HOLLOW PHOTOCATHODE CONCEPT FOR E-GUN

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Abstract

Photocathodes are the key devices for high-quality electron bunches generation. Such bunches are needed as initial electron source in contemporary linear accelerators. In all cases there are several important parameters: fast response time, quantum efficiency, long lifetime, low thermal emittance, minimal effect on RF properties of the accelerating system. In this paper the new concept of the photocathode is proposed – hollow (absolutely transparent for the laser beam) photocathode. Such cathode geometry allows quantum efficiency rising due to surface photoelectric effect which is concerned with normal to material surface wave electric field multiplier. Usability investigation experimental results for both hollow photocathodes made of bulk materials (Nb, Cu) and by thin-film technology (CsITe and diamond-like carbon as film on copper substrate) are given. After Nb hollow photocathode irradiation by a laser beam (λ = 266 nm, τ_{pulse} = 15 ns, frequency 1 Hz) a charge of 64nC was extracted. Backside irradiation radically simplifies laser beam targeting on emitting surface, accelerator equipment adjustment and allows photocathode working surface laser cleaning.

INTRODUCTION

Despite that fact that today considerable results in effective photocathodes (RF, SRF, DC) development and creation are achieved, the work on this line is underway [1, 2, 3].

Progress in basic photocathode parameters is possible by optimal usage of photoemission initializing laser beam potential.

Response time and emittance of electron beam increase upon thermoemission current appearing and rising, so there are several signatures that distinguish photoemission from thermoemission.

- Since upon photoelectric effect electron output is inertialless so current pulse lateness relative to laser pulse is absent. At that, for one-photon process, current pulse length is equal to laser pulse length. Lateness is absent at intensities less than 4 MW/cm^2 [4]. At intensities above 4 MW/cm^2 lateness is observed and photocurrent pulse broadening occurs, what is evidence of thermoemission process appearing. For impulses shorter than 10^{-11} s coverage of the photoelectric effect against a background of thermoemission can be expanded to intensities of 10÷100 GW/cm^2 [4, 5]. In the picosecond range of pulse duration thermoemission nature changes severely. With such durations electron subsystem is isolated out of the lattice and in view of small thermal capacity warms up nearly inertialless. So, for thermoemission under the picosecond pulses influence, current lateness against laser pulse is absent. Such thermoemission almost can not be observed separately from photoemission but can cause emittance increasing.
- As is well known, surface photoelectric effect is a typical vector phenomenon. Current magnitude is concerned with normal to surface wave electric field multiplier and dramatically depends on laser beam hade and polarizing angle. From the other side, thermoemission current completely depends on metal surface temperature which depends on accepted power.

It is interesting to investigate the following questions:

- Thermoemission minimization degree by cathode accepted power decreasing (by close to 90° laser beam to work surface hade using).
- Quantum efficiency increasing due to normal to cathode work surface electric field multiplier.

HOLLOW HOTOCATHODE AND EXPERIMENTAL RESULTS

Investigations were done by a stand [6] (Fig. 1) with a chamber vacuum of $2 \cdot 10^{-9}$ torr and gun anode voltage of 6 kV.

Monopulse YAG:Nd3+ (yttrium-aluminium garnet alloyed with neodymium) laser was used for cathode irradiation. Wavelength of generated UV-radiation was 266 nm, beam Ø6 mm, pulse energy less than 15 mJ.

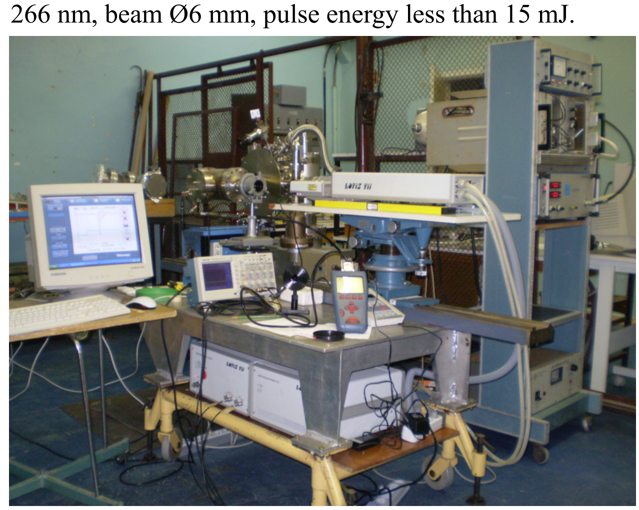

Figure 1: Photocathode stand overview

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In this article the new concept is proposed: hollow photocathode – transparent for the laser beam cathode made like a washer with the width of 4-6 mm with a cone or cylinder aperture in the middle (Fig. 2). Work surface of the photocathode is the cone (or cylinder) generatrix. In the case of a cone obliquity is 1:50. Outcome diameter is ~2 mm.

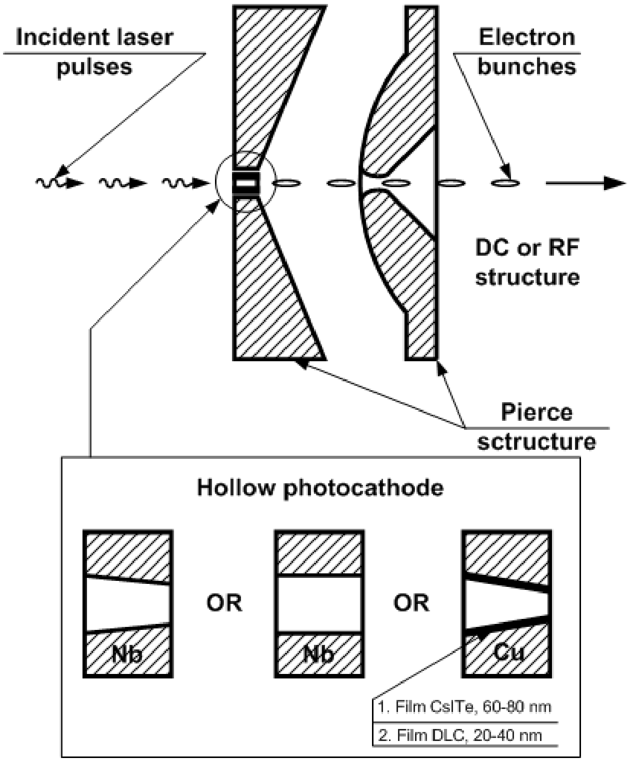

Figure 2: Scheme of the hollow photocathode operation.

Backside irradiation radically simplifies laser beam targeting on emitting surface, accelerator equipment adjustment and allows photocathode work surface laser cleaning.

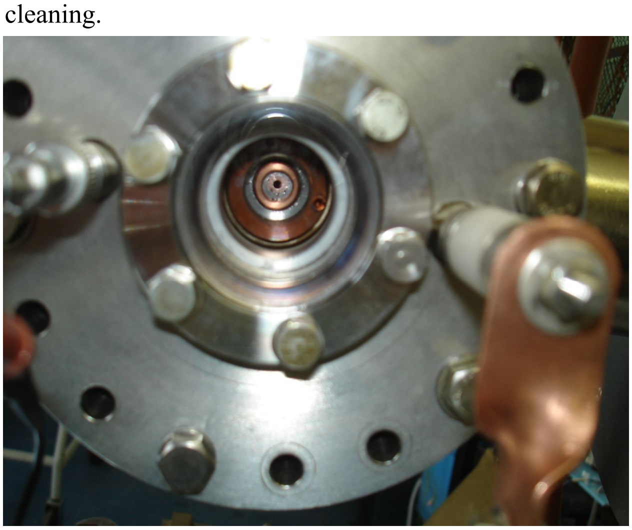

Figure 3: E-gun with hollow photocathode (back view).

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

Preliminary emission characteristics of common photocathode (Nb, Ø10 mm disk 1 mm thick, normal hade) investigations were done. Radiant flux density (intensity) was changed from 0.8 MW/cm^2 to 4.1 MW/cm^2 for unfocused beam and from 3.2 MW/cm^2 to 16.4 MW/cm^2 for focused beam, cathode surface was laser cleaned.

During unfocused beam irradiation up to obtainable intensity no thermoemission was observed.

As shown in Fig. 4, thermoemission is almost absent by intensity under 4.2 MW/cm^2. From intensity about 4,8 MW/cm^2 thermoemission appears – photocurrent pulse duration increases.

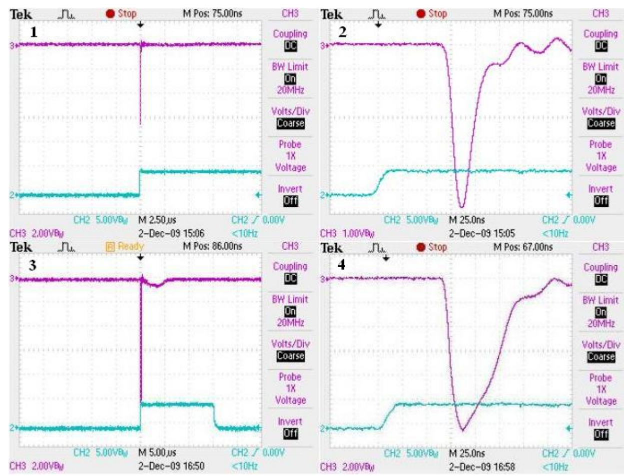

Figure 4. Nb solid photocathode photocurrent oscillograms: 1, 2 – 4.2 MW/cm^2 intensity, unfocused (for different time scales); 3, 4 – 4.8 MW/cm^2 intensity, focused (for different time scales).

Quantum efficiency was defined as a ratio of numbers of emitted electrons and injected laser photons. QE of common photocathode without thermoemission was not exceeded $2 \cdot 10^{-6}$ ($2 \cdot 10^{-4}$ %).

As shown in Fig. 5, QE of hollow Nb photocathode is not less than $6 \cdot 10^{-5}$ ($6 \cdot 10^{-3}$ %).

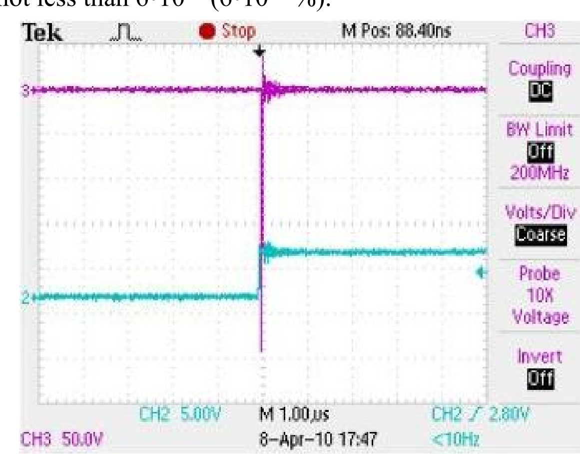

Figure 5. Quantum efficiency of hollow Nb photocathode

Current density on the cathode was ≈ 70 A/cm^2. Extracted charge was Q ≈ 90 nC (I ≈ 6 A).

For the demonstration purpose hollow photocathodes with film work surface on copper substrate were produced (by plasmachemical precipitation in vacuum): CsITe (film thickness 80 nm) and DLC (film thickness 40 nm). After laser cleaning was measured QE of $7 \cdot 10^{-5}$ ($7 \cdot 10^{-3}$%) for CsITe and $1 \cdot 10^{-5}$ ($1 \cdot 10^{-3}$%) for DLC.

CONCLUSION AND OUTLOOK

Investigations have shown that hollow photocathode usage radically simplifies laser beam targeting on emitting surface, accelerator equipment adjustment and allows photocathode working surface laser cleaning.

Quantum efficiency of investigated hollow photocathodes is at least ten times more then QE of solid ones. So it seems to be interesting to continue experiments with hollow photocathodes.

In future it is planned to investigate:

- Hollow photocathodes with polished work surface;
- Operation life of the thin-film photocathodes. We can expect cathode lifetime increasing both because of cathode accepted power decreasing due to sliding beam incidence and because of back ion bombardment effect decreasing.

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