Approaching picosecond temporal resolution in off-axis electron holography

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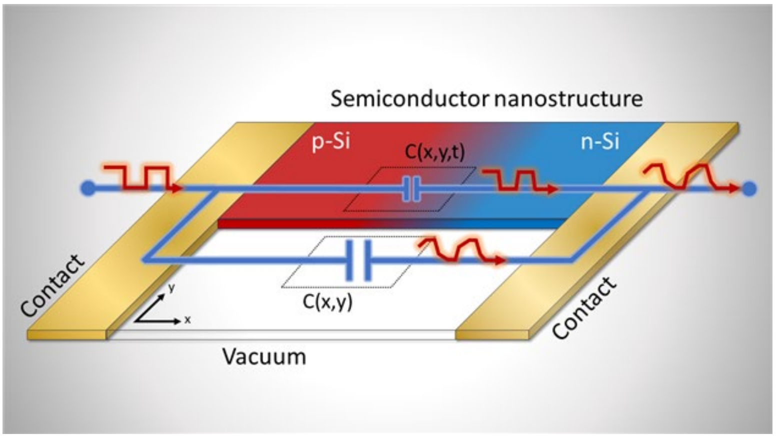
In the course of new technological and instrumental possibilities, time-resolved investigations in transmission electron microscopy are currently gaining particular relevance [1]. For phase-resolving methods, however, there are hardly any realizations for the investigation of dynamic processes on ultrashort time scales, although these are of great importance, especially for in-operando investigations of dynamic potential distributions in nanostructures (e.g. switching semiconductor or magnetic topological nanostructures).

Recently, interference gating (or iGate) has emerged as a simple, but robust method to address this circumstance [2]. It is based on the intentional destruction of the interference pattern for a large part of a measurement, utilizing short undisturbed time periods (called gates), which are synchronized to a periodic process under investigation, to generate time-resolved interferometric information. In particular, the simple technical realization of the method (only a two-channel signal generator, two coaxial cables, an dedicated aperture holder and an electrical biasing sample holder are required) enables low-barrier access to the investigation of ultrashort phenomena on existing instruments [3].

Through continuous improvements in sample preparation, automated measurement and reconstruction routines, control signal design, and the necessary electron-optical components, the time resolution achievable with iGate has recently broken through the picosecond barrier. By an application to silicon diodes, switching at repetition rates in the MHz range, variations of the local capacitance C(x,y,t) could be observed and the cause of the anomalous (MOS-cap-like) switching behavior of a defective semiconductor nanostructure was revealed [4]. A schematic representation of the experiment is illustrated in the accompanying figure. The nanostructured diode sits in between two extended metallic contacts, forming an overarching electrical system (e.g. parallel connected capacitances in vacuum C(x,y) and the diode C(x,y,t)).
In addition, the method itself could already be implemented in transmission electron microscopes in further laboratories in very short time frames (less

than a work day), whereby the FPGA-based conversion of a JEOL JEM-2200FS into a versatile phase-resolving instrument with sub-nanosecond temporal resolution is discussed here in detail. The presented results will highlight the advantages of image-based investigations of projected dynamic potential distributions with nanometer and sub-nanosecond resolutions and their application to materials science problems, and pave a new path for decoding dynamic processes and their physical causes directly at the point of their occurrence.

Graphic:



Keywords:

electron-holography, time-resolved, ultrafast, semiconductor-nanostructures, interference-gating

Reference:

[1] A. Arbouet, et al, Advances in Imaging and Electron Physics (2018), 1-72.
[2] T. Niermann et al., Ultramicroscopy 182 (2017), 54-61.
[3] T. Wagner et al., Ultramicroscopy 206 (2019), 112824.
[4] T. Wagner et al., Phys. Rev. B 109 (2024), 085310.