The Production of Short Intensive Bunches From GaAs Photocathode

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Abstract

The installation for length measurements of the electron bunches emitted from $GaAs$ photocathode is constructed. Two methods of bunch length measurements are suggested and applied. The bunch length is calculated on the basis of experimental data. The experimental results are analyzed and compared with results of computer simulations.

1 INTRODUCTION

The idea of using RF guns as the source of electrons for e^+e^- colliders excites the great interest since the intensive and originally short bunches with small emittance could be obtained [1]. RF gun parameters are basically determined by choice of the photocathode type. $GaAs$ photocathode is distinguished from other cathodes by its ability to emit the polarized electron beams [2]. The experiments on the installation for length measurement of the bunches emitted from $GaAs$ photocathode were started a few years ago [3]. In this paper the results obtained in the last series of experiments are presented.

2 EXPERIMENTAL SETUP

The schematic view of an experimental setup is shown in Fig. 1. $GaAs$ photocathode (p-doped by Zn, 10^{19} cm^{-3}) is activated by depositing Cs and O_2 at its surface with a standard procedure in UHV preparation chamber [4]. When the activation has been accomplished, the cathode is fastened to the DC gun by manipulator. The cathode is negatively biased with a voltage U_g ranging $0 \div 60$ kV. A pulsed mode-locked $Nd:YLF$ laser is used in the experiments on photoemission. The basic parameters of the experimental setup are:

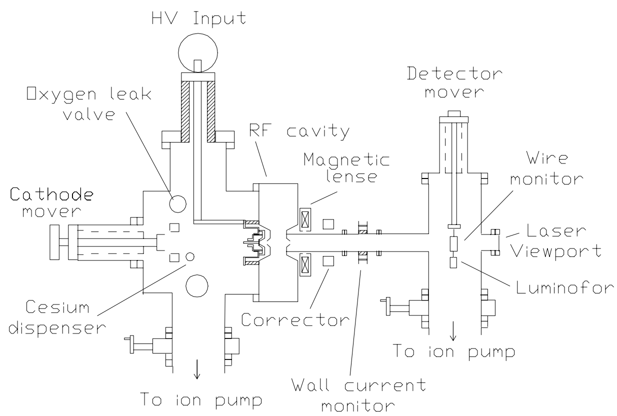

Figure 1: Experimental setup

- laser wavelength		524 nm
- laser pulse duration (FWHM)		60 ± 20 ps
- laser spot diameter on the cathode surface		2 mm
- vacuum	not worse than	$2 \cdot 10^{-10}$ torr
- thickness of $GaAs$ crystal		0.45 mm

3 METHODS OF BUNCH LENGTH MEASUREMENT AND EXPERIMENTAL RESULTS

The first method of bunch length measurement is based on circular scanning of the electron beam travelling in rotating field of an RF cavity [5]. The dependence of the bunch length on the bunch charge obtained with this method at $U_g = 60$ kV is presented in Fig. 2. When the current density is high, the transverse growth of an electron beam complicated the precise length measurements. To avoid these problems and to measure the length of much more inten-

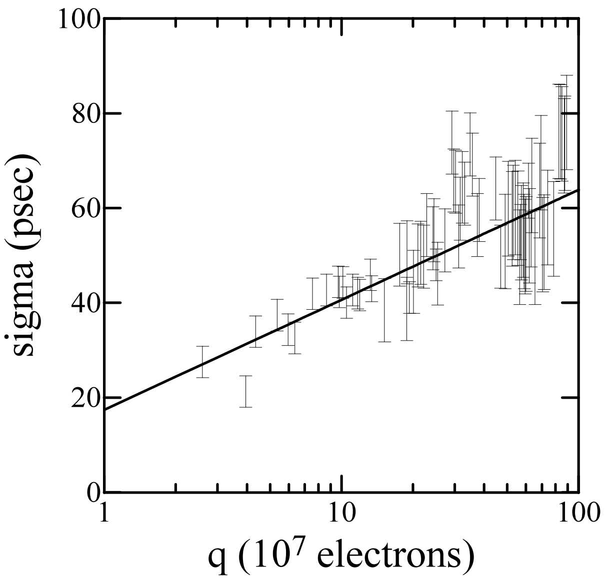

Figure 2: Method of circular scanning: bunch length vs. bunch charge at U=60 kV

sive bunches, the method of passive cavity is applied [5]. In this method the same cavity as in the previous method is used. The shape of the current pulse $I(t, \sigma)$, where σ is a parameter of bunch length, is connected with dependence of spectral density on frequency and σ by Fourier transformation, so one can calculate the bunch length when the bunch spectrum is measured. For spectral density measurement one can use the dependence of electromagnetic field energy excited in cavity after electron bunch pass on current pulse spectrum. If the bunch length is in the range when two first modes are excited mainly, then the output power can be described by the sum of two exponents with different decay times τ_{01} and τ_{02}, and initial values P_{01} and P_{02}. In this approach it is possible to calculate the amplitudes of excited modes using the least square method, and to determine the bunch length. The voltage induced by the bunch in the cavity is measured and after computer procession the values P_{01} and P_{02} of power stored in first and second symmetric modes of the cavity are determined. That can be described as [6]:

$$P_{0n} = a_n q^2 |F(\omega_n)|^2, \quad (1)$$

where a_n is a coefficient which depends on cavity geometry, q is the bunch charge and $|F(\omega)|$ is a Fourier spectrum of the bunch. Bunch charge q can be expressed through the quantum efficiency of the photocathode Y_{pc} and the laser pulse energy W:

$$q = const \cdot Y_{pc} W. \quad (2)$$

After some transformations the normalized intensities of excitation of cavity modes are calculated:

$$f_n = \sqrt{\frac{P_{0n}}{c_n W^2}} = Y_{pc} |F(\omega_n)| \quad , \quad (3)$$

where $c_n = const \cdot a_n$. Values f_n do not explicitly depend on laser power and characterize the bunch length (through $|F(\omega_n)|$) and pulse emission ability of the cathode (through Y_{pc}). The ratio $f = f_2/f_1 = |F(\omega_2)|/|F(\omega_1)|$ depends just on the bunch length. The dependencies of f on the laser pulse energy W are presented in Fig. 3 and demonstrate the

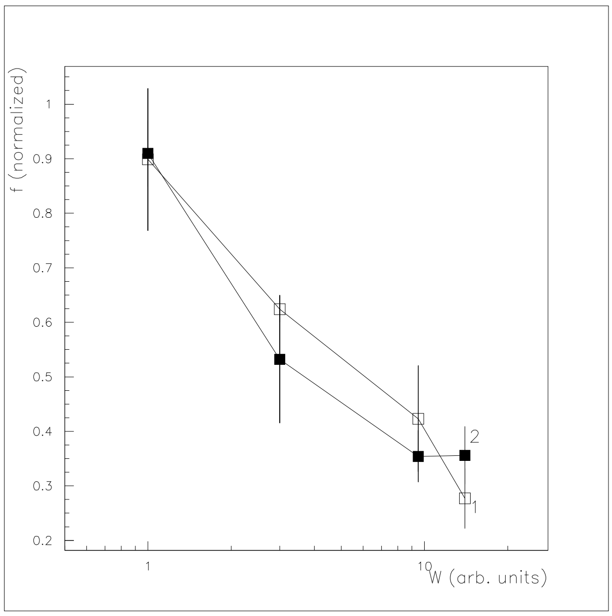

Figure 3: Intensities of excitation of 1st and 2nd modes ratio vs. laser pulse energy. 1 - 35 kV, 2 - 45 kV

decrease of f_2 compared with f_1 while W is increased. This shows us the bunch length growth with the bunch charge increase.

To find out the obvious dependence of the bunch length σ on charge q it is necessary to set the current pulse shape $I(t, \sigma)$. Figure 4 presents $\sigma(q)$ dependencies in assumption of Gaussian bunch shape. The bunch current amplitudes can be calculated as:

$$I = \frac{q}{\sqrt{2\pi}\sigma} \quad (4)$$

The dependencies of the current amplitude on bunch length for different periods of time after activation and different voltages U_g are shown in Fig. 5. This figure also contains the results of computer simulation of particles motion in the gun using PARMELA code. The simulation assumed the Gaussian current shape on the cathode with $\sigma = 30$ ps. The limitation of emission current at $I \simeq 0.75$ A when $\sigma < 80$ ps is evident and corresponds to emission current density $j_e \simeq 25$ A/cm^2 when the laser spot diameter on the cathode is 2 mm. This limitation doesn't connect with the space charge effects as the experimental values for $U_g = 35$ kV and 45 kV are equal (in error limits) and lower than the values are taken from computer simulation and demonstrating the space charge limitation.

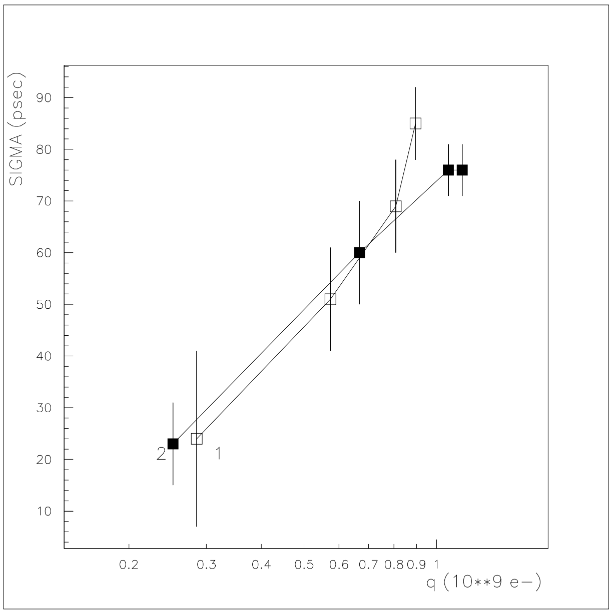

Figure 4: Method of passive cavity: bunch length vs. bunch charge for Gaussian bunch shape. 1 - 35 kV, 2 - 45 kV

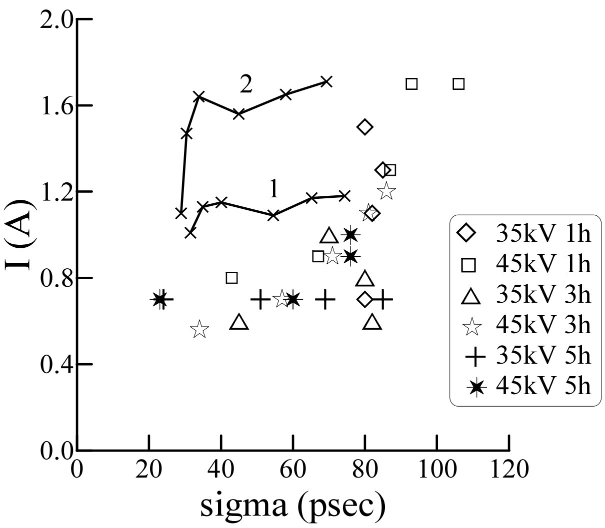

Figure 5: Current amplitude vs. bunch length for different voltages and different periods of time after activation. Solid curve - the results of simulation. 1 - 35 kV, 2 - 45 kV

4 CONCLUSION

Experimental investigations of photoemission time properties from $GaAs$ photocathode surface in the range of small durations (less than 100 ps) and high emission current densities ($> 25\ \mathrm{A/cm^2}$) are provided. The dependence of emitted bunch duration on current density is discovered.

Very short and intensive current pulses from $GaAs$ photocathode (30 ps rms at peak current density $25\ \mathrm{A/cm^2}$) are obtained. In this case no essential emission duration growth compared with laser pulse duration is detected.

5 REFERENCES

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