Ultrafast Electron Microscopy: Femtosecond imaging, diffraction and spectroscopy for material science and quantum applications

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Understanding the ultrafast evolution of atomic and electronic rearrangements under nonequilibrium conditions in nanomaterials plays a fundamental role in deciphering the mechanism governing physical and chemical functions. With direct visualization, the technological development of future innovative devices on the nanoscale would become feasible.

Although an enormous effort has been devoted to the comprehension and improvement of these materials and devices, the capability of investigating their dynamic behavior is hindered by the difficulty of simultaneously studying their evolution in space and time at the appropriate scales. The traditional characterization techniques and the steady-state theoretical models are both not adequate for describing their nonequilibrium behavior. Instead, a novel approach for visualization of matter with high temporal and spatial resolutions, together with energy and momentum selection, is indispensable to fully exploit their potential.

Ultrafast Electron Microscopy (UEM) has been developed with the capability of performing time-resolved imaging, diffraction and electron spectroscopy. The high spatial, temporal, energy and momentum resolution, provide the real-time access to the dynamic behavior of surfaces, interfaces and nanosystems.

Here, after outlining the UEM approach, which enables sub-nanometer spatial resolution and temporal speed of 10 orders of magnitude faster than previously possible, I will address several recent applications in materials science and quantum applications, highlighting for each case the challenges that had to be overcome, the main scientific contributions, and future trends in the field. The highly inter- and multi-disciplinary approach presented here will pave the way for an unprecedented insight into the nonequilibrium phenomena of advanced materials, and should play a decisive role in the rational design and engineering of future applications.