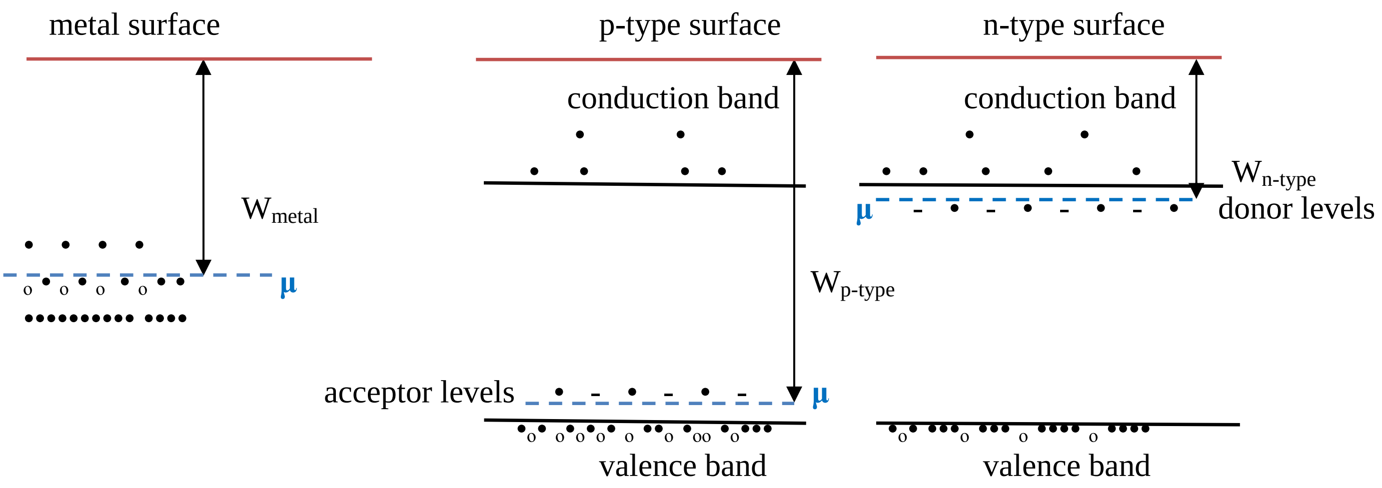
# METAL-SEMICONDUCTOR JUNCTIONS

Our last topic will be to consider the metal-semiconductor junction. We have already investigated the semiconductor energy scheme: the valence band and the conduction band with the Fermi level somewhere in the energy gap between the two. For p type semiconductors, the Fermi level is close to but above the valence band; for n type semiconductors the Fermi level is close to but below the conduction band. For intrinsic semiconductors, the Fermi level is close to the middle between the bands.

But what about the energy scheme for a metal? We know that for a metal we have a half-filled energy band, and the Fermi level is where the highest energy electrons are close to.

We also know from the photoelectric effect that it takes a certain amount of energy to remove an electron from a metal. This amount of energy is called the **work function**, W, for the metal. Hence we can determine how far below the surface energy the Fermi energy for the metal is.

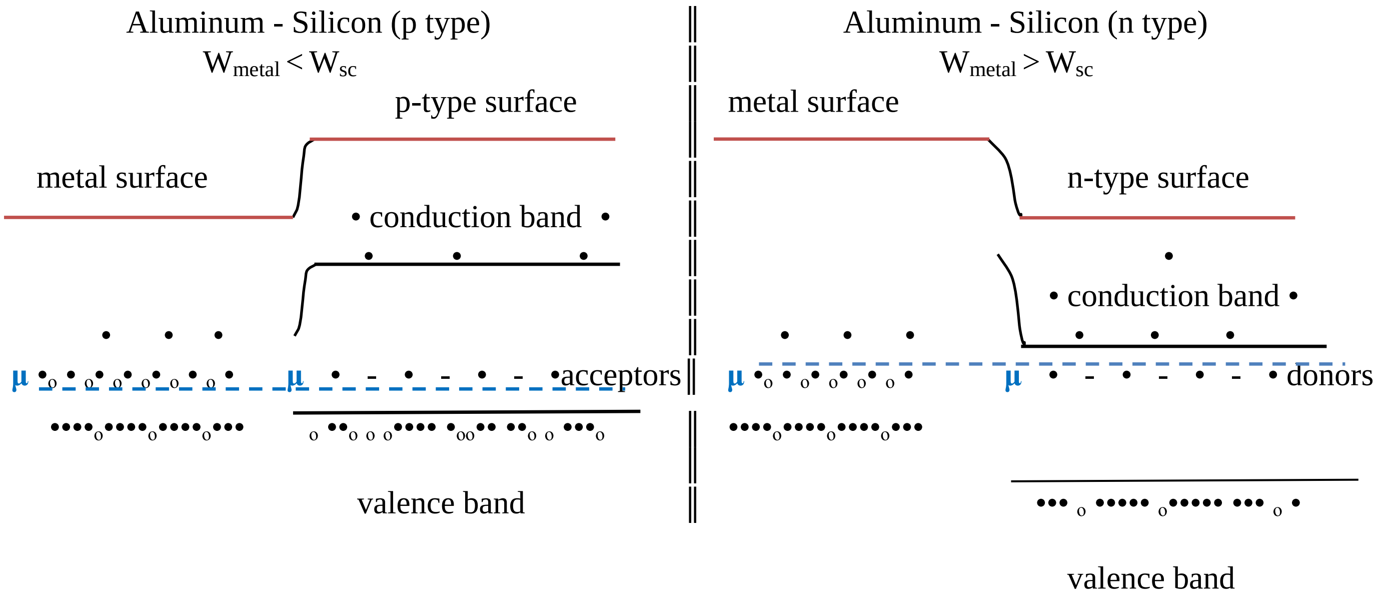
We can also obtain a work function for semiconductors as well: we can eject electrons from the conduction band of a semiconductor if we have a sufficient photon energy. (Note that this is different than moving electrons up from the valence band to the conduction band. In the photoelectric effect we are actually ejecting electrons out of the material!) The electrons in the conduction band do have some energy already, so the work function obtained for semiconductors is really a measure of how far the Fermi level is from the surface energy, just as for metals. See the following figure:



When we put a metal in contact with a semiconductor, the **surface energies must match**. This means that the **Fermi levels will initially be different** for the metal and the semiconductor. But just as in the case of two differently doped semiconductors (the pn junction), the **electrons will flow toward the lower Fermi level material**. These extra electrons will raise up the energy levels in the lower material and the lack of the electrons will lower the energy level in the higher material **until the two Fermi levels match**.

We use as our specific example the junction between aluminum and silicon with doping to make the silicon either n or p type. However, **the important distinction is that the junction of the left side has a work function for the metal that is smaller than that for the semiconductor, while the junction on the right side has a work function for the metal that is greater than the work function for the semiconductor**. See the figure below.

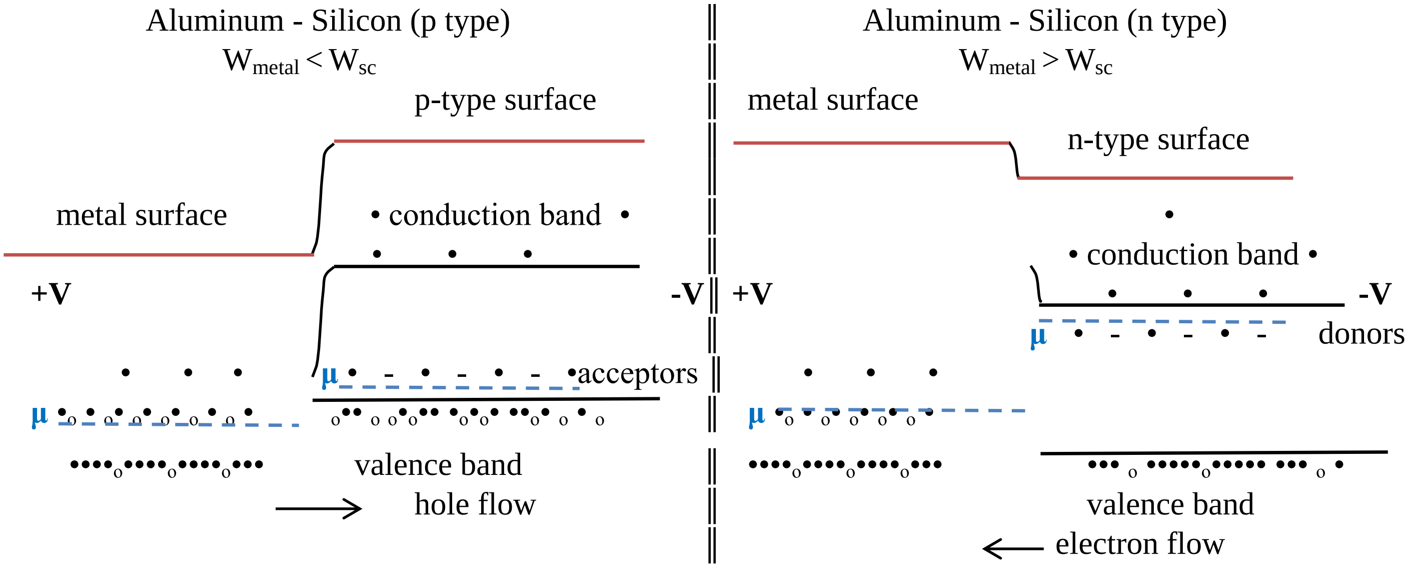
UNBIASED METAL-SEMICONDUCTOR JUNCTION



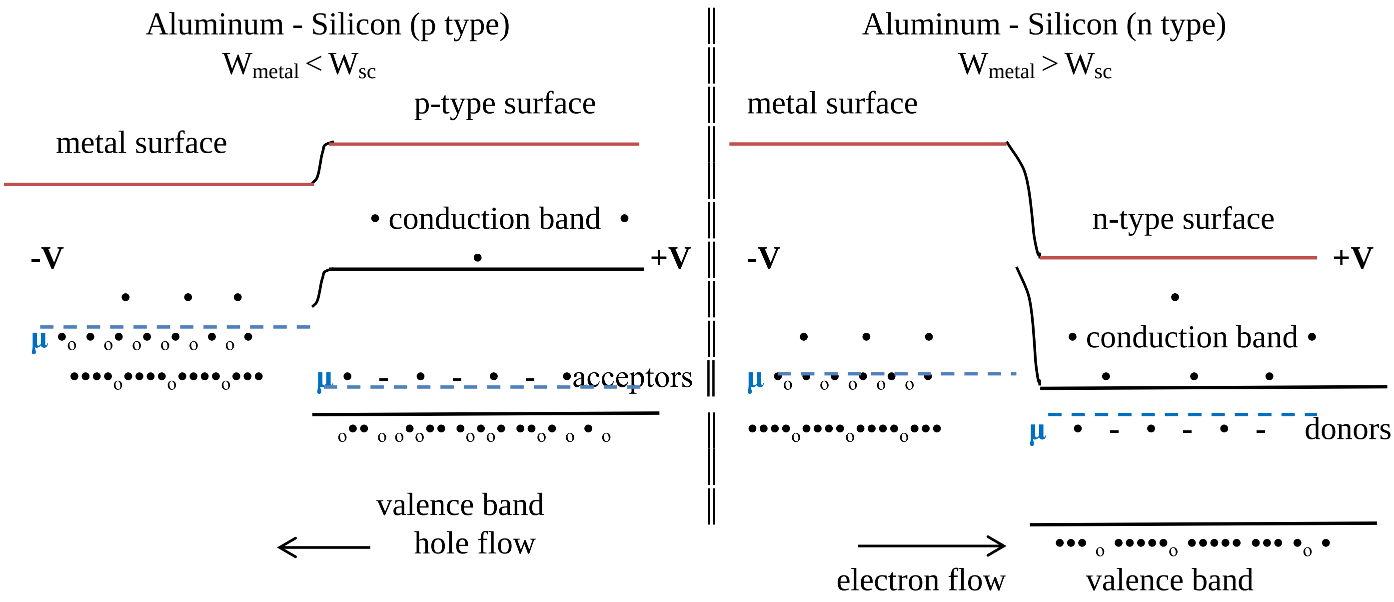
Note the existence of a "hill" called the **Schottky barrier** between the Fermi level in the metal and the conduction band in the semiconductor. With no voltage applied, we have no net current and so we have no effect after the initial flow of electrons to match their Fermi levels.

If we now apply a **positive voltage to the metal and a negative voltage to the semiconductor**, we lower all the electron energy levels including the μ level for the metal (since the electron has a negative charge, a positive voltage provides a negative potential energy); we also raise the electron energy levels in the semiconductor. See the figure below:

**POSITIVE VOLTAGE ON METAL SIDE** OF METAL-SEMICONDUCTOR JUNCTION



## **NEGATIVE VOLTAGE ON METAL SIDE** OF A METAL-SEMICONDUCTOR JUNCTION



**For the p-type**, the majority carriers are holes, and holes flow from the high voltage side to the low voltage side. With a positive voltage applied to the metal side (and so a negative voltage applied to the p-side), we have a reverse bias on the p-type, and we see that the Schottky barrier gets higher with higher voltage and so limits the current. With a negative voltage applied to the metal side, we have a forward bias on the p-type, and we see that the Schottky barrier gets lower with higher voltage and so makes it much easier for current to flow. This combination acts like a pn diode.

**For the n-type**, the majority carriers are electrons, and electrons flow from the low voltage side to the high voltage side. With a positive voltage applied to the metal side (and so a negative voltage applied to the n-side), we have a forward bias on the n-type, and we see that the Schottky barrier gets lower with higher voltage and so makes it much easier for the current to flow. With a negative voltage applied to the metal side, we have a reverse bias on the n-type, and we see that the Schottky barrier gets higher and so limits the current. This combination also acts like a pn diode.