Surfaces

Caution: STM, synchrotron radiation experiments and other modern techniques have rendered much of the hand-waving about surface states in most older textbooks obsolete.

Preparation of "clean" surfaces

- "Perfect" free surfaces are obtainable in ultra-high-vacuum (UHV). In the UHV environment, such surfaces remain uncontaminated for hours or even days. This makes it possible to perform detailed experiments on the intrinsic properties of surfaces. More recently, unique materials processing methods are being developed under UHV conditions.
- Cleavage: Si and Ge "cleave" at (111) planes. If done in UHV this is a convenient way to form flat, clean surfaces. GaAs, other zinc-blende's cleave at (110) planes.
- Clean surfaces can be sometimes formed by careful chemical treatment in the ambient laboratory environment to prepare a thin surface oxide. After transferring such a sample into UHV the oxide may be thermally evaporated, leaving a clean surface. This method works well for Si, Ge, but not GaAs due to As evaporation.
- Clean surfaces can be grown using molecular beam epitaxy (MBE). MBE is commonly used to grow a variety of III-V compound semiconductors. Use of MBE to grow unique Si and SiGe alloy structures is receiving growing interest in recent years.

Surface states:

Semiconductors are covalently bonded. At the surface, 'dangling' bonds give rise to states other than the Bloch-state bands. These states often lie energetically in the bulk band gap.

Surface reconstruction:

Due to the interplay between the surface state energy and relative ease of movement of surface atoms, the surface atoms often re-arrange themselves relative to the "bulk terminated" positions. This can produce new periodicities on the surface, which are detected by diffraction (x-ray or electron) or STM.

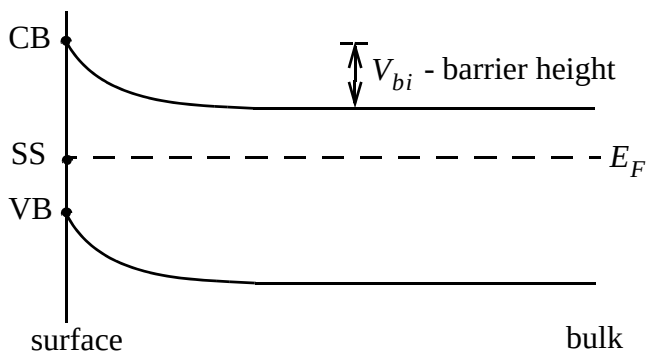
"Practical surfaces" - (non-UHV prepared)

In air, surfaces usually form some sort of "native oxide". The surface is then dominated by chemical bonds to this layer.

"Fermi-level pinning"

Surface states act as donors or acceptors. The density of surface states can be very large (e.g., 1 state per surface atom). The crystallographic density of surface atoms is in the range

of $\sim 10^{14} cm^{-2}$. Because of the large density of states at the position of the surface state, the Fermi level becomes "pinned' at surface state energy. The consequence of this Fermi-level pinning is the formation of a space charge layer at the surface, similar to a diode space charge layer.



"Band-bending"

SS accumulates charge and sets up space-charge layer.

Schottky barriers

For metal-semiconductor interfaces, Fermi-level pinning is the most common situation. Surface states evidently are formed at the interface. These surface states control the barrier height. With the metal Fermi-level lined up a the position of the surface state within the band gap, we have a diode structure. The energy barrier from the metal to either of the band edges (depending on the doping type of the semiconductor) is called the Schottky barrier. Contrary to the most elementary treatment of metal-semiconductor junctions, which you may have been exposed to, the work function is irrelevant to the barrier height.

Si-SiO_2 interface

This interface is unique. It can be easily formed with a very low density of surface (interface) states. The Fermi level is not pinned and can be controlled by a metal gate on top of the oxide. This is the key to the dominance of silicon in electronics.

No such magic interface has yet been found for GaAs. $\rightarrow$ No GaAs MOSFET. GaAs field effect transistors can be fabricated, but these must use Schottky gate contact. This is a severe limitation.