doi:10.1017/S1431927620014646
Microsc. Microanal. 26 (Suppl 2), 2020

Ultrafast Imaging the Evanescent Electromagnetic Field of Nanostructures by UEM

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Recently, Ultrafast Electron Microcopy (UEM) has been used to study the ultrafast dynamics of matter in physics, chemistry and materials science with temporal resolution of hundreds of femtoseconds [1], which is 10 orders better than that of conventional electron microscopy limited by the camera read-out rate. We care about this femtoseconds time scale because it gives us new and fundamental understanding about how nature works. In UEM, ultrafast time resolution is reached by using two separated but synchronized ultrashort laser pulses, one to generate a probing electron pulse by photoemission at the microscope cathode and the other to excite the specimen into a non-equilibrium state. Scanning the time delay between arrival of the pump and probe pulses at the specimen allows the evolution of the specimen to be traced.

Although UEM is a powerful tool for scientists, there are not enough of such kinds of equipment for the science community in the world. We established one state-of-art UEM user facility at the Center for Nanoscale Materials (CNM), Argonne National Laboratory. In my talk, I will present an introduction to the UEM at CNM and its capabilities and will provide research examples focused on how to capture the ultrafast evanescent electromagnetic fields of nanostructures. Ultrafast electron microscopy has enabled not only the study of light-mater interactions, but also can be used to investigate the light-electron interactions at nanoscale. One unique technique called Photon-Induced Near Field Electron Microscopy (PINEM) was developed to image the evanescent electromagnetic field around a nanostructure or interface at nanoscale and femtoseconds time scale.[2] In conventional transition electron microscopy, the interactions between the electrons and the matter will cause electrons to lose its energy due to the inelastic scattering events when passing through the specimen. However, in UEM, the electrons not only lose energy, but also gain energy when they pass nearby the nanostructures under simultaneous optical excitation. Formation of the image using those electrons which gained energy enable scientist to image the evanescent electromagnetic fields of the nanostructures.

The UEM at the CNM is equipped with one GIF spectrometer, which enables it to work in energy filtering mode and to record PINEM image. We have demonstrated its success in capturing the evanescent electromagnetic fields of silver nanowires and Au-bead@Ag nanorods. Fig.1a shows a bright-field image of silver nanowires (with diameters of 60-300 nm) recorded in UEM mode. Fig. 1b and c show the PINEM image of evanescent plasmons fields around nanowires recorded at time t=0 ps and t=-4 ps, respectively. As seen from the plasmonic field distribution, they are extensively affected by the overlapping of nanowires. Fig.2a shows one bright-field image of Au-bead@Ag nanorods [3] with aspect ratio of 6.5+/-0.4. The PINEM image in Fig. 2b and Fig.2c recorded at time t=0 ps under different polarization directions, indicated by blue arrows. The polarization dependence changed the electromagnetic fields distributions between the nanorods. The field enhancement and confinement between nanorods due to the field interactions scattered from adjacent nanorods were observed, especially at the intersection of one nanorod and one nanorod dimmer in Fig.2b. One fundamental step toward the development of functional nanodevices is to understand properties of nanoparticle ensembles and their time-dependent structural characteristics.[4] Investigation of the coupling between electric and plasmonic of nanostructures under different time range, fluence and polarization influences will help to develop novel electronic and optical

properties of nanostructure materials and enable scientists to explore new windows in biomedical applications, optical signal processing, nanophotonics, quantum science and surface-enhanced Raman scattering applications [5].

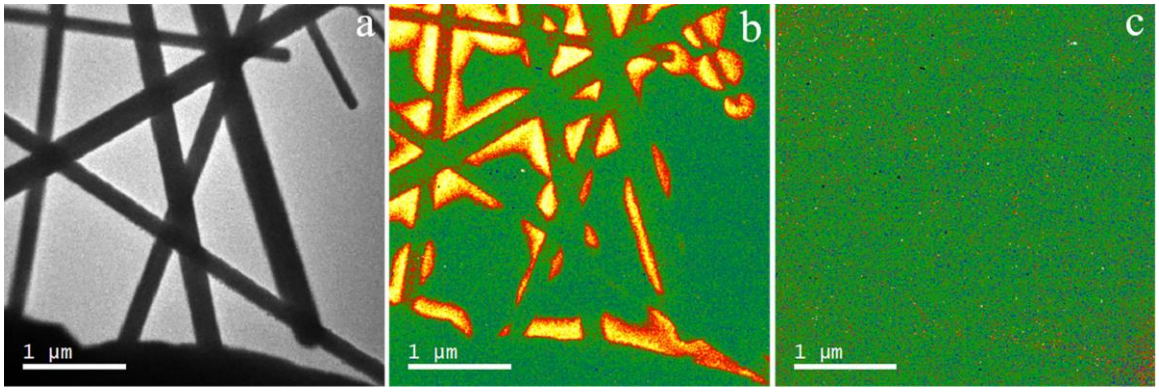

Figure 1. a. UEM bright-field image of silver nanowires. b and c. PINEM images of the plasmonic field around nanowires obtained at the delay time of 0 ps and -4 ps under 1030 nm excitation, respectively. The scale bar presents 1 µm. The fluence of optical excitation is 15 mJ/cm2.

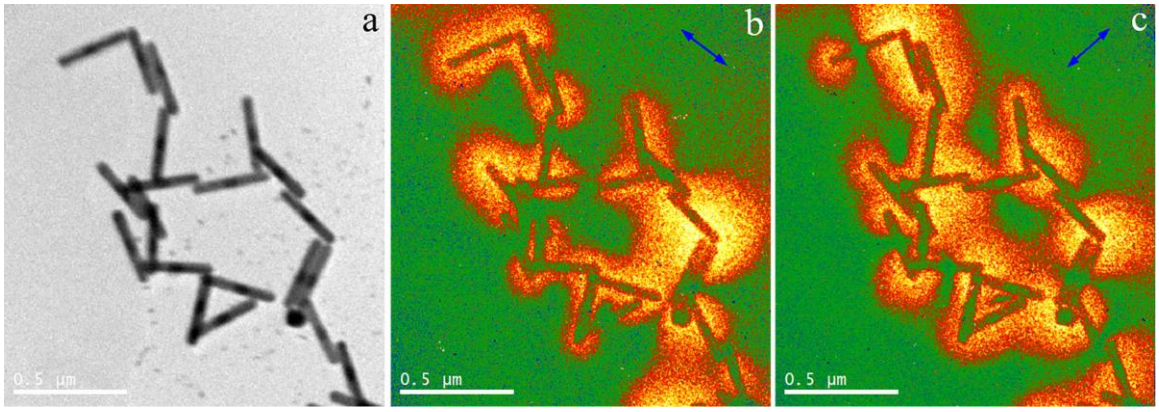

Figure 2. a. UEM bright-field image of Au-bead@Ag nanorods. b and c present the PINEM images of the plasmonic field around the nanorods obtained at the delay time of 0 ps under different linear polarization directions of 1030 nm optical excitation. The scale bar presents 500 nm. The fluence of optical excitation is 3.3 mJ/cm2. The blue arrows in b and c indicate the direction of linear polarization of incident light.

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[5] The authors acknowledge the use of the Center for Nanoscale Materials was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract DE-AC02-06CH11357, and funding support from Department of Biotechnology (DBT), Government of India, under project number BT/PR14749/NNT/28/954/2015.