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High Brightness Nano-patterned Photocathode Electron Sources for UEM

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Ultrafast electron microscopy (UEM) aims to combine the high spatial (sub-nm) resolution of electron microscopy with the high temporal (sub-ps) resolution afforded by today's ultrashort pulse lasers. Key to the development of such a research instrument is a laser-driven photoemission source with a high brightness; that is, a low normalized transverse emittance, $\varepsilon_T = \Delta x.\Delta p_x/(mc)$, where Δx and Δp_x are the spatial size and transverse momentum width of the source respectively. However, Δx is primarily determined by the required pulse charge for the experiment, which is limited to roughly $\varepsilon_0 E(\Delta x)^2$, where E is the photo-gun's electric field strength at the surface of the cathode. As a result, for a viable UEM, the value of Δp_x will likely need to be reduced below that of conventional photoemission. A potential solution to this problem is to employ laser-driven plasmon-enhanced photoemission from a nano-patterned photocathode [1]; the idea being to use the strong oscillatory local surface plasmon field to 'control' the divergence of photoemitted electrons through the combined action of photoemission barrier suppression and ponderomotive acceleration [2].

Here, we present the observed properties of laser-driven plasmon-enhanced photoemission from a gold-coated, single-crystal silicon nano-patterned photocathode. Figure 1(a) shows the nano-patterned Si substrate with a ~1μm period and a ~10% (near sinusoidal) modulation depth produced by focused ion beam (FIB) milling using a defocused Ga ion beam in a Zeiss 1540XB FIB. Subsequent deposition of a 300nm-thick gold film provided the necessary nano-structure for the observation of resonant plasmon-enhanced photoemission at close to the expected $\theta \approx 41°$ incidence angle (Figure 1(a) inset) evaluated for gold (dielectric constant, $\varepsilon = -3.95$ [3]) at $\lambda = 523$nm – the green second harmonic of our high-power femtosecond Yb:KGW laser [4] with a 2.37eV photon energy that is less than half the $\Phi = 5.1$eV work function for gold. The use of a substrate with a relatively high thermal conductivity to dissipate the heat generated by the laser-driven plasmon allowed for the continuous operation of the 63MHz pulsed electron source at an average incident laser intensity of 1kW/cm^2. Prior efforts using a commercial gold grating (750 lines/mm) as the nano-patterned photocathode under similar operational conditions were limited by the low thermal conductivity of the glass substrate (Figure 1(b)). The transverse momentum distribution of this laser-driven electron source is compared to that of a conventional Ta photocathode ($\Phi = 4.25$eV) driven by the 261nm (4.75eV) fourth-harmonic of the Yb:KGW laser using the scheme depicted in Figure 1(c), where the detector is located at the back focal plane (Fourier plane) of the magnetic lens system with focal length $f \approx 20$cm.

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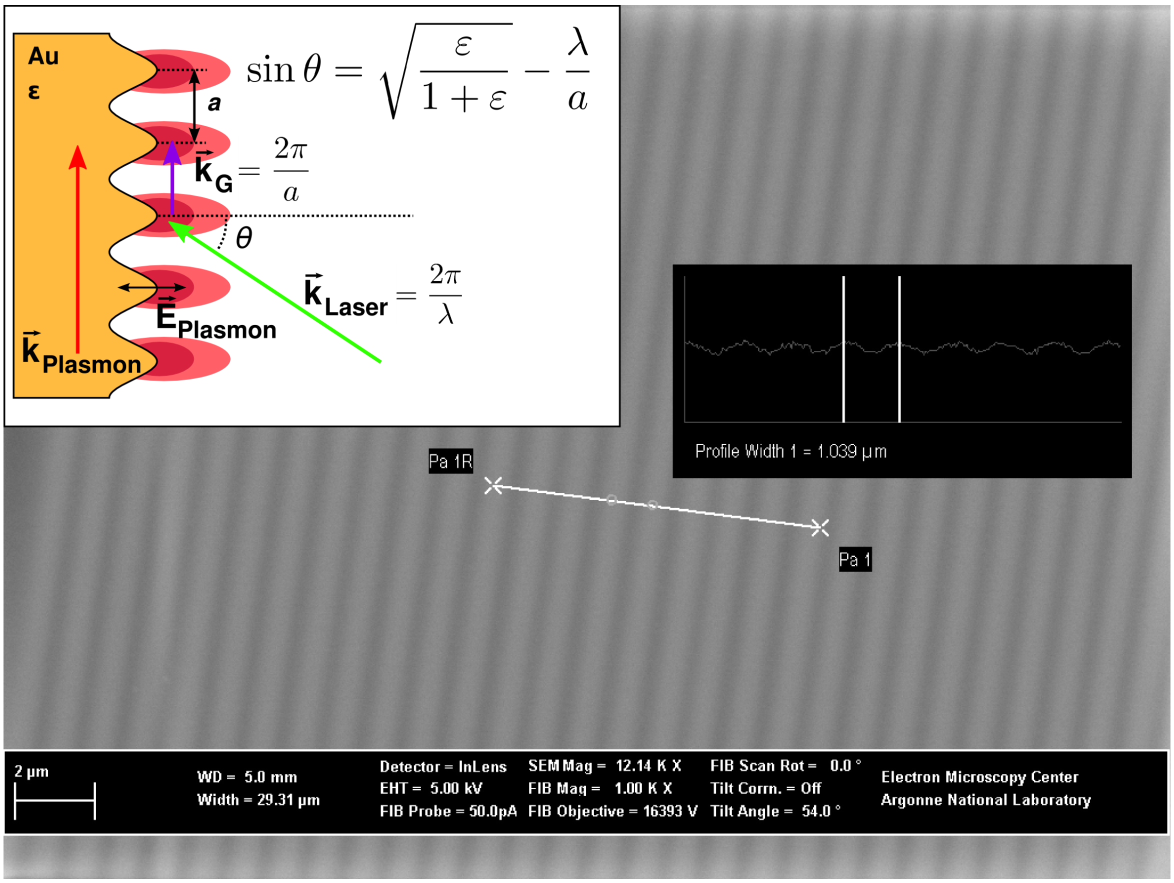
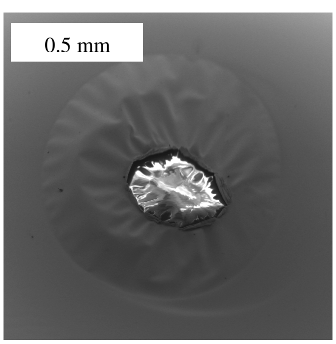
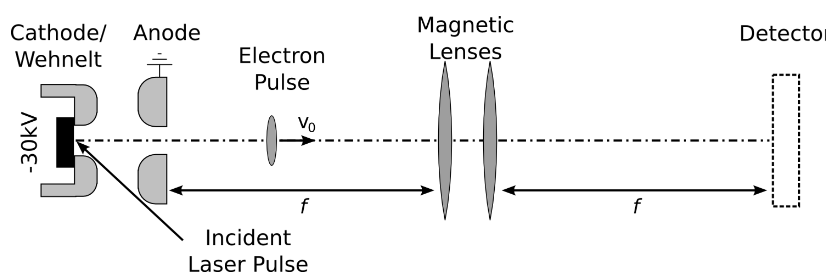


(a)



(b)



(c)

FIG 1. (a) High resolution SEM image of the FIB-milled sinusoidal nano-structure in single crystal Si. Inset: Laser-driven resonant surface plasmon excitation on a periodic gold surface. (b) SEM image of laser-induced damage (due to plasmon heating) on a commercial 750 lines/mm gold grating. (c) Schematic of experiment designed to measure transverse momentum distribution of pulsed electron beam.

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