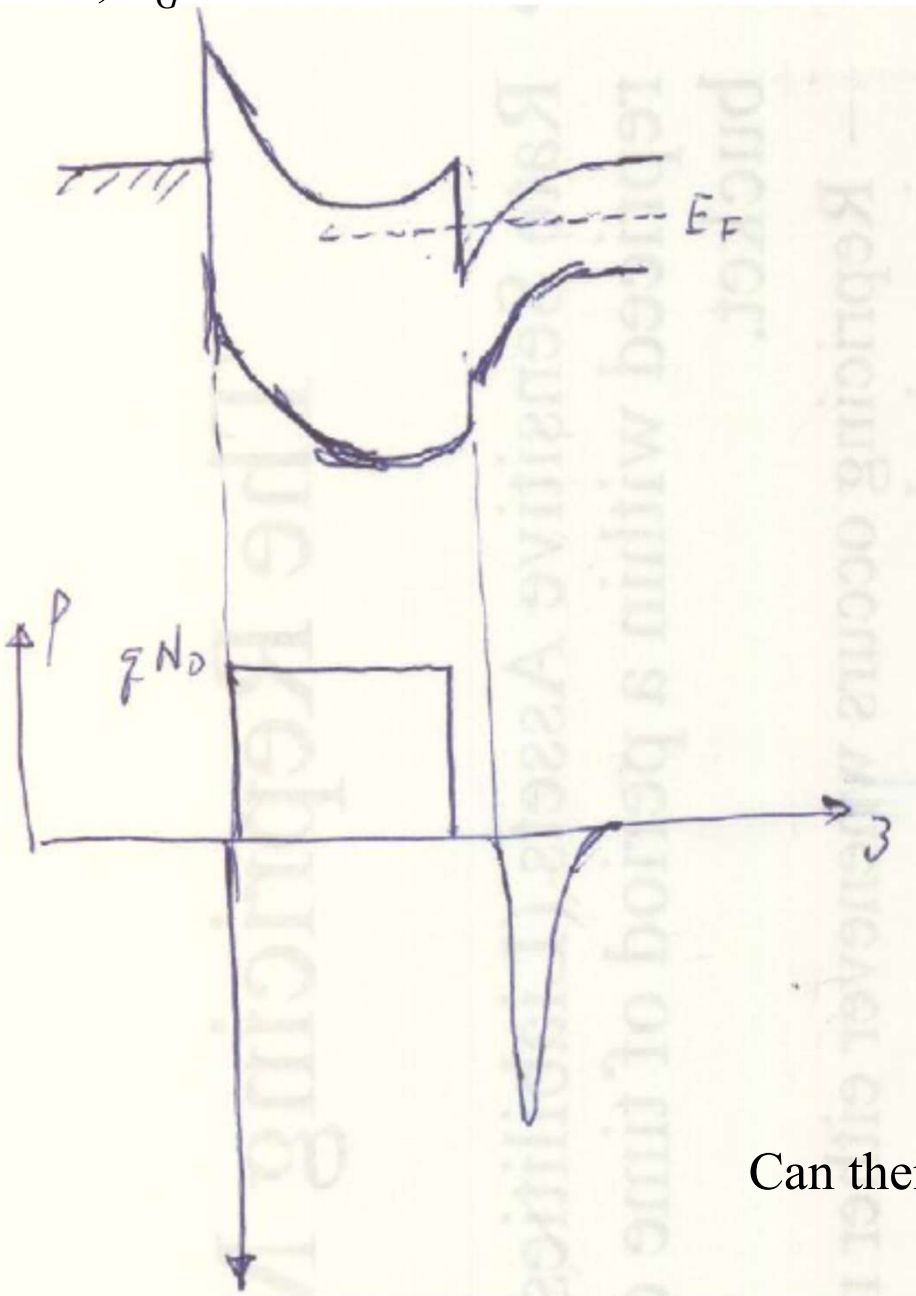
An undoped spacer layer is grown before the n doped AlGaAs layer, to separate ionized dopants from channel.

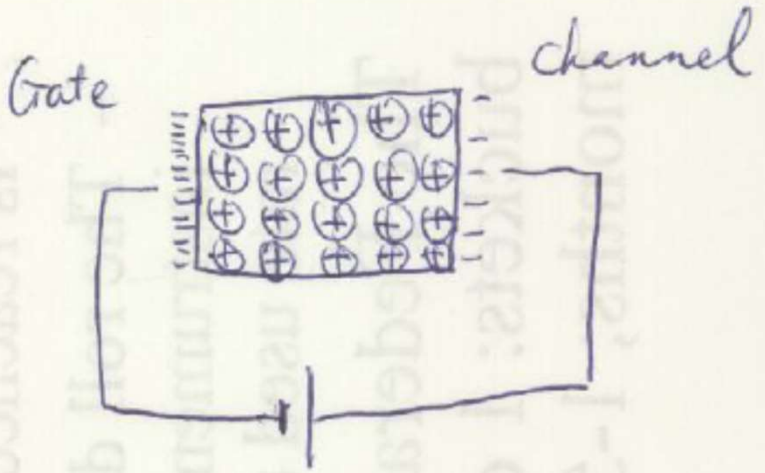

metal
n
Al GaAs
i-GaAs
Semi-insulating
GaAs


Source
Drain
Gate
n^+ GaAs
n^+ Al GaAs
Undoped
Al GaAs
spacer
2DEG
Undoped GaAs
Semi-insulating GaAs Substrate

(not to scale)

Now, $V_G < 0$



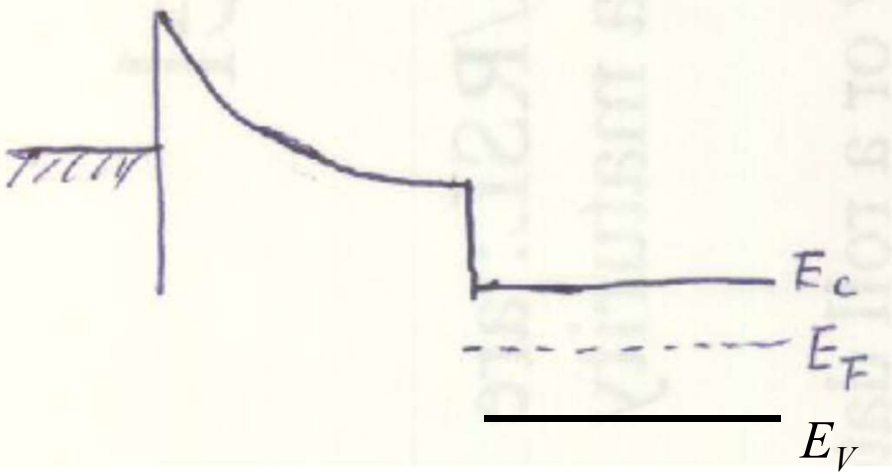


The battery pumps e's to the gate. Total charge conserves.

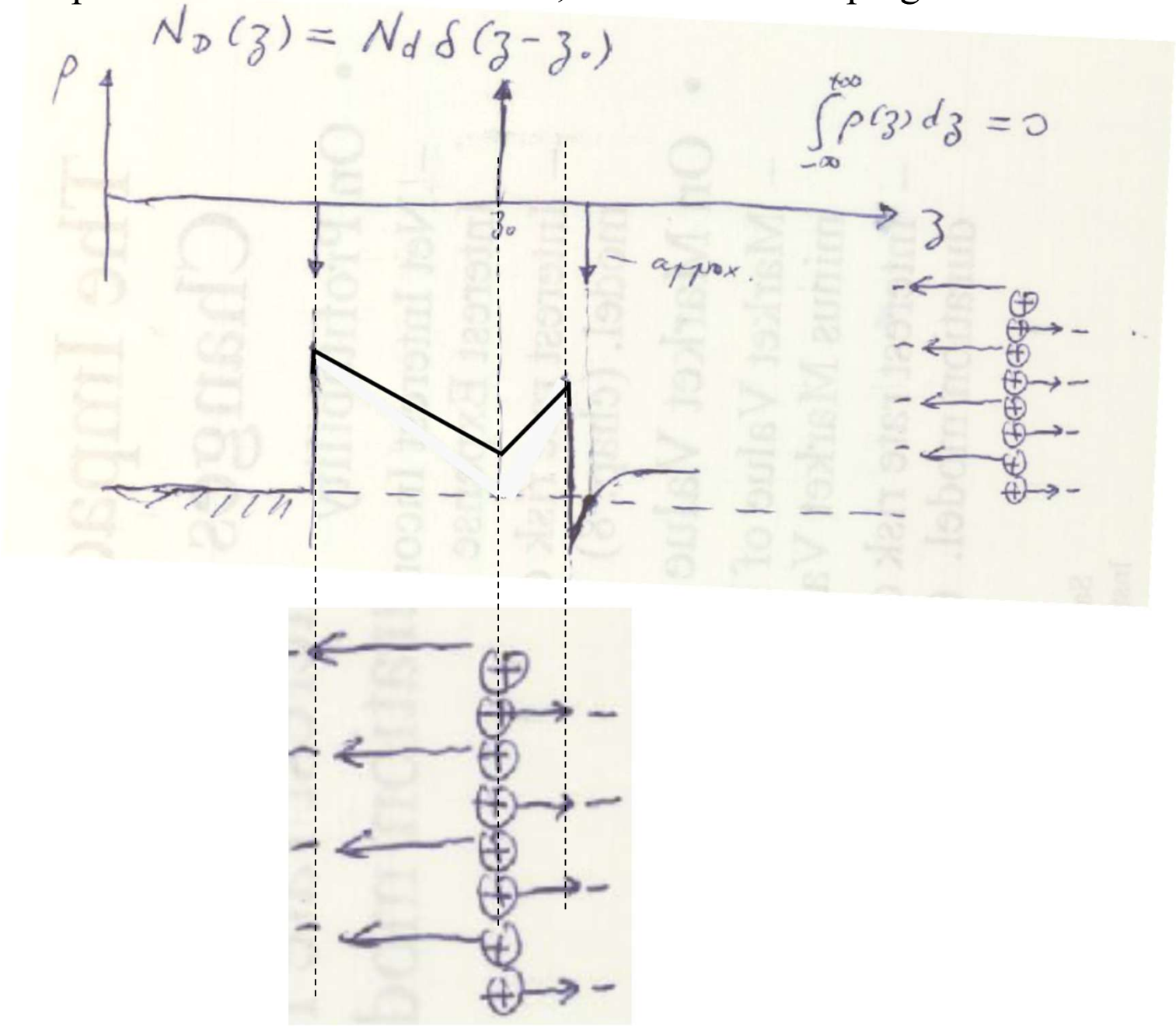
Negative charge (electrons) partition between 2DEG and gate.

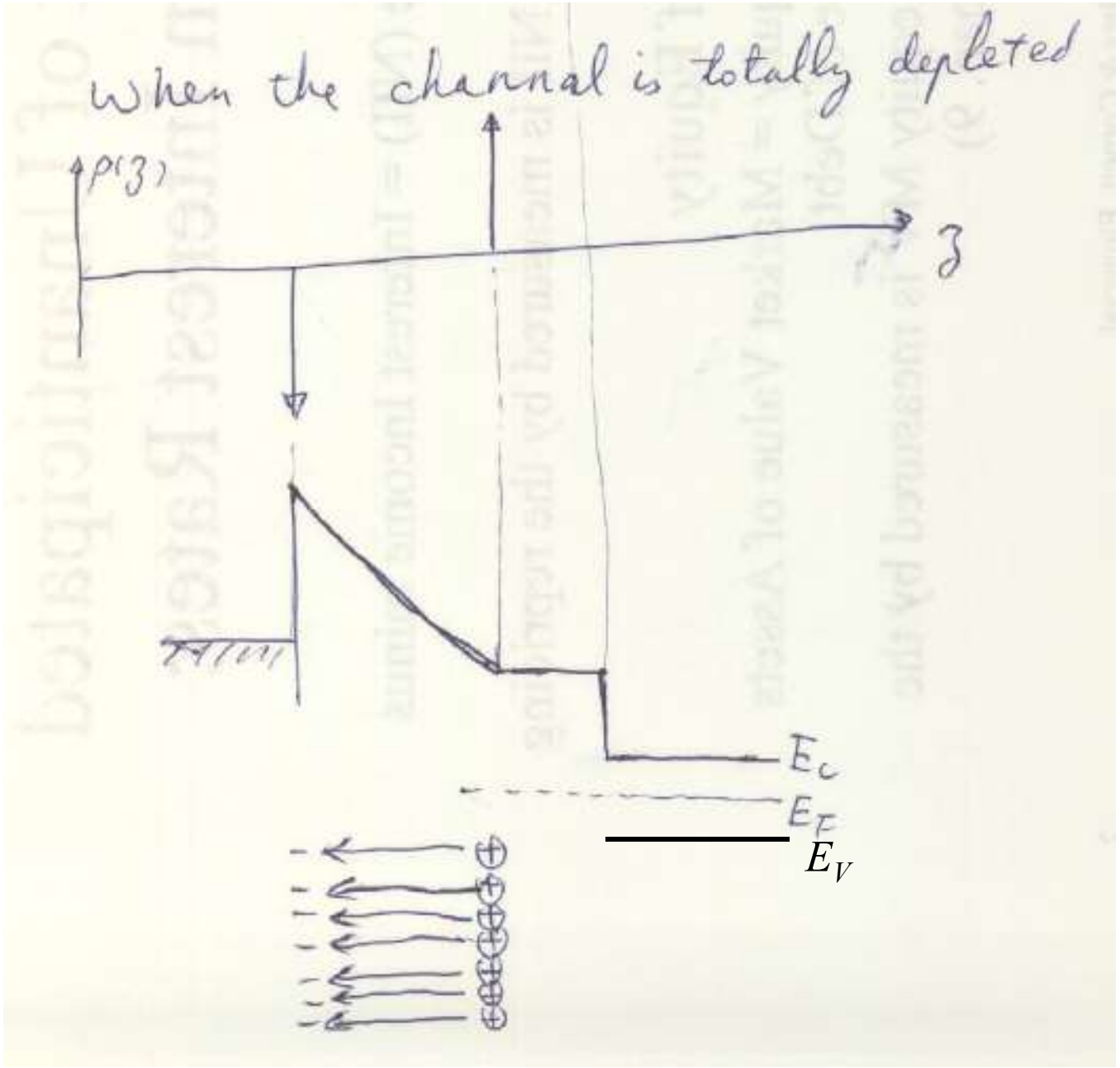
Can there be an inverted p channel in AlGaAs?

Now, more negative V_G, channel depleted.



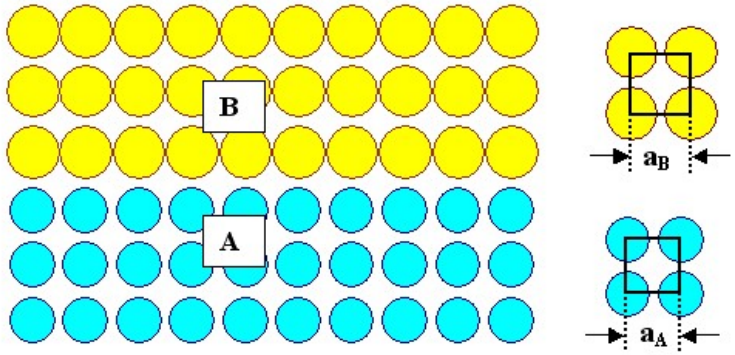
To avoid “parasitic channel” in AlGaAs, can do “delta doping”




When the channal is totally depleted
ρ(z)
z
E_c
E_F
E_V

To really understand MODFETs, we need to understand heterojunctions.

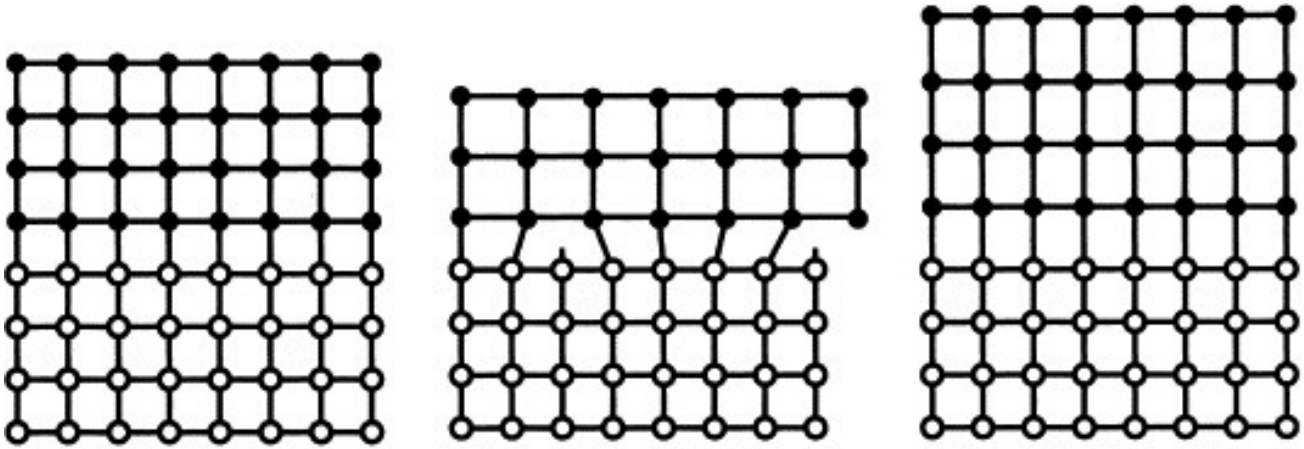
- Fabrication of heterostructures: epitaxy



Lattice match: $a_A \approx a_B$

https://www.tf.uni-kiel.de/matwis/amat/semitech_en/kap_3/backbone/r3_4_1.html

(Epitaxy may be homoepitaxy, e.g., undoped GaAs on semi-insulating GaAs in our MODFET example)



(a). Commensurate

$a_A \cong a_B$

(b). Incommensurate, relaxed

(c). Pseudomorphic, with uniaxial dilation

https://www.sciencedirect.com/science/article/pii/S0039602801015254

III	IV	V
5 B	6 C	7 N
13 Al	14 Si	15 P
31 Ga	32 Ge	33 As
49 In	50 Sn	51 Sb
81 Tl	82 Pb	83 Bi

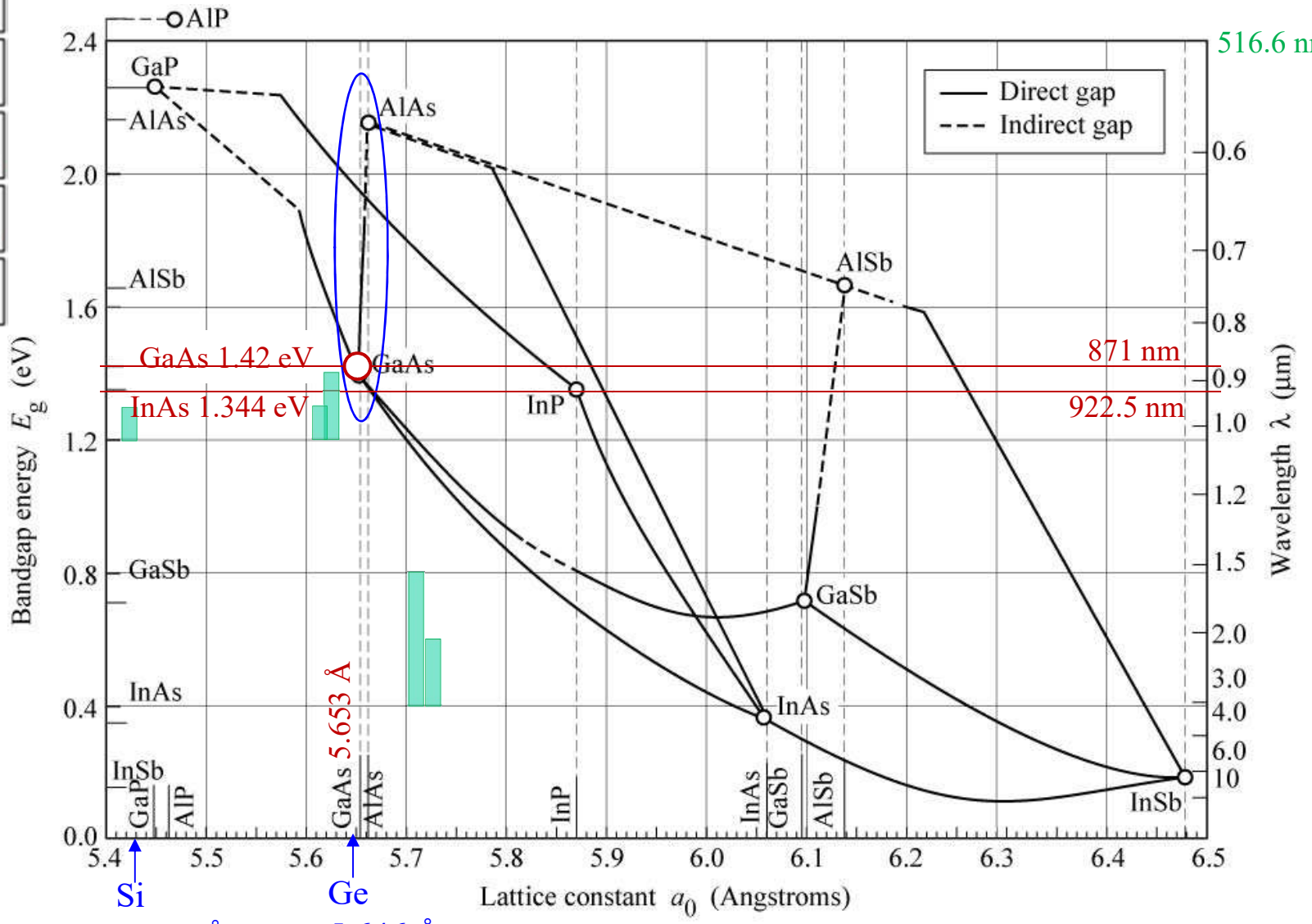


Fig. 12.6. Bandgap energy and lattice constant of various III–V semiconductors at room temperature (adopted from Tien, 1988).

- How do energy levels line up at interfaces?

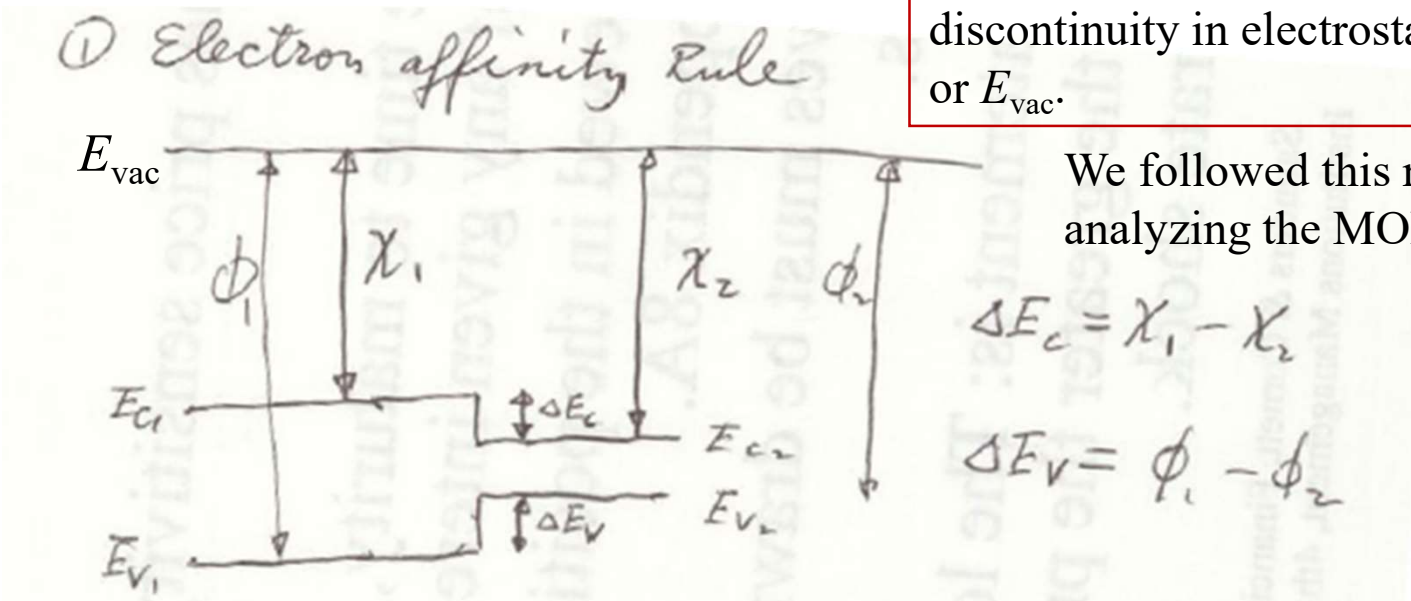
  There are no simple theories.

  Pretty much every interface (even the same pair of materials but opposite growth order) needs to be experimentally determined.

  Recently, first-principles calculations become able to predict.

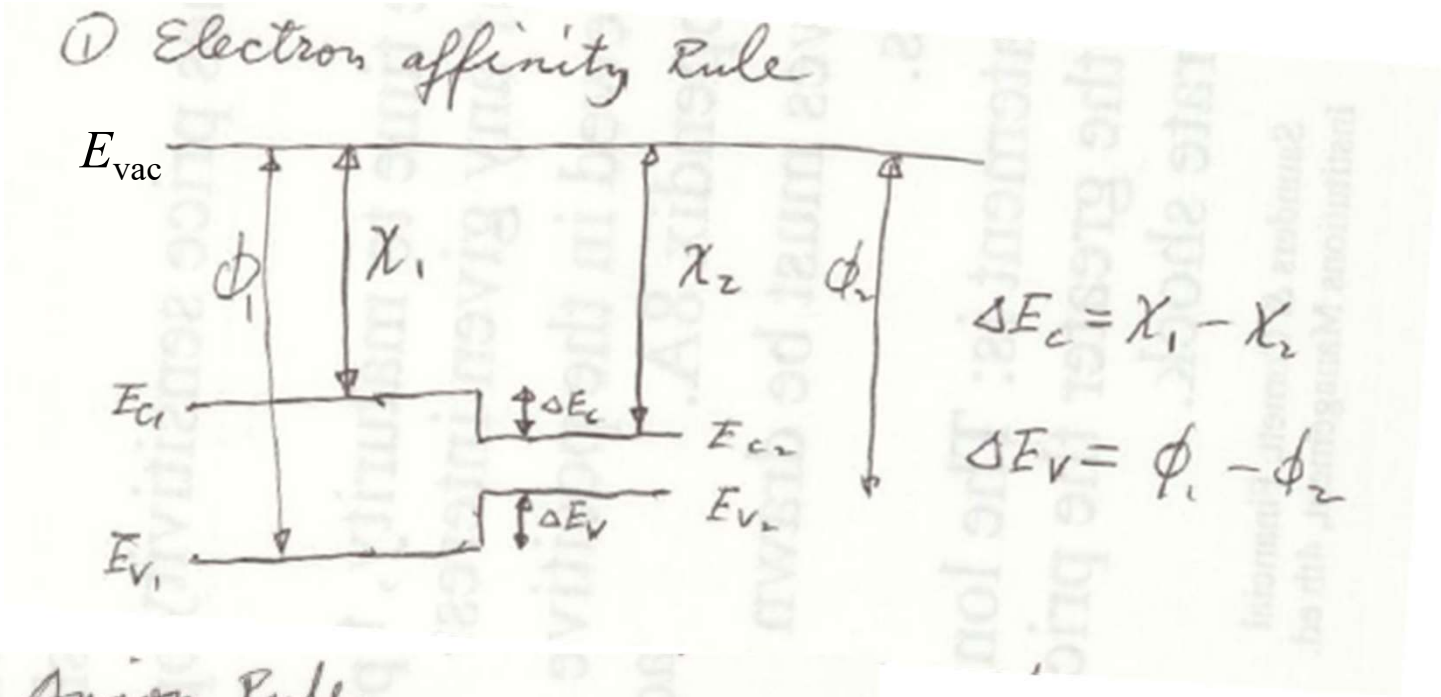
For simple descriptions, there are two "rules" that are **not** obeyed.

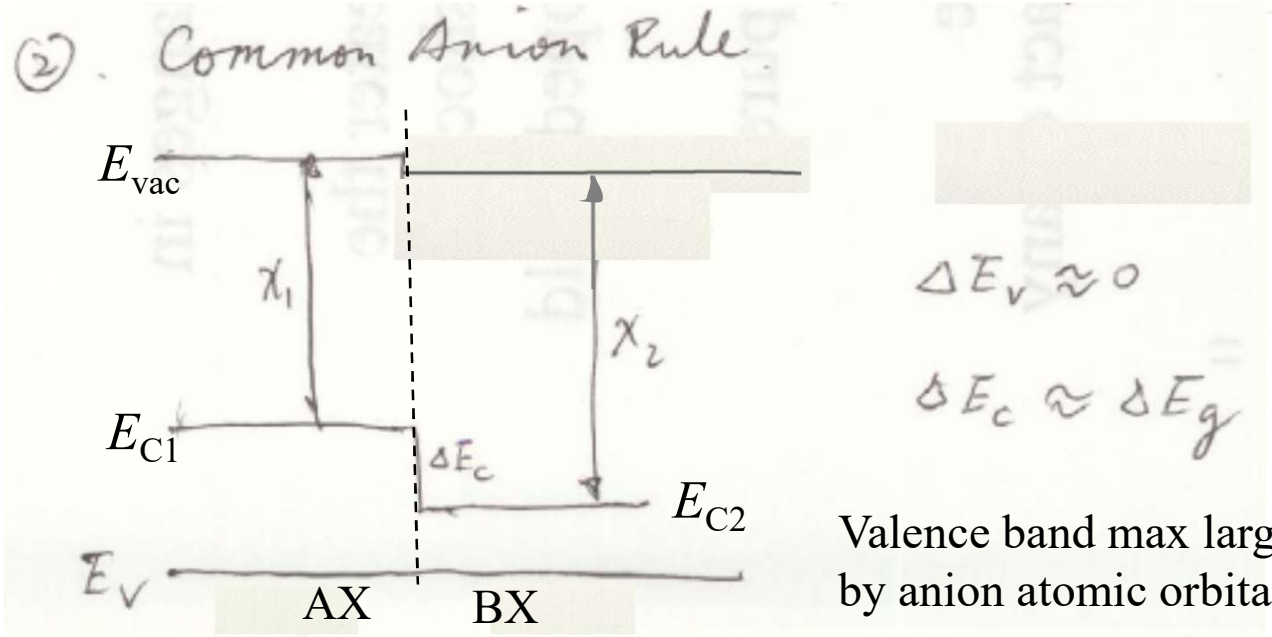
Details (chemistry) of interface ignored, therefore no interface dipoles ➔ no discontinuity in electrostatic potential, or E_{vac}.



We followed this rule when analyzing the MODFET example.

In this illustration, the horizontal dimension is not meaningful except marking the interface; charge transfer dictates band bending.





Valence band max largely determined by anion atomic orbitals.

Both "rules" ignore interface dipoles.