Special Program in Applied Mathematics and Applied Mechanics

4-dimensional electron microscopy of ultrafast charge carrier dynamics in semiconductors and anomalous Brownian motion of nanomaterials in water

Prof. Jau Tang

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10:00 - 12:30
308, Mathematics Research Center Building (ori. New Math. Bldg.)

Using 4D electron microscopy we combine the nanometer spatial resolution of electron microscopy and femtosecond temporal resolution of fs laser pulses and electron pulses to investigate ultrafast phenomena of nanostructured materials so that we could discover novel properties of these materials and elucidate their dynamics, in a hope that we could find potential applications in solving energy, environment and biomedicine related issues.
In our first Science paper, we presented ultrafast scanning electron microscopy (USEM) of photoinduced carrier dynamics across semiconductor p-n junctions. We observed fast charge separation of electrons and holes at the p-n junction and extremely high speed ballistic carrier dynamics, novel to the conventional solid state textbook description. We attributed such phenomena to slower electron-phonon collision time on the surface at high carrier temperatures and also polarity-dependent gating mechanism at the junction.
In another more recent Science work, we demonstrated novel applications of ultrafast electron microscopy (UEM) in liquid solution. We have discovered very fast anomalous Brownian motion of gold nanoparticles upon femtosecond laser excitation. Unlike the well-known linear time dependence for the mean square displacement in Einstein's theory for Brownian motion, the observed dynamics exhibits several kinds of time dependence, covering

ballistic, super diffusion and normal diffusion regimes. Moreover, the corresponding diffusion constant is 3 to 4 orders of magnitude greater than same nanoparticles in the absence of laser excitation. We elucidated the impulsive driving forces caused by water vapor nanobubbles from pulsed laser heating.

On one aspect, future development of electronic devices utilizing ballistic carriers could significantly improve the switching speed and operation efficiency, and will be an important task to revolutionize the IC industry. On the other aspect, development of molecular motors, miniature machinery utilizing nanobubbles or other driving forces for propulsion might one day offer potentials for industrial or medical applications.

1. E. Najafi, T. D. Scarborough, Jau Tang, A. H. Zewail *, Science 347, 164 (2015), “4D imaging of carrier interface dynamics in p-n junctions.”

2. X. W. Fu, B. Chen, Jau Tang*, M. Th. Hassan, A. H. Zewail, Science 355, 994 (2017), “Imaging rotational dynamics of a nanoparticle in liquid by 4D electron microscopy”.