The Field Effect Transistor (FET)

Two Cuts

nMOS
(The carriers are electrons)

Applying a positive voltage to the gate draws electrons into the channel and thereby closes a switch between source and drain.

Off
\[ V_{\text{Gate}} \approx 0 \]

On
\[ V_{\text{Gate}} > 0 \text{ removes the barrier} \]

This Cut: Source – Channel – Drain
= back – to – back diodes

Other Cut: Gate – Oxide – Channel
MOS = Metal – Oxide – Semiconductor
Metal Oxide Semiconductor (MOS) Cut

**n-MOS** goes with a **p-type semiconductor** in the channel, since it **turns on by inversion**.

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**Guide for constructing these band diagrams:**

1) **Which situation?**  
   - n-MOS or p-MOS, accumulation or inversion (FET on).

2) **Capacitor Model:** The dominant **charges** are generated by the **gate voltage**.*

3) **Voltage Drop:** Across the capacitor  \( \Rightarrow E_F \) (dotted lines).  \( V_{\text{Gate}} \) from 1)

4) **Bands at the Channel/Oxide Interface:** Have to match charges and \( E_F \).*

5) **Bands in the Bulk:** From doping.**

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* For example, when a n-MOS is on, a positive gate voltage attracts electrons to the opposite side of the capacitor, i.e., the channel.

** For example, if there are electrons in the channel, they must be at the CBM, and the CBM must be close to \( E_F \) to have any electrons there.

*** A common mistake is to start with the doping. The carriers from doping are overwhelmed by the charges from the capacitor during inversion. For that reason the dopants themselves are not even shown here.
**CMOS** (Complementary Metal Oxide Semiconductor)

- Back-to-back nMOS and pMOS with common gate.
- Low power consumption, draws current only when switching.

**DRAM** (Dynamic Random Access Memory)

- Field effect transistor + storage capacitor $C_d$ (charged = 1, discharged = 0).
- Needs to be refreshed due to leakage current.
- Matrix architecture.
**Flash Memory (EEPROM)**

- Use a floating-gate transistor containing a second, electrically-insulated gate.
- The charge on the floating gate determines the value of the bit.
- It changes the threshold voltage of the transistor (repelling electrons from the channel when charged).
- The floating gate is charged/discharged by a high voltage spark (“flash”).

**Floating-Gate Transistor**

![Diagram of a floating-gate transistor](image)
CCD (Charge-Coupled-Device)

- Array of MOS capacitors, one for each pixel.
- They temporarily store the electrons generated by light in the conduction band.
- During readout the charges are passed from one capacitor to the next along a row.

This is also a MOS capacitor, but the resistance in the depletion zone of the semiconductor is made so high that it takes a while for electrons to flow into the channel and form a two-dimensional electron gas. During that time, electrons generated by photons can be collected in the capacitor.

A series of such pixels is read out by shifting their charges step-by-step to the right until the end of a row (like a bucket brigade). CCDs are used as detectors for telescopes and in digital cameras. But in many cameras with high pixel numbers they are being surpassed by CMOS transistors, which can be designed and processed like standard silicon electronics.