The electron dynamics in an ultrafast transmission electron microscope with Wehnelt electrode

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We describe the electron beam characteristics in an ultrafast transmission electron microscope operating with photoelectrons from a thermionic gun. The optimization of the spatial and temporal resolution and the minimization of the energy width of the beam need a detailed understanding of the electron dynamics in the microscope, in particular the electron trajectories in the gun and the electron-electron interaction in a pulse.

The electron microscope is based on a Jeol 2100 with thermionic gun and Wehnelt electrode. The microscope was modified by IDES Inc. to operate with photoelectron pulses. The laser-optical periphery is attached to the microscope. As photoemitter, discs or flattened tips of tantalum are used. Two sets of mirrors and lenses direct and focus an IR drive laser onto the specimen and a UV laser for electron emission onto the photocathode, allowing pump-probe experiments. An additional electron lens above the condenser is used to increase the throughput of the electron beam. A laser with 350 fs pulses and an average power of up to 10 W is used at repetition frequencies up to 40 MHz. An optical delay line with a movable mirror in the IR beam is controlled by the imaging software.

The spatial resolution of the microscope in the stroboscopic photoelectron mode is approximately 0.2 nm (without excitation of the specimen). An energy width of the electron beam of down to 0.8 eV, measured by an electron energy-loss spectrometer, can be obtained at low UV intensities on the cathode. The synchronization of the pump and probe pulses is achieved by the PINEM effect (photon-induced near-field electron microscopy). By taking PINEM spectra at different delays, a temporal scan over the electron pulse is obtained. This is carried out at different UV intensities and different settings of the Wehnelt bias to probe the electron distribution along the beam direction in one pulse.

It is shown that both the Wehnelt bias and the UV laser intensity have a decisive influence on the characteristics of the pulses. An increasing Wehnelt bias leads to considerable temporal broadening of the electron pulses due to the Boersch effect at the gun cross-over. Increasing UV intensity also leads to a broadening of the pulses. The energy width of the pulses is considerably increased with increasing UV intensity whereas an increasing Wehnelt bias even reduces the energy width. At low UV intensity, i.e., a small number of electrons in a pulse, a temporal resolution of approximately 2 ps is attained. Furthermore, it is shown that the electron trajectories in the low-energy region of the electrons, i.e., close to the cathode, have an important influence on the arrival time of the pulses on the specimen and on the coherence of the beam. The measurements of the beam characteristics will be presented and discussed in detail.