HIGH CAPTURE EFFICIENCY FOR THE POLARIZED BEAM AT MAMI BY R.F.-SYNCHRONIZED PHOTOEMISSION

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Abstract

The current from a GaAs-type source of polarized electrons is limited because some photocathode detoriation processes - like the production of ions from the residual gas - tend to increase with the current itself.

Therefore a high longitudinal capture efficiency of the injection into the accelerator is desirable in order to use the produced charge economically. This may be achieved by the 'synchro-laser' method: Picosecond light pulses are synchronized to the accelerator r.f. and generate a 2.45 GHz electron pulse train. Reliable operation has been achieved with a bunch length of 50 ps that resulted in a transmission from the source to the target of $>$90 %.

1 INTRODUCTION

Experiments using polarized electrons at MAMI require polarized electron beams with intensities of up to 20 Microamperes. The beam is produced by photoemission from uniaxially deformed GaAsP-photocathodes. The efficiency of the photoelectric process is reduced by several processes:

- desorption of molecules or ions from the vacuum chamber
- ionization of the residual gas
- nonlinearity of efficiency due to internal space charge in the crystal

All effects are at least proportional to the average beam current, what in practical operation leads to a decrease of efficiency with time. Because of this phenomenon and because the quantum efficiency of uniaxially deformed cathodes is low at an excitation wavelength were a high polarization is available (typically $2 \cdot 10^{-3}$ for a polarization of 75%) we find a limitation of the average beam current. This operational limit lies in our installation between 25 and 50 microamperes, consequently a beam transmission from the source to the target close to 100% is required.

In our case this problem was attacked by two methods:

a) Optimization of the longitudinal capture efficiency by an f/2f prebuncher system. This system was described by Shvedunov et. al. [1] and put into operation in early 1997. The expected phase acceptance of 180 degrees was easily achieved [2].

b) Installation of a phase-synchronized laser system which allows to produce electron bunches in the time intervals corresponding to the phase acceptance of the f/2f prebuncher. This was realized by the installation of a semiconductor Master-Oscillator-Power-Amplifier (MOPA) system, which is similar to the one described in [3] but operating at twice the frequency (2.45 GHz).

2 LASER-SETUP

The whole set-up is divided into the r.f.-components which drive the oscillator laser-diode and the light optical part. This is depicted in figure 1:

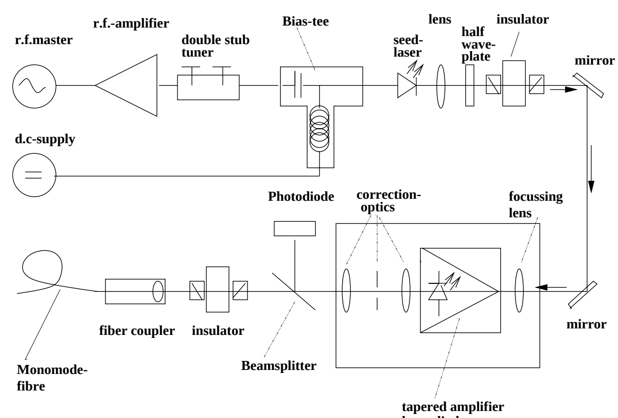

Figure 1: Set-up of Laser-system

The r.f.-signal from the MAMI-master is amplified and then coupled into the diode laser (model Rohm RLD-83 MF) by a bias tee. Impedance matching at 2.45 GHz is achieved by a double stub tuning element. The diode is biased at a level just above lasing threshold. This situation leads to a periodic variation of the carrier density in the active region of the laser (gain switching). The laser radiation emitted from this socalled 'seed-diode' is directed by two mirrors into an optical amplifier (model: Spectra Diode Labs SDL 8630).

The bandwidth of the amplifier is about 20 nm (10 THz). Therefore it can be expected that any structure on the picosecond timescale will be linearely amplified. The typical single pass gain is betweeen 50 and 100.

After passing the amplifier the beam is astigmatic which is corrected by cylindrical lenses. Then it is guided by fibre optics to the recently installed polarized electron source in the MAMI-hall [4].

The output power may be controlled by attenuating the emitted light from the seed diode or by changing the amplifier drive current. Two optical insulators (circulators) are necessary to avoid unwanted feedback.

3 LASER-OPERATION

The fundamental advantage of gain switched diode operation lies in the fact that the pulses resulting from the harmonically driven seed-diode are not only phase synchronized to the r.f. but they are also shortened by the nonlinear light amplification process in the diode. The laser output can be simulated by solving the laser rate equations which are coupled differential equations between the photon flux $P(t)$ and the carrier density $n(t)$:

$$\begin{aligned}\frac{dn(t)}{dt} &= \frac{j(t)}{ed} - \frac{n(t)}{\tau_s} - g(n(t))P(t) \\ \frac{dP(t)}{dt} &= \beta\frac{n(t)}{\tau_s} + \Gamma g(n(t))P(t) - \frac{P(t)}{\tau_p}\end{aligned}$$

The parameters of these two equations are:

- semiconductor specific parameters: τ_s: spontaneous emission lifetime, τ_p: photon lifetime, $g(n(t))$: (exponential) gain coefficient, d: thickness of active region in semiconductor.
- geometrical factors: β: Rate of spontaneous emission in active laser-mode, Γ: optical confinement of laser mode in active region.
- drive-function: $j(t)$: current density, as it as externally modulated by the r.f.
- e: electron charge

The pictures in figure 2 show the solutions of the equations for the first 5 ns after initial turn on of the laser.

After about 3 ns stable periodic output of Gaussian Pulses with 40 ps FWHM and a low d.c. background is predicted by this computersimulation [5].

The experimental verification of the expected bunch length was done by using the circular deflecting chopper [6] at the entrance of MAMI (see figure3):

The chopper produces a circular deflection of the beam with a rotation period of the MAMI frequency. The longitudinal distribution is then imaged on an azimuthal distribution on the deflected trajectory. The angular extension corresponds to the pulse length. This extension can easily be measured by phase shifting the laser pulses and with it the electron bunches with respect to the chopper-r.f. The measured current transmitted by the minimized collimator-slit gives the longitudinal intensity for a given phase.

Figure 4 shows the measured bunch profile: It is gaussian with a FWHM of 53 ps. The real bunch length of the

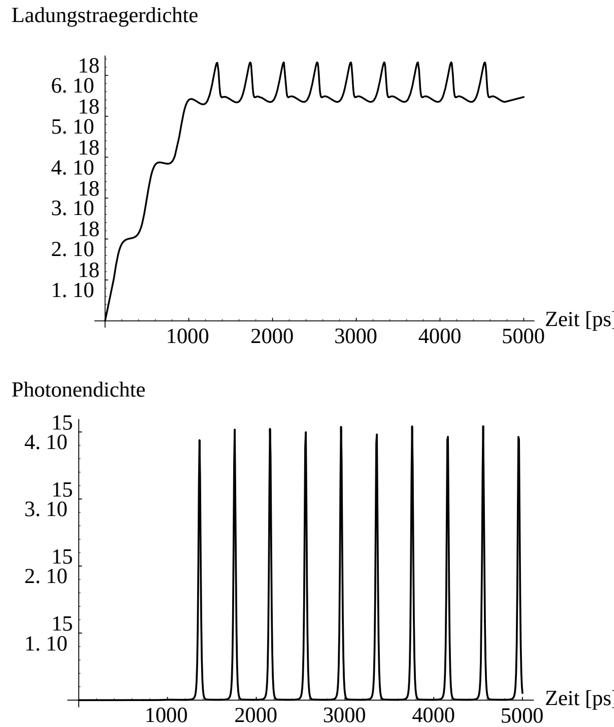

Figure 2: Computersimulation for the time evolution of carrier density and light output.

pulse should be around 45 ps because the finite size (0.5-0.7 mm) of the beam at the chopper slit increases the measured width. The time response of the semiconductor crystal in the polarized gun is below 8 ps, so that this response function does not contribute significantly to the measured bunch length [7].

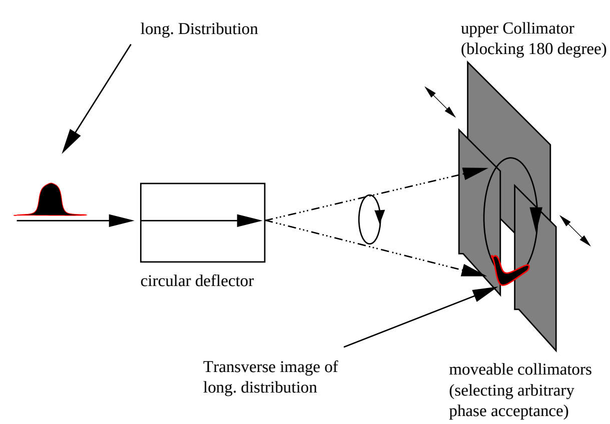

Figure 3: Principle of bunch length measurement

The d.c. background below the pulse profile is less than 0.5% . This led to a transmission of 98% of the pulse profile through the prebuncher system. The total transmission from the source to the target was found to be 94%. Four percent of the beam current were lost on the collimators in the injection system which restrict the transverse emittance.

No change of this transmission was observed for beam currents up to 35 μA. The current was limited by the available quantum efficiency and laser power. Tests with a high peak power laser which was synchronized on the 32 th subharmonic (76MHz) indicate that the chopper transmission remains constant also at much higher currents.

A comparison was made with d.c. injection ($180°$-accepted) at a current of $20\mu A$: The observed radiation in the machine due to beam loss was reduced in pulsed mode by a factor of ≈ 3. This can be explained by the smaller illumination of the longitudinal acceptance.

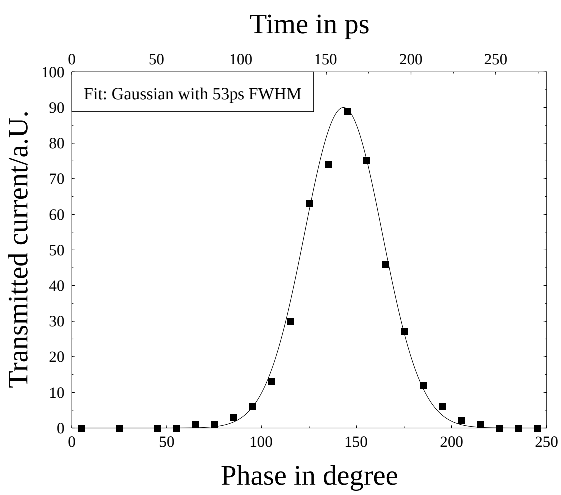

Figure 4: Measured bunch profile

4 LASER-STABILITY

The laser has operated for long term nuclear physics experiments for about 500 hours up to date. The long term drift of the output power is about 3% per day which is caused by an instability of the beam transport from the seed diode to the amplifier. For the usual production runs at MAMI practically no maintenance time is required.

The short term noise on the millisecond/microscond time scale is less than 1 percent (rms).

The average electron beam transmission over 150 hours of a beam-time was found to be 90 percent. In that period the longitudinal transmission remained constant, whereas an increasing amount of beam was lost on the transverse collimators.

The following table summarizes the typical operational parameters of the polarized injection system in operation with the synchronized laser.

repetition rate	2.449 GHz
seed-laser power	2.8 mW
average output power	150 mW
laser intensity noise (rms)	$< 1\%$
pulse length (FWHM)	< 50 ps
d.c. background	$< 1\%$
beam transmission to target	$> 90\%$
electron beam current	20 μ A.
beam polarization	75%

Table 1: Main parameters of the MAMI-synchrolaser system

5 SUMMARY AND ACKNOWLEDGEMENTS

The polarized photoinjector at MAMI can reliably be driven with a 2.5 GHz repetition-rate r.f.-synchronized laser. This increases the beam transmission by roughly a factor of 2 which under the condition of limited average current from the source also doubles the available current for nuclear physics experiments.

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