Non-linear Transport Imaging by Scanning Impedance Microscopy

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Scanning Probe Microscopy (SPM) techniques such as Scanning Surface Potential Microscopy and Scanning Impedance Microscopy (SIM) have been demonstrated to be powerful tools for quantitative dc and ac transport imaging in semiconductor structures and at grain boundaries. SPM techniques have been exclusively used to access the linear static and frequency dependent lateral electronic transport in materials and devices at the nanoscale, while current-voltage transport properties of most electro-active interfaces are intrinsically non-linear, a highly desired property for device functionality. A novel non-linear SIM technique is proposed to extend the nanoscale transport measurements of intrinsic material properties to the *non-linear* regime, through detection of frequency harmonics. This technique can be readily transferred to most cantilever-based scanning probe microscopes. As a test for the technique, we used a prototypical metal-semiconductor interface prepared by cross-sectioning a commercial Au-Si Schottky diode and connected in series with two current limiting resistors. A non-linear SIM signal is shown to originate from both the intrinsic non-linear behavior in the device and from frequency mixing in the tip-surface junction. An approach to differentiate the two is demonstrated. Under certain conditions, the n-th order non-linear SIM signal is shown to be directly related to the corresponding derivative of the I-V curve of the interface. We also demonstrate the use of the first and second resonance of the cantilever to provide resonance amplification for topography and electrostatic measurements simultaneously while avoiding cross-talk between the two. The imaging mechanism, surface-tip contrast transfer, optimal experimental conditions, and potential applications of non-linear SIM are discussed. Although non-linear properties are generally too complex in macroscopic techniques, non-linear SIM allows spatially resolved imaging of non-linear transport properties of individual microstructural elements and provides a new approach for quantitative nanoscale characterization of non-linear transport phenomena.

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