NEW TYPE PHOTOCATHODE FOR X-RAY STREAK CAMERA OF THE 10-FS RESOLUTION

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Abstract

High current streak camera with new principle of operation allowing to get resolution of the order of 10 fs in the frequency range both of visible light and x-ray is described. One of the key units of the camera is photocathode of spherical configuration with its surface radius of 10…100 micrometers. For creating the photocathode new technologies, developed and realized, are described. The results of the photocathode fabrication and investigations of its main features are presented and discussed.

INTRODUCTION

Longitudinal profile monitoring of short electron bunches or x-ray pulses with temporal resolution of the order of 10 fs and less is playing an increasingly critical role at present that is dealt with creation, first of all, of the x-ray FEL, based on the SASE FEL concept [1, 2].

All well-known methods for short electron bunch length and shape monitoring with resolution in femtosecond range may be divided onto two groups. One of them bases on measurement of bunch radiation spectrum in frequency range of coherent radiation with further retrieving of the bunch shape assuming that the spectrum, emitted by a single electron in specific terms of device, is known exactly, - that is not so [3] and that can be extend to any type coherent bunch radiation. The coherent technique can be considered more as a technique for indication of changes in the bunch length or shape.

The second and more reliable method is the method based on registration of the bunch radiation intensity in the frequency range of incoherent radiation by means of technique like a streak camera.

A conventional streak camera is a reliable tool for recording the bunch radiation, but its resolution in the range of visible light does not exceed 300…200 fs [4], and in the range of soft x-ray the streak camera is the only tool, but its resolution here is near 1 ps [5].

Hence, at present we need the measuring technique exceeding the reached temporal resolution by a factor of 10^2 at least for the mentioned x-ray pulse measurement.

In the paper x-ray streak camera realizing new principles of operation [6, 7] is considered.

The results of investigating a space-charge and photocathode surface roughness effects on the new type camera resolution have been carried out early and published in papers [8, 9].

The key unit of the camera is a principal new photocathode of spherical configuration, technology fabrication of which is presented in the paper.

NEW PRINCIPLES IN STREAK CAMERA OPERATION

New principles consist in the following: transformation of the time of photoelectron escapement from photocathode into its energy is carried out at the moment of the escapement and for the shortest time.

By combining the electrostatic accelerating field and rf-field, modulating electron on its longitudinal momentum, and taking the radius of the photocathode surface rather small (100…20 μm) one can enhance and localize the field near the surface of emitter so that the time of effective interaction between photoelectron and these fields will be about 1 ps. In the case many effects cannot develop, and the resolution can reach 10 fs and much less.

CAMERATRON - NEW GENERATION PHOTOELECTRON CAMERA WITH THE LIMITING TEMPORAL RESOLUTION

By reserving the name “streak camera” for a conventional photoelectron camera with transverse swiping photoelectron beam it could be reasonable to call the new camera, emphasizing its principal distinctions, shortly as “cameratron” where time transformation is occurred at a photocathode surface by using a longitudinal modulation and the photocathode surface with a small radius of its curvature.

In Figure 1 a possible scheme of cameratron is shown, where the photoelectrons, modulated in energy in the gap, are analysed with a spectrometer. The rf-gap is a capacity gap of a quarter wave coaxial resonator with its internal conductor ending by needle with a tip in the form sphere, covered by a photocathode material.

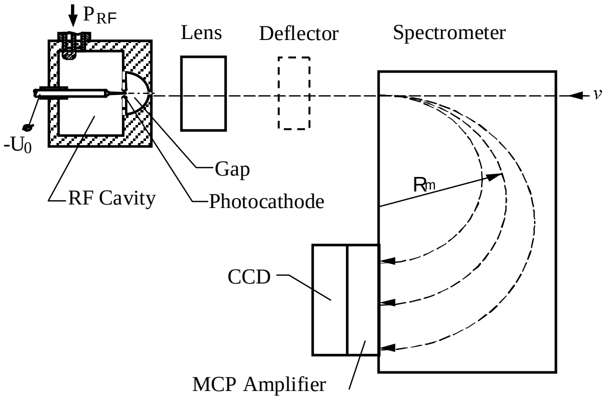

Figure 1: Scheme of cameratron with longitudinal modulation of photoelectrons in spherical gap.

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For recording the longitudinal bunch charge distribution within the bunch train and without them superimposing the deflector, in the scheme, is installed, that deflects the bunch distribution from bunch to bunch during the train in the direction perpendicular to plane of the picture.

As to chromatic aberration of the lens and deflector, shown in the camera scheme, it should be noted that the resolved line of the camera (corresponding to its temporal resolution nearly 10 fs) equaled to about 0.01% in particle momentum and total relative spread in the photoelectron bunch after the modulating gap is less than 1%, so that the aberration will be negligible.

Rf-power for the camera resonator can be supplied from appropriate rf-system of an accelerator, so that, in the case, there is no, in fact, a time jitter, and electronic part will be more simple in comparison with corresponding part of a conventional streak camera.

In Figure 2 the scheme of the spherical gap more in detail is presented, where the diaphragm radius and its thickness are r_d = 1 mm and h_d = 1…2 mm, the external and internal conductors of resonator - r_{in} = 1.6 mm and r_{ex} = 19 mm at the frequency 3 GHz, r_a= 1 mm, l_n= 5 mm.

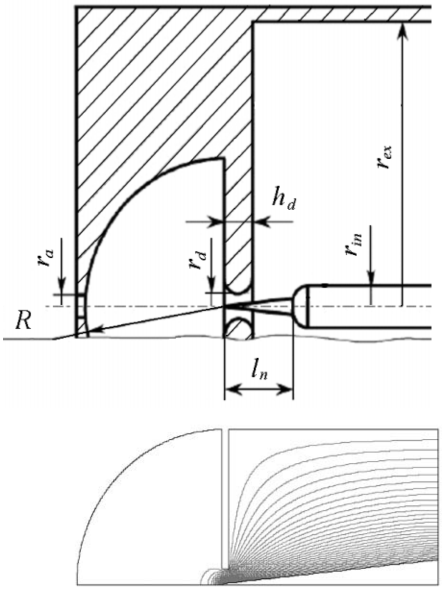

Figure 2: Layout of quarter wave coaxial resonator with its capacity gap forming itself the modulating gap of the camera, below which equipotentials in the gap with the outside line relative level of 0.025 are shown.

The photocathode radius was taken R_0 = (50±5) μm; the electrostatic voltage on the gap - U_0 = -4 kV. The amplitude of the modulating field at the 3 GHz frequency is U = 10kV.

Space charge effect in the camera has been investigated in detail with self-consistent bunch dynamics simulation by representing the bunch as an assembly of charge rings in the paper [8]. More in detail of cameratron, its characteristics one can find also in paper [7].

PHOTOCATHODE

The photocathode surface roughness is main parameter that strong impacts on the camera resolution. This effect is rather importent also for bunch emittance formation in photogun. The first time and in detail, with high accuracy the effect has been investigated in paper [9].

Requirements

By means of statistical tests the temporal resolution of the camera, taking into account an angular distribution as a cosine-cube type and initial energy distribution for the gold photocathode, illuminated by x-ray, taken from the paper [10], has been determined for the photocathode surface roughness with its rms slope of 0.3 and 0.1, (definition of which is presented in the paper [9]). The resolution of the camera gap have been defined as ratio of a twice standard of electron distribution in the r-component of the electron momentum at the exit of the camera gap to the derivative of outlet momentum of the electron with respect to its time of start.

In Figure 3 the dependences of temporal resolution for the x-ray camera on the rms height surface roughness are presented.

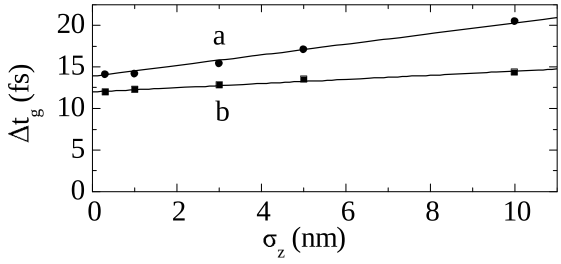

Figure 3: Dependences of x-ray camera resolution on rms height of the gold photocathode surface roughness for two rms slopes of it: $\sigma_{tg\alpha}$ = 0.3 (**a**), $\sigma_{tg\alpha}$ = 0.1 (**b**).

Hence, for getting temporal resolution not worse 20 fs, the rms height of roughness must not exceed 10 nm.

Technology

The technology of metallic photocathode fabrication consists of the following steps.

1. Shaping photocathode holder with semi-angle of taper within 3°…5° by electrochemical etching.

2. Spherical shaping the tip of the holder (see Fig. 5) by means of its heating in an electric discharge causing melting and roll-up into a ball by surface tension [10]. Scheme of the bench for spherical photocathode fabrication is presented in Fig. 4, where for preventing an oxidation of the photocathode during the melting a shielding gas is used. The developed and created spark generator for discharge ignition, photo of which is presented in Fig. 4, generates a rectangle pulse with controllable parameters of its duration and current. This technique allows to form high accuracy sphere of a required radius with accuracy 1 μm.

3. The electrochemical gold plating of spherical part of the photocatode with the 1 μm layer.
4. Scaling down the surface roughness by pulsed melting the gold layer using spark generator and subsequent heating in vacuum during 3 hours at 900° C that one can see in Fig. 6.
5. Combined chemical and electrochemical polishing the photocathode surface. This polishing allows to get a rms height roughness, compared with a noise of AFM.

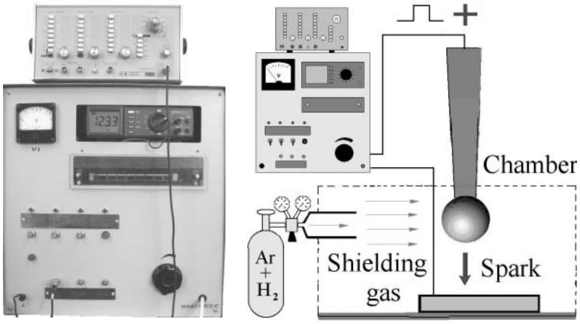

Figure 4: Photo of the spark generator (left) and scheme of the bench for spherical photocathode fabrication and for pulsed melting of gold plating.

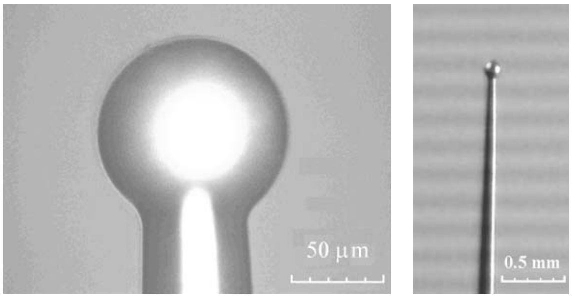

Figure 5: Gold-plated photocathode with the 50-μm radius before polishing (left) and conical steely holder of the spherical photocathode before its gold plating.

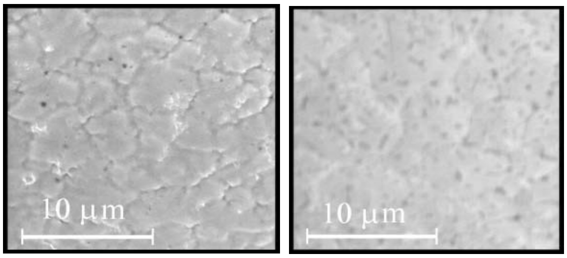

Figure 6: Gold-plated photocathode surface after its pulsed melting (left) and the same surface after subsequent heating in vacuum during 3 hours at temperature 900° C.

All listed steps of technology for the photocathode production allow to get the desired result: the rms height of the surface roughness was less than 10 nm.

CONCLUSION

From our consideration one can conclude:

the considered camera for x-ray pulse or electron bunch radiation photochronography, so named cameratron that is based on new principles of operation, allows to carry out measurement with temporal resolution of 10 fs at radiation registration in the range from the visible light to x-ray with practically the same high temporal resolution;

the considered camera is a high current camera allowing to operate in the regime single shoot or for measuring the bunch train, from bunch to bunch without superimposing the bunch distributions;

the mentioned high temporal resolution can be reached at rather low static voltages on photocathode (not more than 4 kV), small pulsed RF-power feeding (100 W at 3GHz), and all device, outlined in Fig. 1, can be placed on the sheet of format A4;

for getting temporal resolution not worse 20 fs, at registering pulses both of visible light and x-ray radiation, the rms height of roughness must not exceed 10 nm;

the key unit of the camera is principal new photocathode of spherical configuration, technology for its production has been proposed, developed and realized that is outlined in corresponding section of the paper.

The photocathodes similar to the considered allow to create a high current photogun of new scheme of implementation with the limiting high brightness of electron beam that will be published in the nearest time.

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