Scanning Probe Microsocopy Methods for Semiconductor Inspection

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Scanning probe microscopy provides access to surface properties with an unprecedented spatial resolution down to the atomic level. A wide range of physical quantities of semiconductors can be studied with methods based on scanning tunneling microscopy (STM), scanning force microscopy (SFM), and scanning near-field optical microscopy (SNOM).

Spatially resolved current-voltage spectroscopy based on STM permits the local density of states to be determined. Thereby, STM delivers a wealth of information not only about the detailed morphologic but also electronic structure of semiconductor surfaces, including the characterization of dangling-bond states, defect states, and chemical reactions with adsorbates. Epitaxy can be studied on an atomic scale. Also sub-surface defects may probed in this way determining both their physical depth and energetic level.

In contrast to STM, SFM does not need a conductive sample surface and can therefore be applied more universally. Several techniques have been developed for probing electrical properties with SFM. Namely, SFM can be used for accessing the local surface potential with a Kelvin force probe technique based on the detection of electrostatic forces. Furthermore, SFM offers the possibility of performing spatially resolved capacitance-voltage spectroscopy, as well as mapping the spreading resistance. While the latter probes the transport properties at semiconductor surfaces or across samples, the former technique is able to specify the doping level for instance in p- and n-doped semiconductor structures, provided the doping level is not too high. With recent developments in non-contact imaging, SFM now has reached a level that permits the routine inspection of surfaces with atomic resolution under ultrahigh vacuum.

Furthermore, SFM has widely been used to initiate also surface or sub-surface modification in semiconductors. Among such applications fall domain engineering in ferroelectrics as well as silicon surface passivation and de-passivation providing access to surface or sub-surface functionality.

Scanning probe microscopy also offers powerful techniques for probing optoelectronic properties in semiconductors. On the one hand, the probing tip can be used for injecting a current leading to electroluminescence. On the other hand, the surface photovoltage arising at an illuminated semiconductor surface may be probed directly with the help of STM or SFM. Thus, information can be obtained about surface and impurity states and recombination behavior.

In this area, further progress will be provided by direct local optical spectroscopy based on SNOM offering an all-optical probing technique. The recent trends here point towards scattering techniques in the optical near-field potentially allowing nanoscale optics to be recorded as easy as in STM or SFM.

This contribution will survey all the mentioned methodologies, specifically addressing also their applicability to organic, inorganic, and ferroelectric semiconductors.