Spectroscopy with the Low Energy Electron Microscope

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The Low Energy Electron Microscope (LEEM) started out as an experimental technique to study surface structure and structure evolution, and this is still one of its main applications. However, in recent years, powerful spectroscopic methods have been developed that greatly expand and enhance the utility of LEEM. LEEM-IV (intensity versus voltage) data contain information on the atomic scale, not accessible by real-space imaging only. Such LEEM-IV data may also be used to perform 2-dimensional potentiometry on externally biased device structures. Measurement of IV data as a function of in-plane k-vector (so called Angle-Resolved Reflected Electron Spectroscopy-ARRES) provides direct insight in to the unoccupied electronic band structure, and is complementary to photoemission (Angle-Resolved Photo Electron Spectroscopy - ARPES) which provides information on the occupied electron bands. ARPES and ARRES experiments can be performed on the same sample in the same microscope, and can be combined with real-space imaging. ARRES data can be obtained on areas as small as 10x10 nm^2. The diffraction patterns contains additional information if we consider not just the intensity of the diffracted beams, but also their intensity distribution in k-space. Spot-Profile Analysis LEED (SPA-LEED) has made many contributions to surface science, but has been relatively neglected in LEEM.

However, Detailed and quantitative information can be obtained from the spot profile. The electrons undergo not only elastic, but also inelastic scattering, and with modern energy filters Electron Energy Loss Spectroscopy (EELS) is readily available. Plasmon loss spectroscopy is a simple tool that can be extremely useful as an electronic 'fingerprint' of the sample under study. Most recently, Transmission Electron Microscopy at few electron-volt energies (eV-TEM) has been developed to study both elastic and inelastic interactions of low energy electrons with single- and multi-layer 2D materials, both in imaging and spectroscopic modes. Quantitative comparison of both reflected and transmitted electron intensities provide a new perspective on the meaning of electron mean free path. And finally, dynamic, real-time studies of the EELS spectrum during low energy electron irradiation of thin organic films provides a new understanding of issues related to sample charging and sample damage induced by electron exposure. In short, the LEEM instrument is much more than a microscope - it is a spectroscopic imaging tools that allows us to address many different sample modalities with high spatial resolution.

This tutorial will provide a comprehensive overview of current capabilities, and an outlook for further developments.