# UHV Analysis Tools: Understanding Atomic-Level Mechanisms for Next-Generation Electronic Devices

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Materials engineering involves the study of the relationship between structure, chemistry and properties of new materials. By manipulating matter at an atomic or molecular level we can build micro and nanostructured materials with new and interesting properties. With nanoscale materials, surfaces and interfaces play a large role in materials properties and interactions. The physical and chemical compositions of these surfaces determine the nature of the interaction. The ability to study and understand the atomic level interactions through monitoring surface chemistry, structure, and morphology, enables us to engineer materials and interfaces to meet new technical challenges. In this seminar, techniques for studying surface chemistry using XPS, RHEED, and AFM and integrating the fundamentals gained from these techniques will be presented.

X-ray photoelectron spectroscopy (**XPS**) is one of the useful characterization techniques for determining surface elemental compositions and bonding states. XPS uses characteristic x-rays, $h\upsilon$, to excite the sample and detect the emitted photoelectrons. The energy of the emitted photoelectrons is then analyzed by the electron spectrometer and the data presented as a graph of intensity versus electron energy. The kinetic energy of a photoelectron is equal to the incident photon energy ($h\upsilon$), minus the binding energy of the electron, minus the work function of the system ($\varphi$): $KE = h\nu - BE - \varphi$. The work function is defined as the minimum amount of energy (eV) required moving an electron from the Fermi level into vacuum.

Reflection high-energy electron diffraction (**RHEED**) is another useful surface analysis technique used to characterize the surface of thin film material. RHEED is a surface-sensitive analysis technique because the glancing angle of the incident beam has a penetration depth on the order of a few monolayers. The electron beam generated by the electron gun has an incident angle around 2°. The beam is then diffracted and imaged on the phosphor screen. The resulting image can be used to determine the surface characteristics of the film such as amorphous, polycrystalline, or single-crystalline, and can even provide information on atomic spacing on the surface. RHEED can be used further to determine the growth rate and growth mode of thin films. Since RHEED is a real time analysis technique, it is possible to obtain diffraction patterns during growth.

Another surface analysis technique is Atomic Force Microscopy (**AFM**), which characterizes surface morphology and roughness. The AFM consists of a cantilever with a sharp tip (probe) at its end that is used to scan the specimen surface. When the tip is brought into proximity of a sample surface, forces between the tip and the sample lead to a deflection of the cantilever according to Hooke's law. Typically, the deflection is measured using a laser spot reflected from the top surface of the cantilever into an array of photodiodes.

The overall research program approach is, taking advantage of the MBE and ultrahigh-vacuum (UHV) environment as well as other higher-rate processing. Then we are able to discover, understand, and control atomic-level influences on effective integration of functional materials with semiconductors in order to enable commercially viable processes for next-generation multifunctional electronics such as multifunctional active sensors and controllers, and high efficiency solar cells.