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STUDY OF MEAN TRANSVERSE ENERGY OF (N)UNCD WITH TUNABLE LASER SOURCE

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Abstract

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 the Schroeder Lab at the University of Illinois at Chicago (UIC). There 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.

INTRODUCTION

Photocathode-based radiofrequency guns are electron injectors for light sources, such as free electron lasers, as well as for high energy electron colliders [1]. There is a strong motivation to develop and understand novel materials with the potential to be utilized as photocathodes. Challenges are to achieve 1) higher quantum efficiency, 2) rapid response time and 3) small thermal emittance or mean transverse energy (MTE) [2]. (N)UNCD photocathodes have potential to become a material of choice for photocathode applications [3]. (N)UNCD has high quantum efficiency when processed in hydrogen plasma [3], low surface roughness, and high electron conductivity through the bulk [4]. However, the MTE of (N)UNCD was not studied yet. In this paper, we report MTE values measured using double-solenoid scan with a tunable laser source at different photon energies.

MATERIAL SYNTHESIS

The (N)UNCD film was deposited on highly doped silicon substrate by using a 915 MHz microwave plasma chemical vapor deposition (MPCVD) technique at the Center for Nanoscale Materials (CNM) at Argonne National Lab. Deposition parameters were identical to those reported in Ref.[3]. The film thickness was found to be 160 nm.

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EXPERIMENTAL SETUP

The emittance test stand at UIC makes use of the double-solenoid method to measure MTE. The setup can be found in Figure 1. The two solenoids are connected to one power supply to have the same magnitude of current, which varies between 0 A and 2.45 A. The electron beam can be focused to different sizes on the scintillator screen at the end of the setup by varying the solenoid current. MTE values at different photon energies are obtained from the beam spot images taken by the CCD camera.

The MTE test stand at UIC has a custom Yb:KGW laser system [5], which has a pulse length of 0.5 ps and repetition rate of 30 MHz with 3.56 eV to 5.26 eV tunability. Figure 1 shows the test stand. An imaging CCD camera can be swapped with a Faraday cup for charge measurements. Figure 2 shows a simplified schematics of the test stand. An elliptical laser beam (1:1.5 aspect ratio) from a nonlinear sum-frequency generation crystal is obliquely incident on the (N)UNCD photocathode surface at 60°. The vertical dimension of the electron beam has a half width 1/e maximum (HW1/eM) of 75-80 µm, and the horizontal dimension a HW1/eM is 240 µm, where the factor of 3 between the horizontal and vertical dimensions is due to the oblique incidence and elliptical shape of the laser beam.

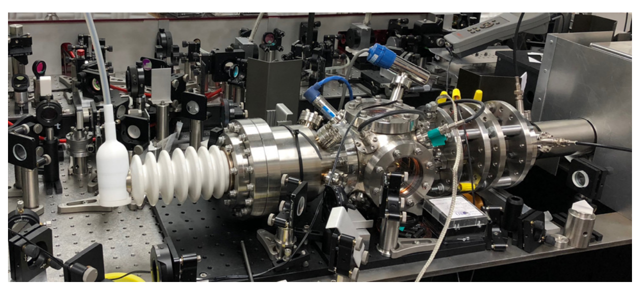

Figure 1: Emittance beamline at UIC. From left to right is DC gun double-solenoid and the scintillator screen with CCD camera connected.

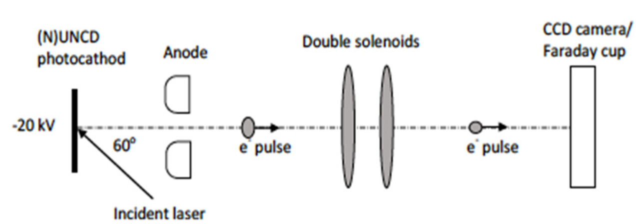

Figure 2: Schematic of the emittance test stand.

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The two solenoids are connected together to a single power supply such that bias current can be varied from 0 A to 2.45 A.

EXPERIMENTAL RESULTS

In order to avoid / minimize the space charge effect on the measurement, we picked a (N)UNCD film of 160 nm which emits quite low charge. Full solenoid scans have been performed at the photon energies of 4.75 eV and 5.26 eV by sweeping the current from 0 to 2.45 A. An example image of the generated electron beam at a solenoid current of 1.80 A is shown in Figure 3. 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. An example of the full scan showing the beam size dependence on the magnetic lens strength (proportional to the square of the solenoid currents) can be found in Figure 4; the photon energy was 4.75 eV for this scan.

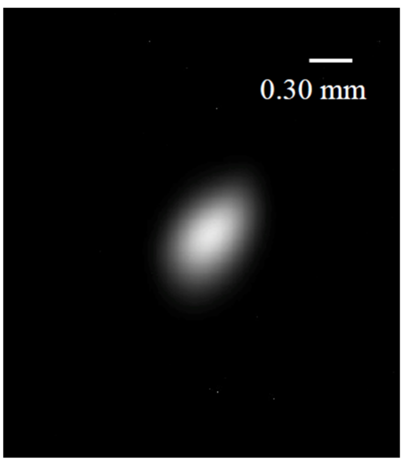

Figure 3: A CCD image of the electron beam at 4.75 eV and solenoid current of 1.80 A.

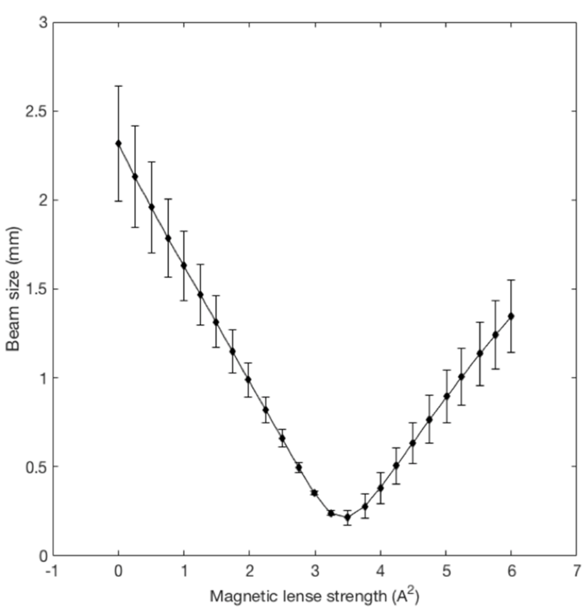

Figure 4: Beam size [mm] vs. magnetic lense strength [A^2] at the photon energy of 4.75 eV.

The slope in the solenoid scan (Figure 4) is proportional to the MTE: the smaller the slope, the lower the MTE. The MTE values at 0.00 A and 1.00 A are calculated for each photon energy. Since the gradient / slope is proportional to the beam size, we used the gradient between 0.00 A and 1.00 A to evaluate MTE values.

The vertical and horizontal HW1/eM dimensions of the recorded electron beam image at different solenoid currents are evaluated as the first step. Then, the horizontal and vertical MTE are calculated using a custom code developed at UIC for this analysis. The results of the average MTE versus photon energy are presented in Table 1(a), 1(b), and Figure 5.

Table 1(a): Horizontal MTEs

	0.00 A		1.00 A		gradient	
Energy (eV)	**HWEM (mm)**	**MTE (meV)**	**HWEM (mm)**	**MTE (meV)**	**Delta**	**MTE (meV)**
4.41	2.64	230.53	2.15	436.50	-0.49	212.17
4.75	2.70	245.12	1.95	356.37	-0.76	410.12
4.91	2.83	275.15	2.09	409.68	-0.75	409.83
5.00	2.60	222.86	1.94	352.98	-0.67	351.35
5.07	2.73	252.09	2.15	437.20	-0.58	287.46
5.18	2.86	280.55	1.98	369.72	-0.87	495.82
5.26	2.68	239.79	1.90	336.73	-0.79	437.13

* In table 1(a): HWEM represents the horizontal half width 1/e maximum; delta is the difference between HWEM of 0.00 A and 1.00 A.

Table 1(b): Vertical MTEs

	0.00 A		1.00 A		gradient	
Energy (eV)	**HWEM (mm)**	**MTE (meV)**	**HWEM (mm)**	**MTE (meV)**	**Delta**	**MTE (meV)**
4.41	1.81	131.51	1.45	194.02	-0.36	207.86
4.75	2.14	186.70	1.64	250.77	-0.50	272.73
4.91	1.95	154.00	1.54	220.90	-0.40	238.54
5.00	1.79	128.47	1.34	163.78	-0.45	268.76
5.07	1.80	106.08	1.39	178.23	-0.41	242.65
5.18	1.73	131.03	1.29	151.05	-0.44	262.52
5.26	1.84	119.96	1.32	160.78	-0.52	309.81

* In table 1(b): HWEM represents the vertical half width 1/e maximum; delta is the difference between HWEM of 0.00 A and 1.00 A.

To finalize the MTE result of a single photon energy, we take average of six calculated MTEs. All of the results of MTE are shown in Figure 5.

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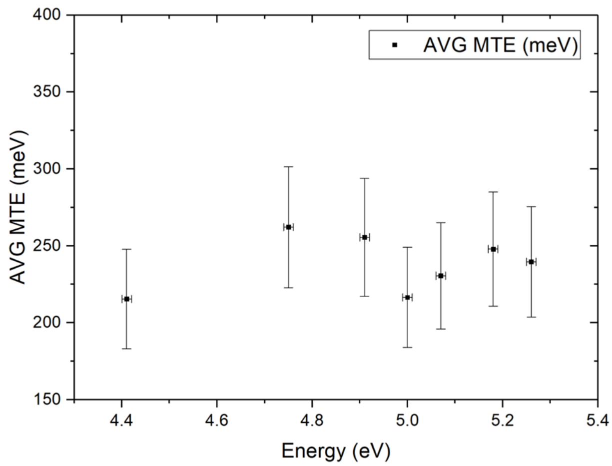

Figure 5: The averaged MTE results in unit of meV of all measured photon energies.

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 MTE had no noticeable dependence on the photon energy. The averaged MTE of (N)UNCD is in the range of 210 meV to 260 meV, which is comparable to the GaAs photocathode [6].

To establish a baseline of the emission properties of UNCD, the (N)UNCD measured at UIC was untreated, and was found experimentally to have a QE of order 10^{-8}, compared to the hydrogen terminated (N)UNCD that has QE of order 10^{-3} [3]. As a next step, we plan to evaluate the emission properties of the hydrogen treated (N)UNCD. 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.

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