Study of Mean Transverse Energy (MTE) of (N)UNCD

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Introduction

Nitrogen incorporated ultrananocrystalline diamond ((N)UNCD) may be an attractive material for photocathode applications due to its remarkable emission properties. A (N)UNCD thin film with thickness of 160 nm was deposited on highly-doped silicon substrate at the Center for Nanoscale Materials (CNM) at Argonne National Lab. The mean transverse energy (MTE) of (N)UNCD was measured using the double-solenoid scan method at University of Illinois at Chicago (UIC). The studies of the MTE of the (N)UNCD sample was done using a tunable laser source with photon energies of 3.56 eV to 5.26 eV. The calculated MTE results will be presented.

Laser Setup

- 2W Yb:KGW laser system at UIC.
- 250 fs, 30 MHz.
- An elliptical laser beam (1:1.5) from a nonlinear sum-frequency generation crystal.
- Laser profile on the cathode has dimension of 75 µm by 240 µm.
- Two solenoids are connected to a single power supply by sweeping the current from 0 to 2.45 A.

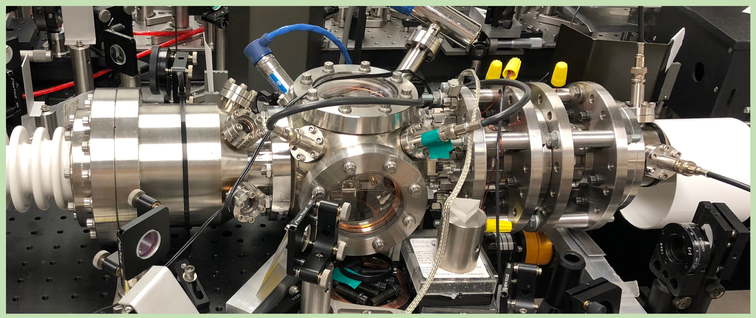


Figure 1: MTE beamline at UIC

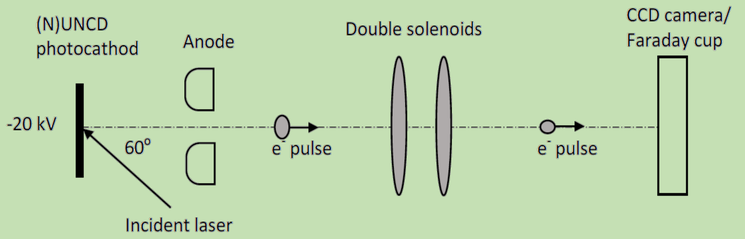
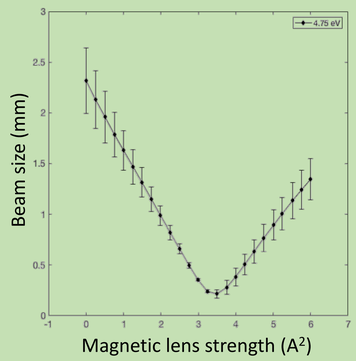


Figure 2: Schematic of the emittance test stand

Beam Spot Analysis



Focusing strength of a single solenoid is proportional to I^2,

Figure 3: Beam size [mm] vs. magnetic lens strength [A^2] at the photon energy of 4.75 eV.

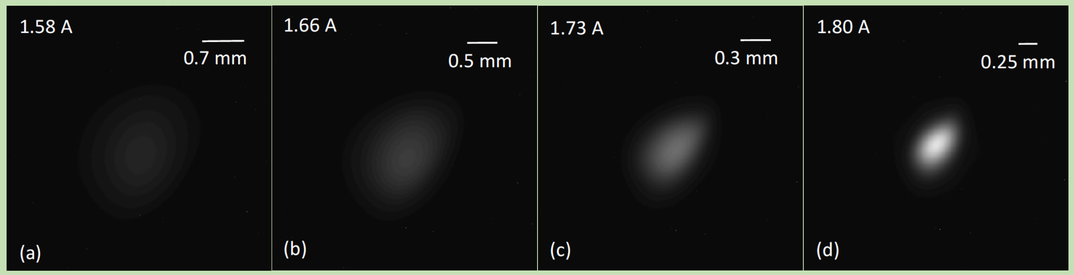


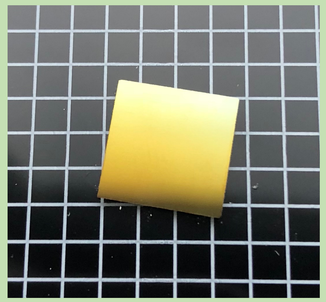
Figure 4: CCD images of the electron beam at 4.75 eV. (a) solenoid current of 1.58 A, (b) 1.66 A, (c) 1.73 A (d) 1.80 A, where at 1.80 A beam spot focuses on the scintillator screen.

A current of 1.83 A was found to have the optical focusing length, such that the focal plane of the solenoid pair coincides exactly with the scintillator screen plane.

The slope in the solenoid scan (Figure 3) is proportional to the MTE: the smaller the slope, the lower the MTE.

(N)UNCD

The (N)UNCD film was deposited on highly doped Si substrate by using a 915 MHz microwave plasma chemical vapor deposition (MPCVD) technique at the Center for Nanoscale Materials (CNM) at Argonne National Lab (ANL).



Thickness ~160 nm

Figure 5: Image of (N)UNCD

MTE Results & Analysis

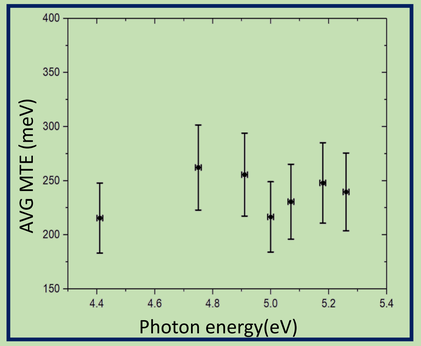


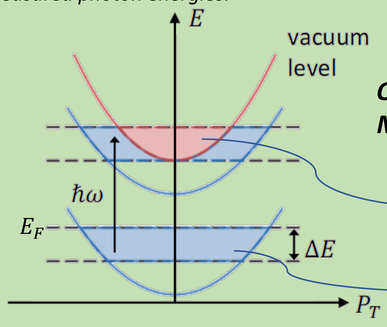
Figure 6: The averaged MTE results of all measured photon energies.

The MTE results display a near flat trend with respect to the photon energy in the range of 4.41-5.26 eV.

In Ref. [1], the paper stated that for metal cathode, the transverse momentum follows,

$$\Delta P_T = \sqrt{\frac{m_0(\hbar\omega - \phi)}{3}}$$

and implies a strong correlation between the transverse momentum and the excess photon energy. *However, this correlation is NOT observed in our results*. Therefore, the one-step model is proposed for the tested (N)UNCD sample, which takes the electronic band structure into account.



ONE-STEP QUANTUM MECHANICAL MODEL

final photo-emitting states

bands with positive excess energy

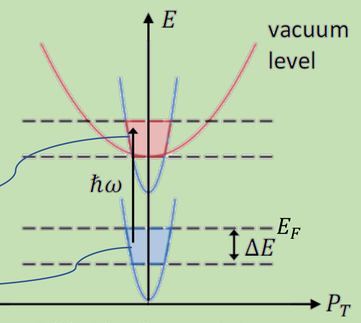


Figure 7 (a): The photo-emitting states are generated from the band states with large effective mass.

Figure 7 (b): The photo-emitting states are generated from the band states with small effective mass.

Conclusion

The MTE of (N)UNCD thin film, which is a promising photocathode material, was measured over a wide range of primary photon energies. The averaged MTE of (N)UNCD is in the range of 210 meV to 260 meV, which is comparable to the GaAs photocathode [2]. The one-step photoemission process is proposed, with emission likely originating from the narrow energy band with low effective mass, therefore resulting an observed near-flat MTE trend.

As a next step, we plan to evaluate the emission properties of the hydrogen terminated (N)UNCD, which has QE of 10^{-3} [3]. The high QE, together with relatively low MTE, and ability to withstand poor vacuum without significant degradation, indicate that (N)UNCD-based photocathode designs are worth pursuing.

References

[1] D.H. Dowell and J.F. Schmerge, "Quantum efficiency and thermal emittance of metal photocathodes ", *Phys. Rev. ST Accel. Beams 12, 074201, 2009.*
[2] S. Karkare *et al.*, "Ultrabright and Ultrafast III–V Semiconductor Photocathodes", *Phys. Rev. Lett. 112, 097601, 2014.*
[3] K.J. Pérez Quintero *et al.*, "High quantum efficiency ultrananocrystalline diamond photocathode for photoinjector applications", *Appl. Phys. Lett. 105, 123103, 2014.*

Acknowledgement

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