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MATERION

TECHNICALTIDBITS

MATERION PERFORMANCE ALLOYS

Work it! – Learn what it takes to free electrons from surfaces, and what you can do with those newly liberated electrons.

- **Valence Electrons**
- **Free Electron Model**
- **Ionization Energy**
- **Work Function (Φ)**
- **Photoelectric Effect**
- **Thermionic Emission**
- **Scanning Electron Microscope (SEM)**

The next issue of Technical Tidbits will discuss scanning electron microscopy in greater detail.

WORK FUNCTION AND THE PHOTOELECTRIC EFFECT

Remembering physics classes, recall that the electrons in an atom occupy various electron shells around the nuclei. When an atom is at its minimum energy (ground) state, electrons fill the shells in order of lowest energy state to highest energy state. The outermost shell is called the valence shell, and its electrons are called **valence electrons**.

Conductive metals can be modelled as positively charged "islands" arranged in a crystalline lattice, swimming in a sea of shared valence electrons. These islands consist of the atomic nuclei and their surrounding filled electron shells. (This is the known as the **free electron model** of metals)

It is almost always the partially filled valence shells that do everything interesting in physics, chemistry and engineering. These electrons are responsible for atomic bonding (ionic and covalent), electrical conduction, thermal conduction, electrostatic charge, galvanic potential, etc., etc. For example, electrical insulators have completed filled valence shells, while those of conductive materials are only partially filled, so there are vacant positions for electrons to occupy. Under an applied voltage, electrons will move easily through vacancies in the valance shells of conductors.

In electrical insulators, the electrons will not move unless the voltage is sufficiently strong enough to move electrons to a higher energy state, where they will then be free to move. (This is the theoretical dielectric strength of the insulator, as discussed in previous months. The actual dielectric strength will be lower than the theoretical maximum due to voids, imperfections, etc.)

Usually, when these electrons are doing something useful for us, like carrying electronic signals or transferring heat, they remain within the metal. Sometimes, however, we need electrons to leave the metal entirely to do useful work.

Each band of electrons has its own energy level. It takes a certain amount of energy to move an electron to a higher energy state. To remove an electron entirely from an atom requires even more energy. This is known as the **ionization energy**. A solid metal, however, consists of an uncountable number of individual atoms.

The energy required to "kick" electrons out of a metallic surface is known as the **work function (Φ)** of the metal. It is the product of the electron charge and the required voltage, expressed in electron-volts. This gives you an idea of the voltage required to generate a stream of electrons from a metal.

One way to provide sufficient energy to remove electrons is by heating the material. This is called **thermionic emission**, and is the basis of the cathode ray. While it may seem crude today, cathode ray technology lasted decades in the television industry, which is practically an eternity by today's technology standards.

One way to provide an electron with sufficient energy to leave the atom is by hitting it with a high energy photon. **The photoelectric effect** describes how incident photons can eject electrons from the surface. This only happens when the energy of the photon exceeds the work function of the target material. Per quantum mechanics, the energy (E) of a given photon is directly proportional to frequency (f) of the light wave. $E=hf$, where h=Planck's Constant 4.14×10^{-15} eV·s.

As the frequency of the incident light increases, the individual photons will possess more energy, and the ejected electrons will have greater kinetic energy. If the frequency of the light is such that $hf<\Phi$, then no electrons will be ejected by the phtotoelectric effect, no matter how intense the light is. (Of course, if the incident light heats the metal up, then thermionic emission is still possible.)

WORK FUNCTION AND THE PHOTOELECTRIC EFFECT (CONTINUED)

Thermionic emission is used as the basis for **scanning electron microscopy (SEM)**. The resolution of any optical microscope is limited by the wavelength of light reflected off the object. The incident lightwave cannot penetrate features smaller than the wavelength. A beam of electrons has a much shorter wavelength than a beam of photons in the visible light spectrum, and will be able to resolve much smaller features (Figure 1). The SEM detector then generates an image of the surface. (These images will be black and white, since photons in the visible light spectrum would be needed to resolve color.) Next month's issue of Technical Tidbits will go into more detail on SEM and its capabilities.

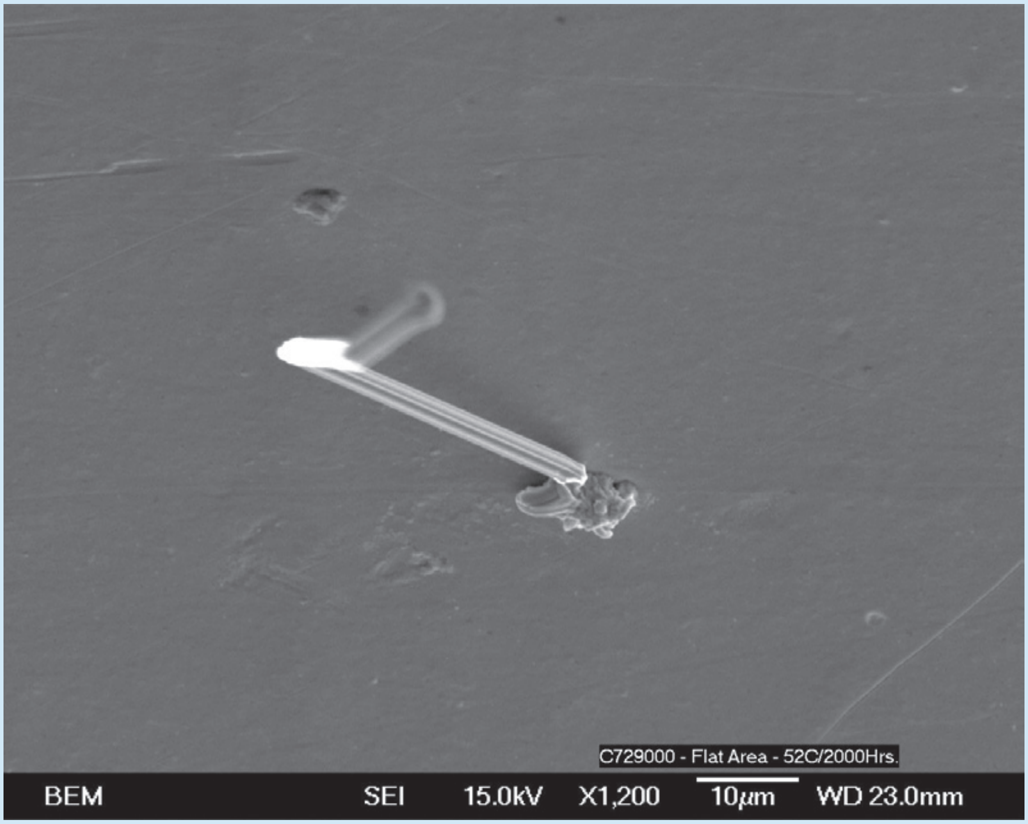

Figure 1 – Secondary Electron Image (SEI) of a Tin Whisker Growing out of a Tin-Plated Surface.
Note that whisker is less than 50 microns in length, yet is easily visible on this SEI image taken by a scanning electron microscope.

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