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# Advancements in UltraFast Electron Microscopy

Darrin Leonhardt[1*], Eric Montgomery[1], Chunguang Jing[2], Bart Wyderski[2], Yubin Zhao[2], Spencer Reisbick[3], Yimei Zhu[3], June Lau[4], and John Roehling[5]

[1] Euclid Techlabs, LLC, Beltsville, MD, USA
[2] Euclid Techlabs, LLC, Bolingbrook, IL, USA
[3] Department of Condensed Matter Physics and Materials Science, Brookhaven National Laboratory, Upton, NY, USA
[4] Materials Science and Engineering Division, National Institute of Standards and Technology, Gaithersburg, MD, USA
[5] Materials Science Division, Lawrence Livermore National Laboratory, Livermore, CA, USA
* Corresponding author: d.leonhardt@euclidtechlabs.com

With the growing applications of temporally-resolved electron microscopy for probing basic chemical and electronic phenomena as well as reducing beam-induced damage, a multifaceted approach to ultrafast transmission electron microscopy is provided. Complex laser techniques with fixed image acquisition times have been complemented by ultrafast rf and microwave-driven techniques that can be synchronized with any sample excitation (laser, rf, thermal) with much faster image acquisition times (from days to minutes), enabling more reliable data and microscope efficiency.

Originally a basic research tool for materials science, transmission electron microscopes (TEMs) have seen a renaissance, as they have been applied in nearly every technology-based field. It has become the gold standard of high spatial resolution techniques and the ever-increasing applications from quantum dots to cellular 3D tomography and holography demand a wider range of imaging capabilities. TEMs are used to connect photonics, nanodevice architecture, and biophysics, each with their individual intrinsic response times on the nanoscale. The continued evolution of applications and maturation of basic TEM instruments have not only created additional sectors in the TEM industry (life sciences, nanotechnology, and semiconductor), but have fostered significant growth in these areas that the new market sectors are comparable in size to the once dominant materials science market [1].

A graphical representation of these growing technology areas with some key applications is provided in Figure 1 with relevant time scales for areas of materials science (red), life sciences (blue), semiconductor (grey) and nanotechnology (green). (Abbreviations DYN and STR represent dynamics and strength, respectively.) Generally, the picosecond regime is common for interrogating basic material phenomena, then longer time scales are generally necessary as material systems get larger physically. Ultrafast TEM (UTEM) was developed using lasers and photocathodes in the mid-2000s to interrogate time-resolved responses to optical stimuli [2]. While ultrafast lasers were a natural enabler for early research in UTEM, the explosive growth of these new applications based on large molecules (proteins, cells) and new 2D/3D architectures (NEMS/MEMS, nanosheets, spintronics) requires broader temporal capabilities due to their widely varying response times. Complementary enabling technologies (rf, microwave) have been used in many of these cases with simplified and typically improved imaging performance.

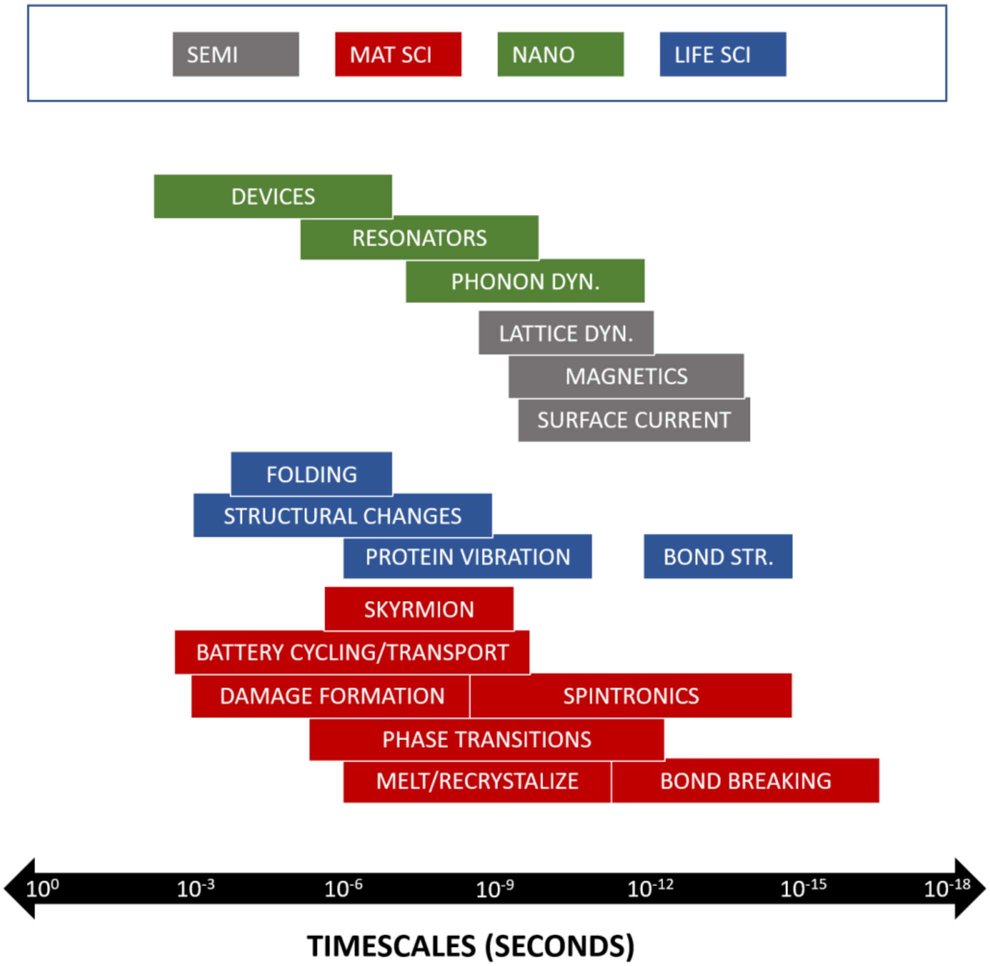


**Figure 1.** Comparison of time scales for various areas of study

This talk will also present the challenges for growing ultrafast techniques [3,4] and compares these complementary methods to laser UTEM techniques [3,4], for electron microscope users to consider when trying to expand their research capabilities. An update on UEM applications supported by recently developed techniques and extraordinary electron beam characteristics [7] as well as implementation perspectives will also be provided.

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