Development of a high brightness ultrafast Transmission Electron Microscope based on a laser-driven cold field emission source

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The potential of scientific instruments for materials science is largely conditioned by the properties of the particle source on which they rely. For instance, in Transmission Electron Microscopy (TEM), it is the superior brightness of cold field emission (CFE) sources that enables the acquisition of electron holograms, from which modifications of the phase of the electron wave function can be retrieved and traced back to the electrostatic, magnetic or strain fields of the sample, or that allowed the amount of coherent probe current to be maximized for optimum high resolution STEM imaging and spectroscopy. The first Ultrafast Transmission Electron Microscopes (UTEM) provided a unique insight into the physics of nano-objects with both sub-picosecond temporal resolution and nanometer scale spatial resolution but could not be used for ultrafast electron holography because of the poor brightness of their electron source [1,2].

We report on the development of an ultrafast cold field electron source and its use for Ultrafast Transmission Electron Microscopy [4,5]. We follow a different approach compared to the recently developed ultrafast laser-driven Schottky electron source in which electron emission is confined to the apex of a tip by the use of the additional suppressor electrode available on usual Schottky type module and by chemical selectivity using a zirconia wetting layer on the [100] oriented front facet of the tungsten (W) tip [3].

In the present work, we have modified a cold field emission source to integrate laser optics in the immediate vicinity of the [310] oriented W nanotip to minimize the size of the laser focal spot on the tip apex, minimize the size of the emission region and therefore maximize the brightness of the source [4]. Most problems related to the integration of optical components in the ultra-high vacuum and high voltage area close to the FE tip have been solved, by paying particular attention to the global electron optics performance of the 200kV based CFE gun (mainly spherical and chromatic aberrations). We will describe the architecture of this ultrafast CFEG, report on numerical simulations of the electron beam properties and electric field in the electron gun. The performance of the electron source as a function of laser parameters, extraction voltage, gun lens strength, as well as the properties of the electron probe (brightness, angular current density, stability) will be addressed [5]. Finally, the potential of this high-brightness ultrafast CFEG-TEM for conventional imaging, diffraction in parallel and convergent beam, high resolution imaging, electron energy loss spectroscopy and off-axis holography using 150keV ultrashort electron pulses will be illustrated.

[1] Zewail, A. H., Science, 2010, 328, 187-193
[2] Zewail, A. H., USPTO n°US7,154,091 of December 26. 2006
[3] A.Feist *et al* Ultramicroscopy. 176, 63-73, (2017)
[4] G.M. Caruso *et al* Appl. Phys. Lett. 111, 023101, (2017)
[5] F.Houdellier *et al* Ultramicroscopy. 186, 128-138, (2018)