1162
doi:10.1017/S1431927613007800

Microsc. Microanal. 19 (Suppl 2), 2013

High Brightness Photocathodes for Ultrafast TEM: A New Paradigm

B.L. Rickman,[1] J.A. Berger,[1] A.W. Nicholls,[2] and W.A. Schroeder[1]

[1] University of Illinois at Chicago, Department of Physics (m/c 273), 845 W. Taylor Street (rm. 2236), Chicago, IL 60607-7059
[2] Research Resources Center, University of Illinois at Chicago (m/c 337), 845 W. Taylor Street, Chicago, IL 60607

Dynamic transmission electron microscopy (DTEM) aims to combine the high spatial resolution of electron microscopy with the temporal resolution afforded by pulsed laser systems [1]. Key to the development of a viable ultrafast (i.e., sub-nanosecond) TEM is a laser-driven photoemission source with a high brightness; that is, a low normalized transverse emittance, $\varepsilon_T = \Delta x.\Delta p_T/(mc)$, where Δx and Δp_T are the spatial size and transverse rms momentum of the source respectively. Whereas Δx is limited by Gaussian laser beam focusing and Child's Law, Δp_T is dependent upon the properties of the photoelectron emitter. For photocathodes at a thermal energy $k_B T$ much less than the excess photoemission energy $\hbar\omega - \phi_{eff}$, where $\hbar\omega$ is the incident photon energy and ϕ_{eff} is the effective work function, the standard expression for Δp_T is $\sqrt{m(\hbar\omega - \phi_{eff})/3}$ [2], where m is the electron mass. Extensive simulations of the photoemission process and detailed experimental investigations of several planar metal photocathodes indicate that this expression is incomplete: the mean square transverse momentum should be written as

$$(\Delta p_T)^2 \approx \frac{M(\hbar\omega - \phi_{eff})}{3}\sqrt{1 + \left(\frac{3k_B T_e}{\hbar\omega - \phi_{eff}}\right)^2} \quad ,$$

where T_e is the photocathode electron temperature and $M = \min(m_T^*, m_0)$, with m_T^* being the transverse electron effective mass of the state (i.e., energy band) from which the electron is emitted and m_0 is the electron rest mass. For m_T^* less than m_0, the electron beam brightness is therefore proportional to $(m_T^*)^{-1}$ – defining a new avenue for the future development of high brightness laser-driven pulsed electron sources.

The results of our photoemission simulations illustrated the cause for the dependence of Δp_T on m_T^*. Shown in Figure 1 are two photoemission efficiency contour plots (as a function of the longitudinal (p_z) and transverse (p_T) emission momenta) for Mo ($\phi_{eff.} = 4.50(\pm 0.05)$eV) when $\hbar\omega = 4.75$eV and $T_e = 300$K; Fig.1(a) for $m_T^* = m_0$, and Fig.1(b) for $m_T^* = 0.3m_0$ – a value of the electron effective mass extracted from cyclotron resonance studies of Mo [3]. Clearly evident is that energy and momentum conservation limit the maximum electron emission angle for $m_T^* < m_0$; specifically, $\theta_{\max} = \sin^{-1}\sqrt{m_T^*/m_0}$ [4], which is 33° for $m_T^* = 0.3m_0$. This then causes a reduction in the extracted value of Δp_T from $0.29\sqrt{(m_0.\text{eV})}$ for $m_T^* = m_0$ to $0.16\sqrt{(m_0.\text{eV})}$ when $m_T^* = 0.3m_0$.

Figure 1(c) displays the experimental results obtained for a 300K planar Mo photocathode in our 20kV photo-electron gun driven by 4ps duration 261nm ($\hbar\omega = 4.75$eV) UV laser pulses [5]. After acceleration, the electron pulses directed down the 'optical axis' of a pair of large-aperture, round magnetic lenses before detection using a YAG scintillation screen and a CCD camera. Their spatial spot size on the YAG scintillator is monitored as a function of the magnetic lens strength (i.e., the square of the current in the lens coils) and compared to a simulation of the measurement technique that employs an extended analytical Gaussian (AG) electron pulse propagation model [6]. The experimental data points are in good agreement with the simulated propagation of an electron pulse with $\Delta p_T \approx 0.15 \sqrt{(m_0.\text{eV})}$ rather than for $\Delta p_T = 0.29(\pm 0.03) \sqrt{(m_0.\text{eV})}$ (the shaded region in Fig.1(c)) which would be expected for $m_T^* = m_0$; thus, providing clear evidence supporting the proposed dependence of Δp_T on m_T^*.

References:

[1] W.E. King, et al., *J. Appl. Phys*. 97 (2005) 111101.
[2] D.H. Dowell and J.F. Schmerge, *Phys. Rev. ST – Acc. & Beams* 12 (2009) 074201.
[3] M. Surma, *J. Mag. & Mag. Mat*. 11 (1979) 56.
[4] Zhi Liu, et al., *J. Vac. Sci. Tech. B* 23 (2005) 2758.
[5] J.A. Berger, et al., *Appl. Phys. Lett*. 101 (2012) 194103.
[6] J.A. Berger and W.A. Schroeder, *J. Appl. Phys*. 108 (2010) 124905.

[7] This work was supported by the Department of Energy (contract DE-FG52-09NA29451).

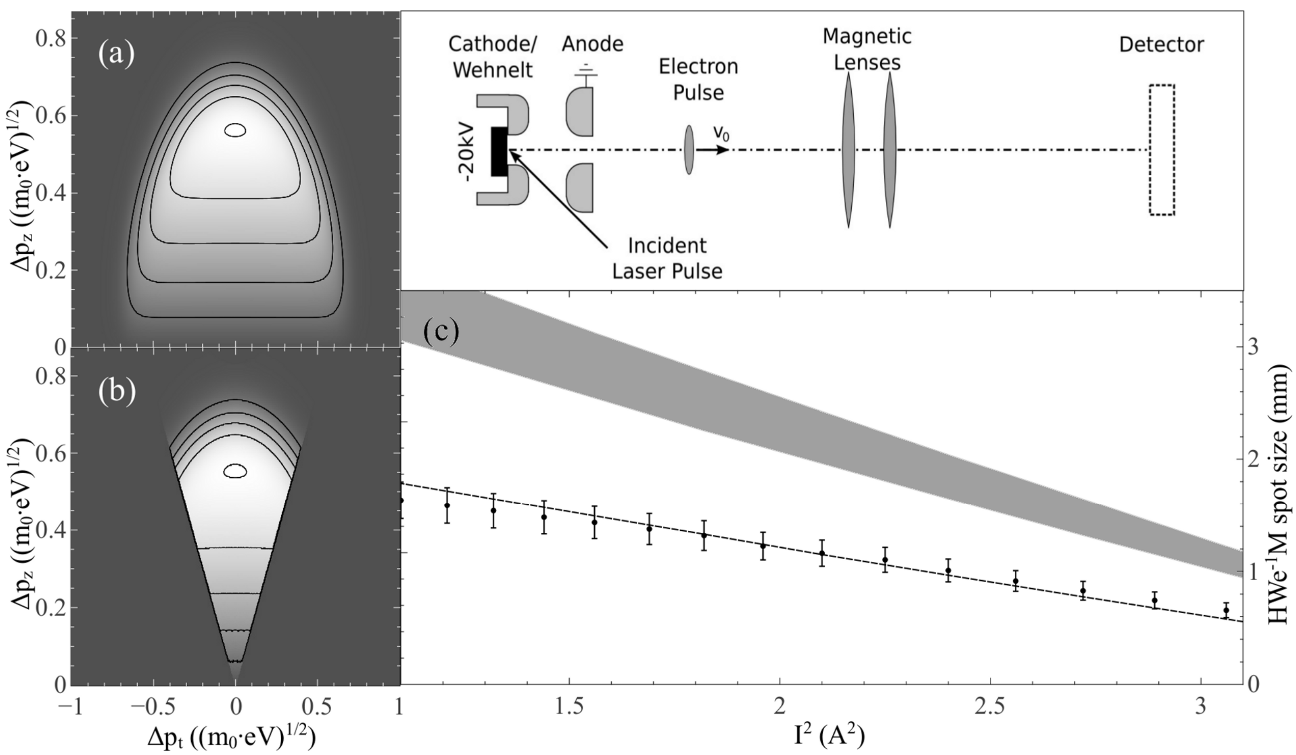

Figure 1. Photoemission from metal photocathodes. Theoretical emission momentum contour plots (longitudinal (p_z) versus transverse (p_T)) for a Mo photocathode ($\phi_{eff.} = 4.50$eV, $\hbar\omega = 4.75$eV, and $T_e = 300$K) for (a) $m_T^* = m_0$ and (b) $m_T^* = 0.3m_0$. (c) Observed electron beam spot size as a function of magnetic lens strength (square of coil current) for a Mo photocathode; AG model simulations for $\Delta p_T \approx 0.15 \sqrt{(m_0.\text{eV})}$ (dashed line) and $\Delta p_T = 0.29(\pm 0.03) \sqrt{(m_0.\text{eV})}$ (the shaded region). A schematic of the experiment is shown top right.