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Probing the Dynamical Properties of Nanoscale Solid-State Systems in Real Space and Real Time

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One of the biggest dreams in solid-state physics is getting quantitative access to the dynamical properties of tiny-tiny systems in real time and real space. Any technique that averages over an ensemble behavior thus inherently cannot be used and is out of scope here. Equally, indirect k-space methods will fail at these small length scales as well, due to the same limitations.
In order to fulfill the above requests, we recently developed scanning-probe-methods (SPM) towards both a superb spatial and temporal resolution. The high spatial resolution is inherently known in SPM from tons of splendid works performed on metallic, semiconducting, insulating, organic and biological nanomaterials, reporting a topographic resolution down to the single atomic and molecular level. What is novel, though, is that these SPM methods can be easily tuned towards an unprecedented time resolution down to pico-seconds. We will introduce into these novel techniques with two examples of solid-state measurements. The first system addresses ultrafast electronic transport properties as exemplified on a thin film organic field-effect transistor (OFET). To monitor the charge recombination in-situ we modified a standard non-contact scanning force microscope (nc-SFM) operated in the Kelvin force probe mode (KPFM) to measure surface potentials, into a time-resolved KPFM (tr-KPFM) technique [1]. tr-KPFM is able not only to delineate and track the charge wave fronts of injected electrons in real time, but equally proves, why today's OFET devices fail to achieve faster switching speeds, simply due to Schottky barrier issues.
The second example will be discussed by quantifying the excited state lifetime of electrons in an optically pumped SiGe semiconductor device [2]. Here, a similar side-band demodulation scheme as for tr-KPFM is implemented into scattering scanning near-field optical microscopy (tr-s-SNOM). We find the charge carrier lifetimes to drastically depend on their ground state population density, as monitored by varying the Si-to-Ge concentration.

References:
[1] J. Murawski et al., (2015) submitted.
[2] F. Kuschewski et al., Scientific Reports (2015) in print.

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