Picosecond Polarized Electron Bunches from a GaAsP Photocathode

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Abstract

At the Mainz electron accelerator MAMI a facility has been set up that allows the measurement of the bunchlength, the energy spread and the averaged and phase resolved polarization of picosecond electron bunches from a source of polarized electrons for MAMI. Electron bunches from a strained layer GaAsP photocathode are presented.

1 INTRODUCTION

In recent years the demand on polarized electron beams for nuclear scattering experiments has constantly risen. Experiments at MAMI , CEBAF , SLAC and many other sites either require tens of microamperes of average beam current or pulse currents of several amperes.
The sources of polarized electrons used to satisfy these demands are usually based on the photoemission from III-V semiconductor photocathodes. One unsolved problem since the first use of GaAs photocathodes at an accelerator site, is the decrease of quantum efficiency with time when current is extracted. Experience at MAMI shows that the cathode lifetime decreases when beam current is increased [1].
Currently, strained layer photocathodes are installed in the MAMI source of polarized electrons. The source emits a d.c. beam using a cw laser [1]. Since the accelerator is radiofrequency (rf) driven, the d.c. beam has to be chopped and prebunched before it is injected into the accelerator. The chopper-prebuncher system has a capture efficiency of 16% at best (see Fig. 1). Thus a major part of the polarized current is not accepted at the injection point, what severely lowers the current of polarized electrons available for experiments at MAMI. One could gain in capture efficiency by chopping the beam at the cathode already. Illumination of the cathode with a pulsed light beam synchronuous to the accelerator rf would greatly enhance the capture, if short enough electron bunches were produced in this way. An increase in the accelerated beam current without a decrease of the cathode lifetime could be achieved. In case of MAMI the pulse duration should be less than 65 ps.

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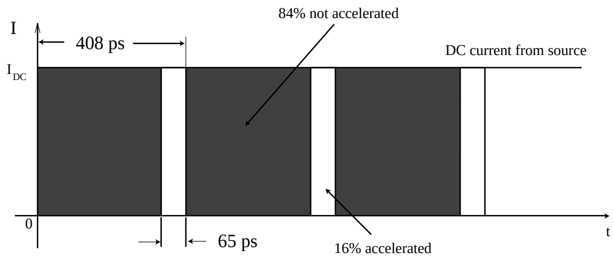

Figure 1: The transmission of the d.c. source current through the accelerator. At best 16% of the generated electrons reach the experiment.

2 THE EXPERIMENTAL SETUP

A sketch of the experimental facility at MAMI is shown in Figure 2. It consists of an electron gun, a beam transport system, a radiofrequency deflector resonator followed by an electron spectrometer and a Mottdetector for polarization analysis. Details of the design may be found in [2].
A modelocked Ti:Sapphire laser provides laser pulses of 105 fs duration with a repetition rate of 76.54 MHz. The laser may be phaselocked to the 32^{nd} subharmonic of the MAMI radiofrequency of 2.4493 GHz. Circular light polarization is provided by a Pockelscell. The laser beam is focused on the semiconductor sample in the 100 keV electron gun. The generated electron beam is transported to the beam analyzer by a set of five quadrupoles and two double

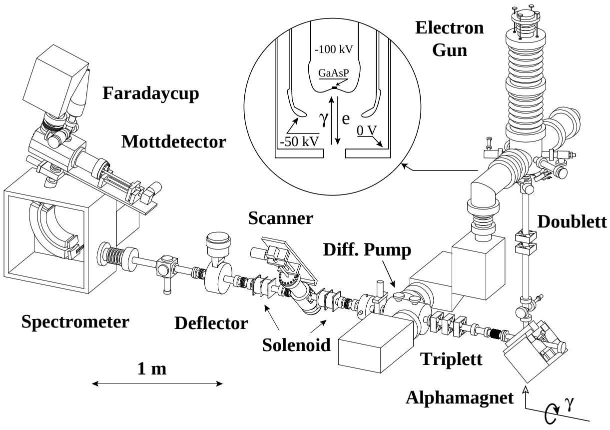

Figure 2: Sketch of the experimental setup

solenoid lenses.

The basic concept of the electron beam analysis is a radiofrequency streak method (see Fig. 3). This method transforms the phase (time) dependent intensity of the electron bunch into a transverse spatial profile. The electron beam is wobbled over the narrow entrance slit of the electron spectrometer using a cylindrical TM_{110} radiofrequency resonator as described in references [3, 4] (see also Fig. 3). Since the laser is synchronized to the wobble radiofrequency, a stable spatial image of the phase dependent intensity profile of the bunch is generated. This spatial pulse image can be shifted over the slit by varying the phase of the laser pulses relative to the radiofrequency. By measuring the dependence of the transmitted current on the phase shift, the phase dependent intensity profile is sampled. The energy resolution of the subsequent electron

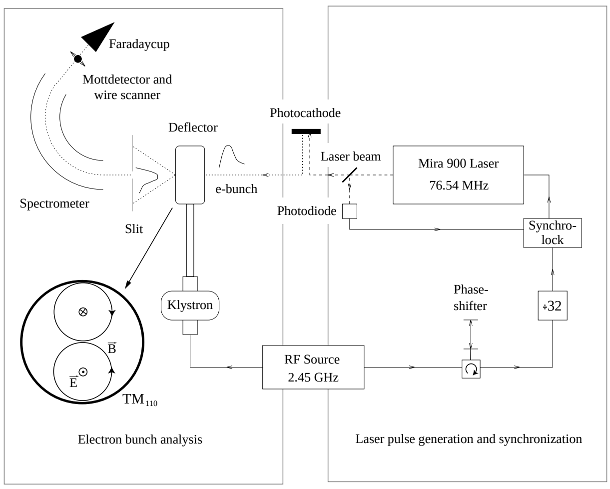

Figure 3: Principle of the measurement is a radiofrequency streak method. On the right side the laser pulse generation and synchronization to the MAMI rf is shown. The left part of the sketch shows the electron bunch analysis with the TM_{110} deflector cavity.

spectrometer is determined to 15 eV at an electron beam energy of 100 keV. The energy spread is measured by scanning the beam spot behind the spectrometer with a movable tungsten wire. The deflection angle is choosen according to the BMT–Formula [5] to transform a longitudinal beam polarization into a transverse one. The transverse degree of polarization is determined by Mott scattering. The transmitted current is measured with a Faradaycup.

Measurements may be carried out in phase mode and in spectrometer mode. In phase mode the deflector resonator (phase analyzer) is switched on to measure the phase-dependent properties of the electron bunch. In spectrometer mode non-phase-dependent properties of the electron beam are measured and the deflector resonator is off.

3 RESULTS

Fig. 4, 5 and 6 show measurements from a strained layer $GaAs_{0.95}P_{0.05}$-cathode purchased from the Ioffe Institute in St. Petersburg [6]. The thickness of the electron emitting epilayer is 150 nm. The same type of photocathode is routinely used in the MAMI source of polarized electrons [1]. Negative electron affinity is achieved by a (Cs + O)-layer on the cathode surface [7]. A quantum efficiency of 5×10^{-4} has been obtained at a wavelength of 836 nm of the irradiating light. All data were taken in the polarization maximum at a laser wavelength of 836 ± 1 nm.

Fig. 4 shows as an example an electron bunch generated

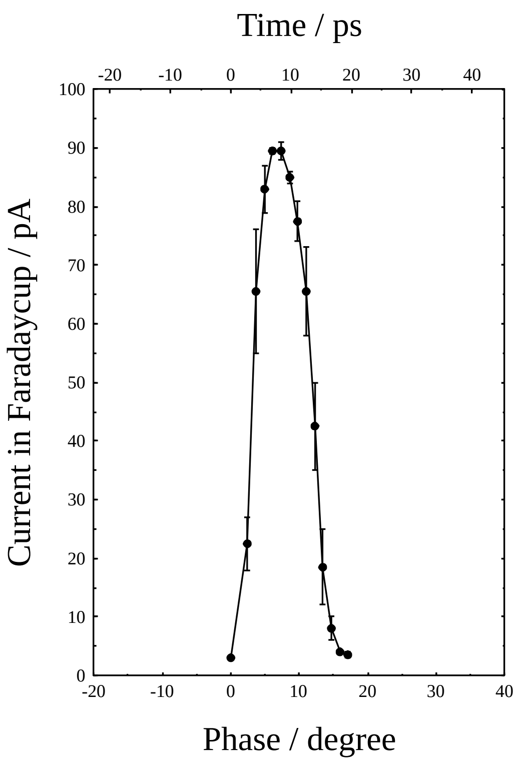

Figure 4: (a) An electron bunch generated with an accelerating voltage of 100 kV at a quantum efficiency of 5×10^{-4}. To guide the eye, the points are connected with straight lines.

with an accelerating voltage of 100 kV at a quantum effi-

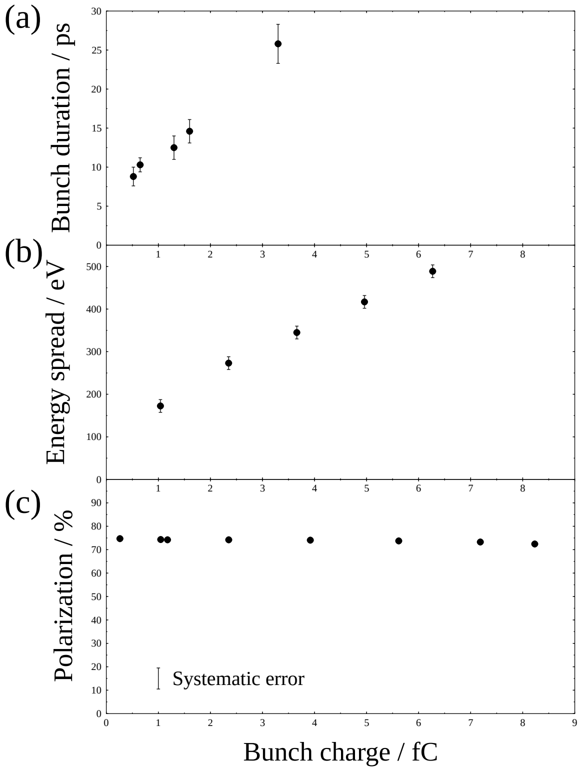

Figure 5: Polarization, bunch duration and energy spread of the bunches vs. the bunch charge. These three measurements were not taken at the same time. The strong dependence of the bunch duration on the bunch charge is considered to be an external space charge effect.

ciency of 5×10^{-4}. The transmitted current, measured with the Faradaycup, is plotted vs. the phase (time) of the phase analyzer. The shown bunch is charged with 0.65 fC.
The widths of the electron bunches (FWHM) for different bunch charges are shown in Fig. 5(a). We observe a strong dependence of the bunch length on the bunch charge. This is considered to be an external space charge effect. It takes place during the transport of the bunch from the photocathode to the deflector cavity [8, 9]. The energy spread of the electron beam is plotted in Fig. 5(b). The monotonous increase of the energy spread with the bunch charge indicates that the major amount of the space charge potential is transformed into kinetic energy. In a simple electrostatic model the offset in kinetic energy of the outermost particles of the bunch relative to the center particle is proportional to their initial space charge potential, which itself is proportional to the total number of electrons in the bunch. The average polarization of the electron beam vs. the bunch charge is plotted in Fig. 5(c). No dependence on the bunch charge was seen up to 8 fC. The highest charge investigated would correspond to a mean beam current of 20 μA if a pulse repetition rate of 2.45 GHz (MAMI-rf) could be achieved.

To investigate the phase resolved polarization, we examine the transmitted current from the phase analyzer (phase mode) with the Mottdetector. Fig. 6 shows the spin polarization (upper points) and the transmitted current (curve on the bottom of the plot) as a function of the deflector cavity phase. Within the error bars no dependence of the polarization on the position in the bunch is observed.

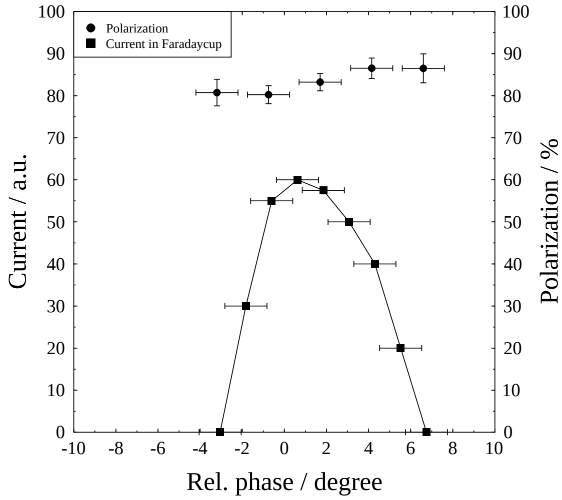

Figure 6: Phase resolved measurement of the polarization of the electron bunches. The spin polarization (upper points) and the transmitted current (curve on the bottom of the plot) are shown as a function of the deflector cavity phase.

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