HOLLOW PHOTOCATHODE PROTOTYPE FOR E-GUN

M. A. Nozdrin#, N. I. Balalykin, A. A. Feshchenko, V. Ph. Minashkin, G. D. Shirkov,
G. V. Trubnikov, JINR, Dubna, Russia
S. Gazi, J. Huran, IEE SAS, Bratislava, Slovakia

Abstract

Photocathodes are important devices for contemporary electron accelerators. Significant photocathode parameters are: fast response time, quantum efficiency, long lifetime, low emittance and minimal effect on RF properties of the accelerating system. In this paper development of the hollow photocathode conception is presented and prototype is described. Such cathode geometry allows quantum efficiency rising due to surface photoelectric effect which is concerned with normal to material surface wave electric field multiplier. Experimental results of hollow photocathode using efficiency are given (266 nm wavelength, 15 ns pulse time with 1 Hz repetition rate). Backside irradiation radically simplifies laser beam targeting on emitting surface, accelerator equipment adjustment and allows photocathode working surface laser cleaning.

INTRODUCTION

Today considerable results in photocathodes development and production are achieved. Despite this, it is still possible to improve photocathode characteristics by optimizing of laser beam usage.

Photo- and Thermoemission

Appearing of the thermoemission at the photocathode increases response time and emittance of generated electron beam. In this connection let’s remind a pair of signs which indicate thermoemission appearing.

- On the photoelectric effect electron output is inertialless, there is no lag between laser and electron pulses. Upon one-photon process electron pulse length is equal to laser one as well. As shown in [1], lag is absent at intensities less than 4 MW/cm^2. At greater intensities lag appears and photocurrent pulse elongates, what means thermoemission appearing. For impulses shorter than 10^{-11} s thermoemission can be observed up to intensities of 10÷100 GW/cm^2 [1, 2]. In the picosecond range thermoemission nature changes: electron subsystem becomes isolated of the lattice and warms up nearly inertialless due to small thermal capacity. Such inertialless thermoemission almost can not be observed without photoemission but can cause emittance increasing.
- The surface photoelectric effect is a typical vectorial phemomenon. Current is defined by normal to surface component of wave electric field and dramatically depends on laser beam angle of incidence and polarization. As regards the thermoemission, its current completely depends on metal surface temperature (which depends on accepted power).

#nozdrin@sunse.jinr.ru

HOLLOW PHOTOCATHODE

Photocathode Stand Setup

Cathode investigations were done at a stand [3] with a vacuum of 2 × 10^{-9} torr, gun anode voltage of 6 kV and monopulse YAG:Nd^{3+} (Neodymium doped Yttrium-Aluminium Garnet) laser. Generated UV-radiation had a wavelength of 266 nm, pulse length of 15 ns, beam diameter of 6 mm and maximum pulse energy of 15 mJ.

Figure 1: Photocathode stand overview.

Hollow Photocathode Concept

Hollow photocathode is a 4-6 mm width washer with a cone or cylinder aperture in the middle (Figure 2). Such cathode geometry allows quantum efficiency rising due to surface photoelectric effect, which is concerned to normal to material surface wave electric field component.

The working surface of such photocathode is cone (with obliquity of 1:50) or cylinder generatrix. Outcome diameter was approximately 2 mm.

Niobium was chosen as a material for the test photocathode due to its machining simplicity. Also this material is of interest to use in SRF photoinjectors.

Test cathode was made mechanically of niobium with purity of 99.97. Working surface was grinded but not polished or chemically etched. Before investigations all cathodes were laser cleaned by a Ø3 mm focused laser beam with 5-6 MW/cm^2 intensity.

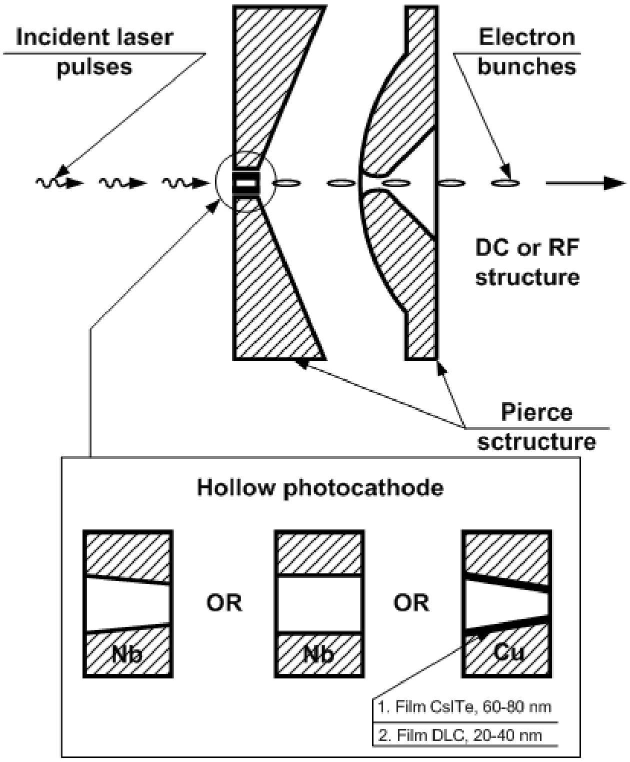

Figure 2: Scheme of the hollow photocathode operation.

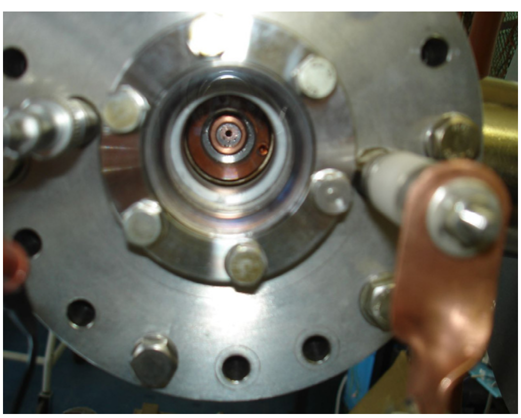

Figure 3: e-Gun with hollow photocathode.

EXPERIMENTAL RESULTS

Common Photocathode Investigations

Preliminary emission characteristics of common solid photocathode (Ø10 mm niobium disk with thickness of 1 mm) were done. Cathode was irradiated by unfocused and focused to Ø3 mm laser beam with normal angle of incidence. Cathode surface was laser cleaned.

Radiant flux density was changed from 0.8 to 4.1 MW/cm^2 for unfocused and from 3.2 to 16.4 MW/cm^2 for focused to Ø3 mm laser beam. For unfocused beam thermoemission was absent up to maximum obtainable intensity. For focused beam thermoemission appeared from intensity of 4.8 MW/cm^2 – photocurrent pulse duration increases (Figure 4).

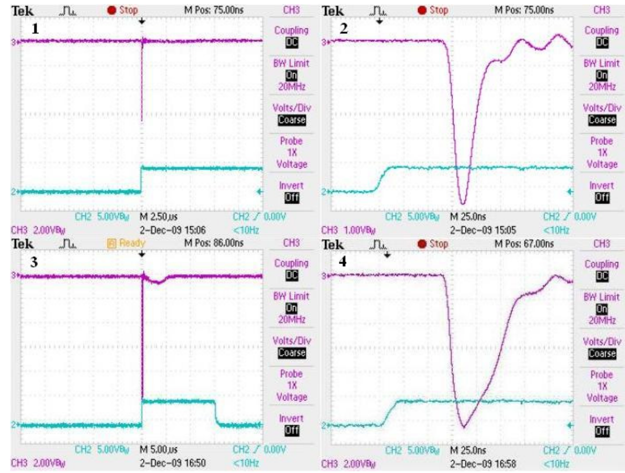

Figure 4: Nb solid photocathode current oscillograms: 1, 2 – 4.2 MW/cm^2 intensity, unfocused laser beam (for different timescales); 3, 4 – 4.8 MW/cm^2, focused laser beam (for different time scales).

Quantum Efficiency Measurements

Quantum efficiency (QE) was defined as a ratio of emitted electrons and laser injected photons. Current density on the cathode was 70 A/cm^2. The charge of 90 nC was extracted (current of 6 A).

For the demonstration purpose hollow photocathodes with thin film working surface were tested. CsTe and DLC (diamond-like carbon) cathodes were produced by plasmachemical precipitation in vacuum. Investigation results are shown in Table 1.

Table 1: QE measurements summary

Cathode type	QE, %
Solid Nb	2×10^{-4}
Hollow Nb	6×10^{-3}
Hollow CsTe (80 nm film)	7×10^{-3}
Hollow DLC (40 nm film)	1×10^{-3}

NEW STAND SETUP

The new picosecond laser was installed in December 2010. Laser parameters are presented in Tables 2 and 3. Preliminary investigations have shown electron beam current of 15-20 A.

Table 2: New laser parameters

Pulse length, ps	70-80
Freqency, Hz	15
Beam diameter, mm	9

Table 3: Energy vs Wavelength for new laser

Wavelength, nm	Energy, mJ
1064	75
532	35
266	5
213	3

CONCLUSION AND OUTLOOK

Investigations have shown that quantum efficiency of hollow photocathodes is at lest ten times more then QE of solid ones. Backside irradiation also radically simplifies laser beam targeting on emitting surface, accelerator equipment alignment and photocathode working surface laser cleaning.

Further Investigation Plans

In future it is planned to investigate the following topics:

- Hollow photocathodes with polished working surface.
- Operation life of the thin-film hollow photocathodes. Lifetime increasing is expected because of cathode accepted power decreasing (due to sliding beam incidence and back ion bombardment effect decreasing).
- Thermoemission minimization by cathode accepted power decreasing (by close to 90º angle of incidence using).

REFERENCES

[1] Ilan Ben-Zvi et al. Superconducting photoinjector. Proceedings of FEL 2007, Novosibirsk, Russia.
[2] T. Rao et al. Photoemission studies on BNL/AES/JLAB all niobium, superconducting RF injector. Proceedings of 2005 Particle Accelerator Conference, Knoxville, Tennessee.
[3] N. I. Balalykin, V. Ph. Minashkin, M. A. Nozdrin, G. D. Shirkov, V. G. Shabratov. The stand for research of charachteristics of photo- and thermoemission cathodes. Proceedings of International Workshop on Charged Particle Accelerators, NSC KIPT, Alushta, Ukraine.