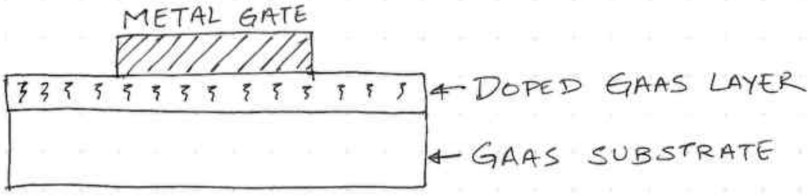
# TYPES OF GAAS FETS

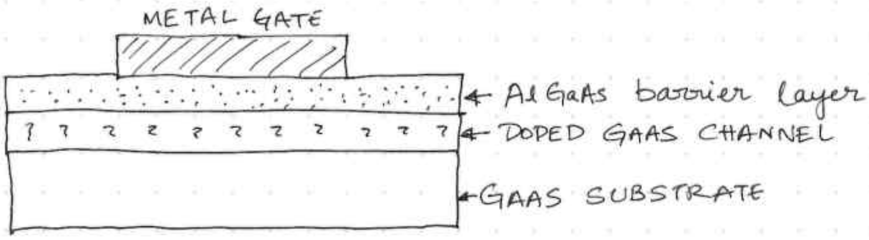
## (A) MESFET




A doped GaAs layer has a lower band gap energy, and when contacted with an undoped GaAs substrate (with higher band gap energy), the electrons from the GaAs substrate move into the doped GaAs layer and makes it a conducting channel.

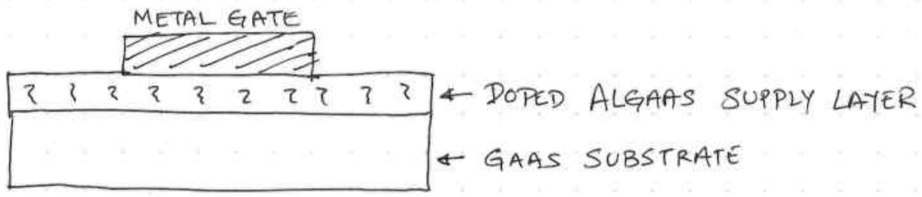
This way to make GaAs devices became the standard manufacturing technique for many years, until the advent of "band-gap engineering".

## (B) HETEROJUNCTION FET (HFET)



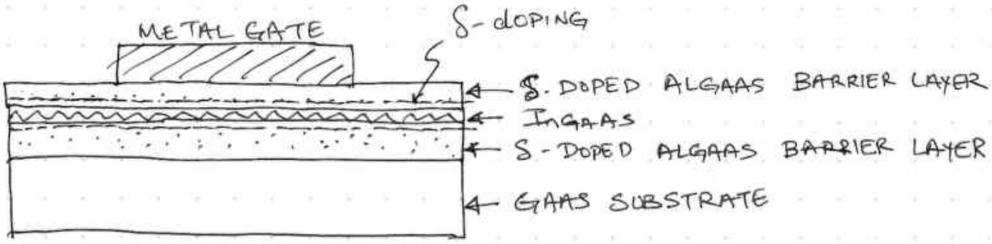

In this variation of the GaAs device, a wide bandgap AlGaAs layer is used as a spacer between the gate and doped channel. Both the GaAs and AlGaAs layers will contribute electrons for conduction in the doped GaAs channel. The large spacer layer means that transconductance is modest, but this device achieves excellent power and linearity performance. InGaP has also been considered as a spacer layer with InGaAs as the doped channel. InGaP as a barrier layer is good because of absent DX centers and lesser surface oxidation, but conduction band alignment with AlGaAs is not good.

## © HEMT OR MODFET




Instead of doping the channel directly, the adjacent AlGaAs layer is doped. The wide bandgap of the doped supply layer ensures that the mobile electrons populate the GaAs channel. At least for low fields, the mobile electrons suffer less scattering because conduction occurs in an undoped medium. The HEMT has been superceded by the pseudomorphic HEMT (pHEMT) but was an important stepping stone in its development.

## (D) PSEUDOMORPHIC HEMT (pHEMT)




The pHEMT is a significant advancement to the HEMT that introduces an InGaAs channel. InGaAs is a narrow bandgap material with excellent electron transport properties. The bandgap energy difference between AlGaAs (1.698 eV) and InGaAs (1.14 eV) is significantly large. This causes the AlGaAs to donate all its conduction electrons to the InGaAs layer on both sides leading to a highly confined charge transport layer that is very thin and is referred to as 2D Electron Gas (2DEG). The channel mobility of InGaAs is not improved over pure GaAs but is much better than doped GaAs and in pHEMT devices, channel mobilities exceeding 6000 $cm^2/Vs$ are obtained.

Additionally, the AlGaAs channel is δ-doped. In δ-doping, the silicon dopant atoms are deposited in a continuous layer just a few atoms deep, as opposed to conventional doping where the dopant atoms are included uniformly in the crystal structure. With δ-doping, the electrons are very close to the channel ensuring maximum trasfer of electrons to the channel, enhancing so called - "modulation efficiency".

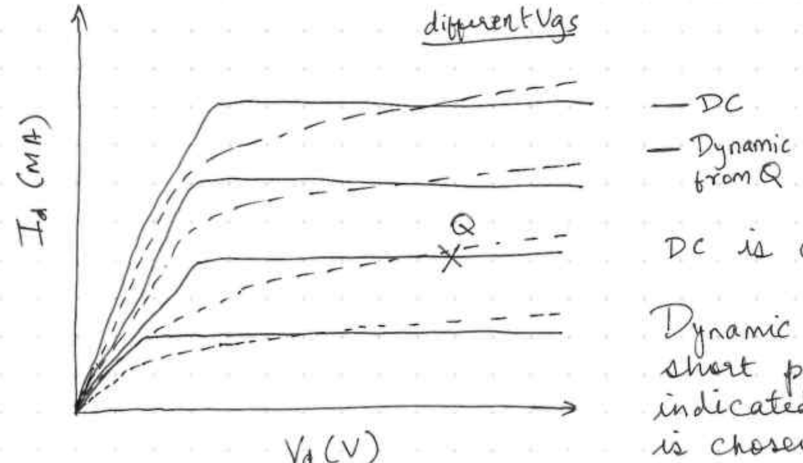
## TRAPPING EFFECTS IN GAAS DEVICES

### What are traps?

They are energy states deep into the semiconductor forbidden band that the likelihood of the carrier interacting with the state is relatively small and when a carrier does occupy such a state then a furthur low probability event is needed in order to be released again. Time constants in the range of μs to ms are commonplace. In short, traps capture and retain electrons for extended periods. The reasons traps exist are many and are not considered yet.

### Impact on Device Measurements

Consider the following Id-Vd plot for a GaAs FET:




DC is a conventional DC-IV measurement

Dynamic measurements are made with short pulses that deviate from indicated Quiescent point Q, which is chosen to be the typical device operating point.

It is observed that the dynamic IV is quite different from the DC measurement, and this is due to the trapping effects that occur at slow time scales. It should also be noted that the IV dynamic measurement will different when a different quiescent point Q is used.

> There is no unique IV characteristic for a particular FET, but a slightly modified one for each unique mean bias condition

A good way to think of the field associated with trapped charges is to consider it to be a slowly varying virtual-gate that modifies the effect of the physical gate.

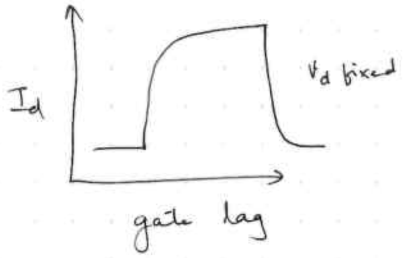
CONSEQUENCES OF TRAPPING EFFECTS

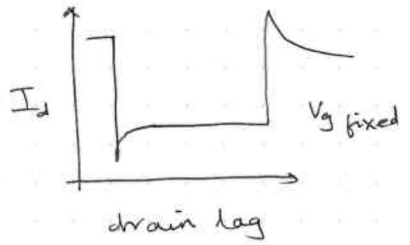
⟨1⟩ REDUCED OUTPUT POWER: Trapping reduces peak device current due to increased depletion, and increases knee voltage by increasing dynamic channel access resistances.

⟨2⟩ GM AND GDS DISPERSION: The variation of Gm and Gds with frequency is called dispersion. Transition frequency range is typically 1kHz to 1MHz. For modern GaAs fets, Gm dispersion is usually small and dispersion of Gds is a dominant phenomena. You can tell from the DC vs dynamic IV curves where Id-Vd is changed quite significantly, but spacing between Id-Vd curves for different Vgs remains unchanged relatively.

SIDE NOTE: DC-IV is always a relatively optimistic set of curves, and dynamic 'IV' is a much more "true" representation of device performance. Trapping effects aid the schottky gate field, resulting in reduced output conductance.

(3) GATE AND DRAIN LAG: Delayed response to gate and drain voltages.




(4) MEMORY EFFECTS: As we saw earlier, the trapped carrier population is a function of the mean bias condition. Thus the response of the device depends on the previous state it was in, and thus the device exhibits hysterisis and is said to exhibit "memory effects".

For a high frequency signal, there is equilibrium trap occupation and a more stable dynamic behaviour is observed. For low frequency signals or for modulated signals with a frequency component that is comparable to trap time constant, RF performance will be subject to memory effects.

(5) INACCURACY OF LARGE SIGNAL MODELS: Models may not completely account for dynamic behaviour in the presence of memory effects, resulting in less preditable large signal models.

(6) INCREASED BREAKDOWN VOLTAGE: Surface states surprisingly improve the breakdown voltage of the device. The associated surface charge is located in parallel with the channel and helps spread the electric field in the gate-drain region over a longer distance reducing the peak field and increasing device breakdown voltage.

<7> <u>KINK</u> <u>EFFECT</u>: As the drain voltage is swept, there is a sudden jump inthe drain current, as though the gate voltage was changed suddenly. One of many explanations for this effect is the field ionization of traps where an increase in drain voltage suddenly releases trapped electrons adding more charge (and reducing depletion) in the conducting channel. Another mechanism is the build up of hole charges at the source end due to impact ionization, and it can result in parasitic bipolar injection, reduction in pinch off voltage, and discharge surface electron traps. There are other complex processes we will not consider at this point.