ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-MOPO010

JINR PHOTOCATHODE RESEARCH: STATUS AND PLANS

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Abstract

Photocathode research in the frame of the "transmission" photocathode conception (backside illuminated cathode based on a quartz/sapphire plate or a metal mesh which is a substrate for thin film made of a photomaterial) is being conducted in the Veksler and Baldin Laboratory of High Energy physics (LHEP) of the Joint Institute for Nuclear Research (JINR). Status of the 30-kev DC Photogun test bench and recent results of the extremely thin carbon film based cathodes research are described. Progress in the full-scale photoinjector prototype (max electron energy of 400 keV) is given. Startup of the photoinjector was performed, 70 keV electrons were extracted (650 pC).

INTRODUCTION

Initial beam quality is of high importance for contemporary and future electron accelerators. Photoinjector sources provide beams of unexcelled quality.

Two main material types for photocathodes are metals and semiconductors. Latter have high quantum efficiency (>10% for CsTe at UV [1]), but have relatively small operational lifetimes and are sensitive to environment [2]. Metals are robust but have low quantum efficiency [3]. Also, GaAs should be mentioned for its ability to produce polarized electrons [4].

Diamond films are considered as promising photo emission cathodes because of their low threshold field as well as high thermal conductivity, high breakdown field and chemical inertness.

Quantum efficiency of diamond films can be additionally increased (up to 14% [5] or even up to 47% [6]) by hydrogenation and usage of the vacuum ultraviolet laser (140 nm).

A new concept of photocathode design was proposed at JINR [7]: a backside-illuminated "transmission" photocathode — an optically polished quartz/sapphire plate or a metal mesh (copper or stainless steel, 40×40 µm cell size, 30 µm wire diameter). This plate or mesh is a substrate for thin film made of a photomaterial. The metal mesh can also work as a photocathode without any coating. Such cathode geometry permits an increase in quantum efficiency due to the vectorial photoeffect. Furthermore, intrinsic emittance reduction is expected for the transmission mode operation [8].

EQUIPMENT

Photocathode research at JINR is being conducted at two benches: Photogun and Photoinjector.

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Photogun Bench

Photogun bench is the main research instrument so far. It consists of the DC photogun (max anode voltage 30 kV), industrial single-pulse driver laser by LOTIS TII, focusing magnet with correction windings and various diagnostics (Faraday cup, laser energy meter, CCD camera for beam imaging). Main laser model is LS-2134 (wavelength 266 nm, pulse length 15 ns, pulse energy 15 mJ). This year second beamline was assembled (Fig. 1). It is based at LS-2132UTF laser (wavelength 266 nm, pulse length 8 ns, pulse energy 45 mJ) with a fifth harmonic external assembly which allows 213-nm laser beam generation.

Figure 1: 213-nm photogun bench setup.

Photoinjector Bench

Photoinjector bench is the photogun bench development. It features the full scale accelerating structure (triode type gun with forced resistive potential distribution which can provide electron beam with an energy of up to 400 keV) and the unique laser driver by IAP RAS (Table 1).

Table 1: Photoinjector Laser Driver Parameters

Parameter	Value
Wavelength	262 nm
Bunch train repetition rate	10 Hz
Bunch train duration	800 µs
Bunches in the train	8000
Bunch duration	10 ps
Bunch energy	1.5 µJ

First electron beam at the bench was obtained in April 2017. Bunch trains with 650 pC total charge were registered, what corresponds to current of 8 mA in the bunch, 0.8 µA in the bunch train and 6.5 nA average current(10 Hz repetition rate). Copper mesh photocathode (40×40 µm cell size,

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30 µm wire diameter) was used. Electron bunch charge was measured by the Faraday cup grounded through 1 nF measuring capacitor. Faraday cup self-capacitance was negligibly small and was ignored in calculations. Capacitor voltage was registered by the oscilloscope, whereupon charge calculation was made according to a formula $Q = C \cdot U$, where C is the measurement capacitor capacitance and U is voltage on it. Bench setup during the startup is shown at the Fig. 2.

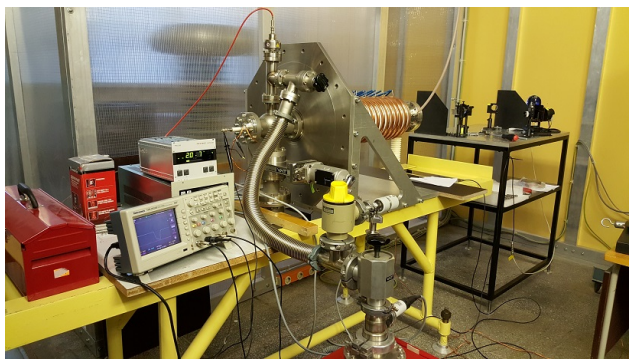

Figure 2: Photoinjector bench setup during the startup.

EXTREMELY THIN CARBON FILM BASED CATHODES

Of particlular interest is a study of the cathodes based on extremely thin films. Characterization of the photocathodes based on N-doped carbon-based films is given below.

Cathodes Preparation

Films were deposited on double side polished quartz glass by radio-frequency (RF) reactive magnetron sputtering using a carbon target and gas mixtures Ar, N_2 and H_2 or D_2. The magnetron carbon target was a high-purity graphite disk three inches in diameter. Prior to deposition, the quartz glass was cleaned in the ultrasonic bath containing acetone for 30 minutes and then rinsed in deionized water and dried in nitrogen ambient. Carbon films were deposited at the working pressure of 0.7 Pa and the magnetron input RF power of 150 W at 13.56 MHz. For all samples argon and nitrogen flows were 25 sccm and 6 sccm, respectively. Flows of hydrogen were: 1 sccm for sample QT2, 3 sccm for QT3 and 6 sccm for QT4. Flow of deuterium for sample QT5 was 3 sccm. Substrate holder temperature during magnetron sputtering was 900 °C. Carbon film thicknesses on quartz glasses were in the range 18–25 nm. Concentration of elements in the films was determined by RBS (Rutherford backscattering spectrometry) and ERD (elastic recoil detection) methods simultaneously. Scanning Electron Microscopy (SEM) was used to investigate the structural morphology of carbon thin films. Raman spectroscopy using a Thermo Fisher Scientific DXR Raman microscope with 532 nm laser was used for determination of the I(D)/I(G) intensity ratios of D and G peaks of carbon films. The G and D peaks were fitted with Gaussians and the intensity was calculated as the peak's area. Electron beam evaporation was used for Ti contact frame preparation on carbon/quartz structures.

Films Properties

Concentration of elements in the carbon fims was calculated from RBS and ERD experimental spectra using program SIMNRA. Concentration data are given in Table 2.

Table 2: Films Elemental Composition [in. at. %]

Sample	C	N	H	D	O
QT1	83	13	2	0	2
QT2	83	12	4	0	1
QT3	82	12	5	0	1
QT4	82	12	5	0	1
QT5	83	12	2	2	1

Results show that concentrations of hydrogen or deuterium in the carbon films are very small due to high substrate temperature i.e. hydrogen or deuterium escapes from growing carbon films at 900 °C. Hydrogen or deuterium and oxygen can be incorporated to the films after magnetron sputtering from the vacuum chamber atmosphere during decreasing of substrate temperature and can be absorbed from air atmosphere after deposition.

Figure 3 shows SEM images of QT1, QT3 and QT5 sample surfaces. Fully amorphous structure was observed for sample QT1 while samples QT2 and QT3 show amorphous structure with nanoscale thickness flakes of random arrangement. Surface images of QT3 and QT5 samples showed no significant difference between its surface morphology, i.e. adding of hydrogen or deuterium to the gas mixture has practically the same influence on carbon very thin films growth conditions.

Figure 4a shows Raman spectra of samples QT1–QT5. Peak intensities that occur at 1350 cm^{-1}, 1580 cm^{-1}, and 2700 cm^{-1} are called the D band, G band, and G' or 2D band, respectively. The G band is a primary an in-plane vibrational mode, and the 2D band is a second-order overtone of a different in-plane vibration. The D band around 1350 cm^{-1} is a breathing mode of A_1g symmetry involving phonons near the K zone boundary, which is activated due to defects and disorder of sp^2 carbon, and the D+G band (2940 cm^{-1}) is a combination scattering peak [9].

Results showed a change in the shape of broad asymmetric Raman scattering bands in the range from 900 to 1800 cm^{-1} due to change of deposition conditions.

Raman bands shape for sample QT1 is owned for GNDC (graphite-like nanocrystalline diamond) and activated carbon. Adding hydrogen or deuterium, Raman bands shapes were changed and can be compared with Raman spectra of mixture of GNCD [10] and small amount of graphene-like carbon. The asymmetric Raman peaks can be fitted with two peaks: the G-peak around 1580 cm^{-1} and the D-peak around 1350 cm^{-1}. In our case, for better deconvolution, we used tree peaks fitting. 1270 cm^{-1} can be assigned to ta-C. Figure 4b shows tree peaks fitting of Raman band from

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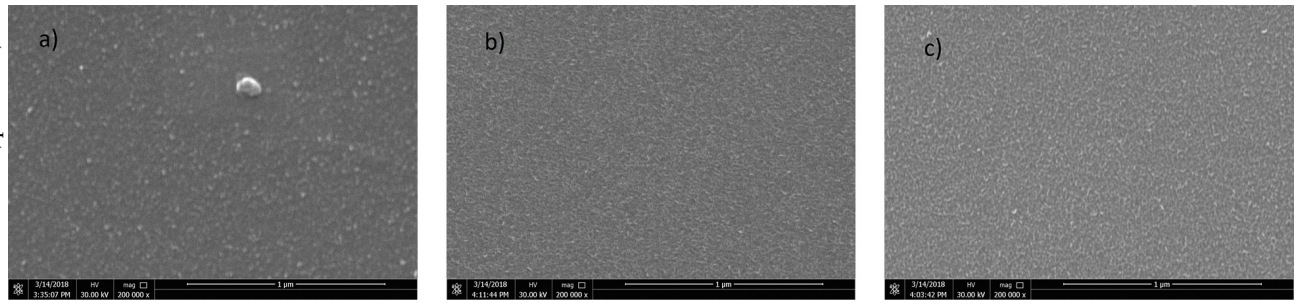

Figure 3: SEM images pf QT1 (a), QT3 (b) and QT5 (c) sample surfaces.

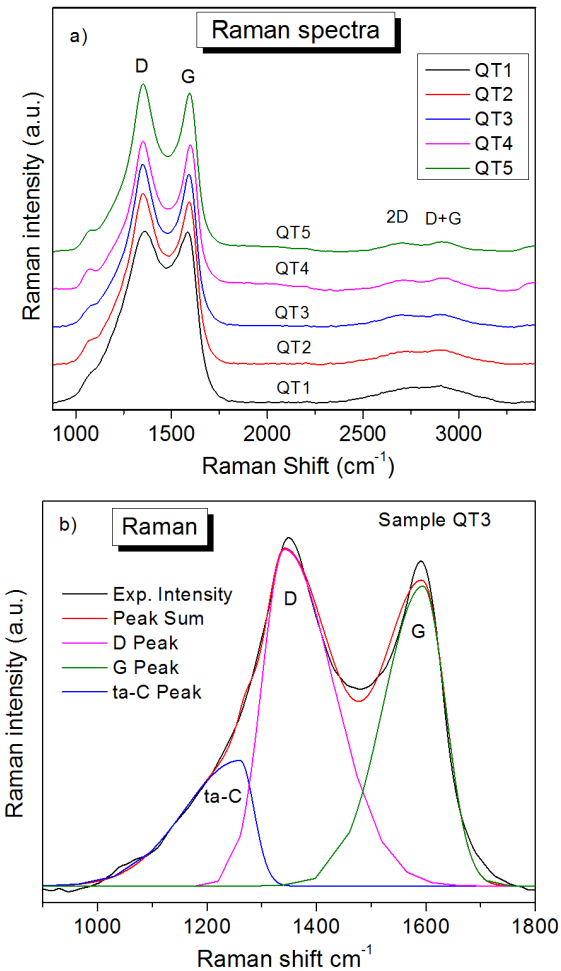

Figure 4: Raman spectra for samples QT1–QT5 in the range from 900 to 3400 cm^{-1} (a) and deconvoluted Raman spectrum in the range from 900 to 1800 cm^{-1} for QT3 (b).

900 to 1800 cm^{-1} for sample QT3. Calculated I(D)/I(G) of all samples are given in Table 3. The decreasing value of I(D)/I(G) ratio in the case of samples QT2–QT5 can be used to estimate the transition of disordered to ordered structure.

Emission Properties

Measured bunch charges, calculated quantum efficiencies (QE) and I(D)/I(G) ratios are given in Table 3.

Table 3: Cathodes Emission Properties and I(D)/I(G) Ratio

Sample	Q, pC	QE (% ×10^{-4}	I(D)/I(G)
QT1	930	4.9	1.14
QT2	1140	6.1	1.39
QT3	1590	8.4	1.29
QT4	840	4.5	1.34
QT5	1470	7.8	1.17

CONCLUSION

Photocathode research infrastracture in JINR is being developed: new beamline with 213-nm laser driver was added to the Photogun bench, startup of the Photoijnector bench was performed, 70 keV electrons were extracted (650 pC). Study of the transmissive photocathodes based on extremely N-doped carbon-based films was conducted. Maximum bunch charge and QE were 1.59 nC and 8,4×10^{-4} respectively.

REFERENCES

[1] R. Xiang and J. Teichert, *Physics Procedia*, vol. 77, pp. 58–65, 2015

[2] R. A. Loch, "Cesium-Telluride and Magnesium for high quality photocathodes," *Master thesis*, 2005

[3] A. Lorusso *et al.*, *Phys. Rev. AB* vol. 14.9, 2011

[4] D. H. Dowell *et al.*, *Nucl. Instrum. Methods Phys. Res. A*, vol. 622, pp. 685–697, 2010

[5] Sh. Michaelson *et al.*, *Diam. Relat. Mater.*, vol. 14, pp. 546–551, 2005

[6] L. Velardi, A. Valentini, and G. Cicala, *Diam. Relat. Mater.*, vol. 76, pp. 1–8, 2017

[7] N. I. Balalykin *et al.*, *Physics–Uspekhi*, vol. 60 (10), pp. 1051–1058, 2017

[8] H. Lee, L. Cultrera, and I. Bazarov. in *Proc. IPAC2016*, doi:10.18429/JACoW-IPAC2016-THPOW023

[9] P-T. Tseng, P-H. Tsai, A. Lu, J-L. Hou, and H-Y. Tsai, *Diam. Relat. Mater.*, vol. 73, pp. 121–131, 2017.

[10] M. A. Nitti *et al.*, *Nucl. Instrum. Methods Phys. Res. A*, vol. 595, pp. 131-13, 2008.