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Novel UEM Setup for Improved Resolution and Extended Experimental Capabilities

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Ultrafast electron microscopy (UEM) has grown rapidly in recent years with a number of new installations and a growing variety of instrument designs [1,2]. This expansion has coincided with an increased demand for the unique capabilities that UEM can provide in contemporary research areas such as photovoltaics, microelectronics and quantum materials. In addition, UEM has demonstrated an ability to further the understanding of fundamental phenomenon in condensed matter physics and chemistry [3]. However, there are certain foundational limits to the resolution of UEM systems which are a product of their unique geometric setup as well as some inescapable challenges resulting from electron-electron interactions and controlled electron packet production [4]. What these exact limits are is the focus of much instrumentation research revolving around UEM. Here, I will discuss some of the approaches that we have taken with the new UEM at Argonne National Laboratory (ANL) to expand its operational parameter space enabling new scientific directions and improved resolutions. The Center for Nanoscale Materials at ANL has recently brought online a UEM system as part of the user facility with a novel laser system and camera arrangement. A JEOL 2100 Plus, shown in Figure 1(b), has been modified by IDES to incorporate a C0 lens and two optical ports, one for specimen excitation and the other for photoelectron generation at the cathode. A custom condenser aperture has been installed which allows for lower electron loss in the column and is a something we believe is a first for the JEOL system. Both cameras, one direct electron (K2) and one CCD (Ultrascan), are after the Gatan Continuum GIF system. This unique setup provides the opportunity to take advantage of the direct electron cameras sensitivity in EELS and EF-TEM modes. The UEM uses a 40 W 1030 nm Carbide laser (Light Conversion) which can operate at frequencies up to 500kHz with 270 fs pulses. The probe laser line can either use a HIRO conversion box to achieve fourth harmonic generation or a non-linear OPA. The non-linear OPA generates laser pulses ranging from 325-450nm in wavelength with < 50 fs pulse duration. By tuning wavelengths closer to the cathode bandgap, it is possible to decrease the electron energy spread resulting from excess photon energy [5]. This coupled with shorter pulses provides a pathway to pushing the temporal and energy resolution to new limits for UEM. Already, we have been able to greatly surpass the thermionic energy resolution of our microscope in photoelectron mode as shown in Figure 1(c). The pump laser system options are composed of the fundamental wavelength and the second harmonic at 270 fs or a second OPA with wavelength ranges from 325-2000 nm with compressed pulses (< 70 fs). This flexibility in excitation wavelengths is critical for allowing a range of experimental designs brought forward by users. In addition to optical excitation, electrical specimen excitation has been introduced as a capability for our UEM [6].

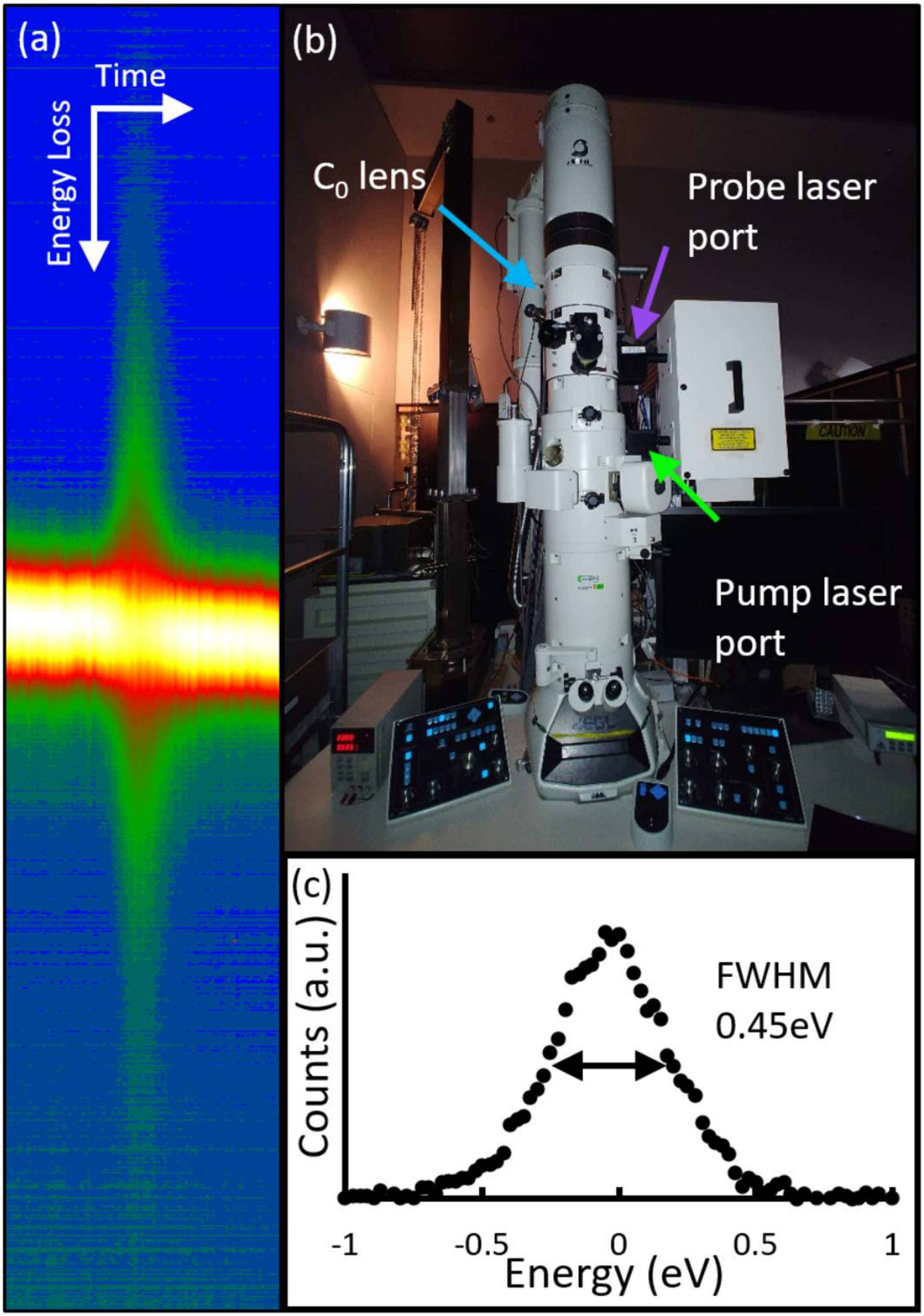
(a)
Time
Energy Loss
(b)
C_0 lens
Probe laser port
Pump laser port
CAUTION
(c)
Counts (a.u.)
FWHM
0.45eV
-1
-0.5
0
0.5
1
Energy (eV)

Figure 1. (a) Time-energy plot for a PINEM scan on our UEM at ANL. (b) Image of the UEM TEM column with after factory modifications annotated. (c) Zero-loss peak for an EELS spectrum acquired in photoemission mode (5 sec acquisition). The FWHM of the peak is 0.45 eV.

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