# The MAMI-Beam of Polarized Electrons

H.G. Andresen, K.Aulenbacher*, T. Dombo, P. Drescher*, H. Euteneuer, H. Fischer*, D. v. Harrach, P. Hartmann, J. Hoffmann, P. Jennewein, K-H. Kaiser, S. Köbis, H.J. Kreidel, C. Nachtigall*, S. Plützer*, E. Reichert*, K.H. Steffens, T. Weis

Institut für Kernphysik, Institut für Physik* Johannes Gutenberg Universität Mainz
D-55099 Mainz

*Abstract*

The first experiments with polarized electrons at the Mainz race track microtron MAMI were succesfully started in spring 1992 with the investigations of the quasielastic reactions $D(\vec{e}, e'\vec{n})$ and $^3\vec{H}e(\vec{e}, e'n)$ [1]. The source of polarized electrons used bases on photoemission of GaAsP. It produces a beam of $50\mu A$ d.c., with a spinpolarization of 34%, and a phase space of $0.5 \cdot \pi \cdot mm \cdot mrad$ at the injection energy of 100keV. Spinorientation at the target is adjusted with help of a spinrotator before accelerator injection. Operational experience with the polarized beam is dicussed.

## 1 INTRODUCTION

Many nuclear physics experiments at the c.w.-accelerator MAMI require a polarized electron beam with high brightness and longitudinal polarization at the target position. In order to fulfil these demands our apparatus consists of four main components:

1. The electron source.
2. The beam transport system.
3. A spin rotator.
4. Polarimeters before and after the accelerator.

## 2 THE POLARIZED ELECTRON SOURCE.

The main components - besides the laser system - are shown in figure 1.

A compilation of the hitherto achieved results is given in table 1.

### 2.1 Laser System.

The light source used for photoemission is a commercially available d.c.-dye-laser system. The output is directed towards the source by a 20 m long optical fibre. The output coupler of the fibre is located about 1.5 m below the photocathode (see figure 1). The laser beam gets circularly polarized by a pockels-cell and is then focused onto the semiconductor surface.

### 2.2 Electron Gun: General Description

The electron source uses photoemission from semiconductor crystals of the GaAsP-type [2]. Electron polarization

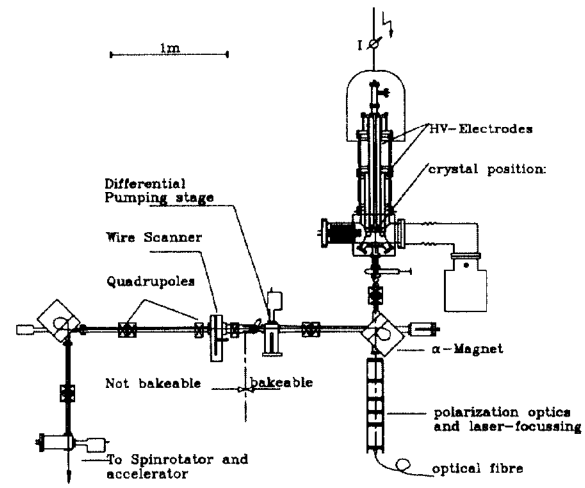


Figure 1: Section of MAMI polarized electron source together with some optical elements and part of the injection beam line.

is achieved by absorption of circularly polarized laser-light with photon energies near the band edge of the semiconductor. Effective photoemission occurs when the surface conditions of the crystal are altered by adsorption of Cs-F or Cs-O layers. In this case the potential energy of an electron in a conduction band state inside the semiconductor has a positive value with respect to a vacuum state. This condition is characterized as **N**egative **E**lectron **A**ffinity **NEA** [3].

The crystal surface is activated in situ to NEA condition. By doing so, we achieve quantum efficiencies of 1% with photon energies near the absorption edge of the semiconductor where high values of spin polarization of the emitted electrons may be expected. In order to keep optimum surface conditions during operation a vacuum system is installed that is capable to maintain extreme UHV ($\approx 3 \cdot 10^{-11}$ mbar) even when the source is operating at the accelerator with it's vacuum of $1 \cdot 10^{-8}$ mbar.

The crystal is mounted at the end of a 1 m long cylindrical electrode. This electrode is kept at a potential of -100 kV which corresponds to the injection energy of MAMI.

The electron optics of the gun is a triode design that was calculated with the EGUN code [4]. The beam is focused towards the axis by a conus adjacent to the crystal. The beam focusing remains constant for all required beam currents. All apertures inside the gun and the beam transport systems are large (>25 mm) in order to provide minimum transmission losses of the electron beam (These losses contribute to electron stimulated desorption that lead to a continous decay of quantum efficiency during operation).

The front ends of the electrodes are especially shaped in order to avoid excessive gradients at the surfaces. This is important because the exposition of the electrodes to cesium during the activation procedure otherwise leads to field emission of electrons.

We observed increased degradation of the quantum yield at field emission currents in excess of 100 nA. In our apparatus this level is only exceeded after very long operation e.g. many crystal activations [5].

### *2.3 Electron Gun: Beam Quality and Emittance*

MAMI requires a beam emittance of about $1 \cdot \pi \cdot mm \cdot mrad$ at the injection energy of 100 keV. In photoemission the value of emittance can be decreased easily by reducing the emitting area on the cathode surface. In our case this was realized by focusing the laser spot to a diameter of 0.29 mm. Under this circumstances we found the beam quality comparable to the unpolarized beam that is produced by a thermionic source. Because of the small emitting area the d.c.-current density during operation for experiments was as high as 70 mA/$cm^2$.

### *2.4 Operational Stability*

The quantum efficiency of the cathode decayes nearly exponentially. In operation the current from the photocathode is kept constant by adjusting the laser power. So the upper limit of operation time $t_{op}$ is given by:

$$t_{op} = \tau \cdot ln\left(\frac{QE \cdot P_L}{I}\right)$$

In this equation $\tau$ is the exponential decay constant, $QE$ stands for the initial quantum efficiency (typically 3–$5\mu A/mW$, $P_L$ for the maximum available Laser power at the crystal (about 100mW) and $I$ for the desired emission current.

We found that the time constant $\tau$ is decreasing with increasing current. It drops from 200 h at zero current to 30 h at 20 $\mu$A. This decay can partially be cured by recesiation of the crystal surface, a procedure that may be done without interference to the experiment. Periodic recesiation increased the 'effective' $\tau$ to about 95 hours at 20 $\mu$A. With $\tau$ = 95 h, QE = 3 $\mu$A/mW, $P_L$ = 100 mA, I = 20 $\mu$A (typical values during the aforementioned investigation $^2D(\vec{e}, e'\vec{n})$) one gets $t_{op}$ = 260 h.

We discovered that the quantum efficiency was reduced on a very small cathode area only. This area included the emitting spot and covered less than 1/20 of the total useful area on the crystal surface. Under this circumstances it was possible to move the emitting area from time to time on the crystal surface so that operation could be maintained for about 150 hours at emission currents of 50 $\mu$A.

A used crystal may be regenerated by heat treatment at $\approx 600C^\circ$. This procedure takes about 24 hours whereas a complete replacement of a crystal requires a new bakeout of the UHV-system, so that no beam is available for about 2 weeks.

## 3 BEAM TRANSPORT SYSTEM

The first part of the more than 20 meter long injection beamline is also shown in figure 1. The beam is focused by quadrupoles and deflected by 270° "alpha" -magnets. 15 beam monitors are installed, which simultaneously offer optical diagnostics of the beam shape and emittance measurements. The former is accomplished by viewscreens whereas the latter is done by measuring the beam profile with the help of wire scanners. The beam transport system has a transmission of more than 95% from the source to the accelerator.

The total transmission from the source to the target is about 20%, a value that is mainly limited by the (longitudinal) chopper/buncher system at the entrance of MAMI. Therefore 50 $\mu$A have to be supplied by the source to get 10 $\mu$A down to a target at the high energy end of the accelerator for example.

## 4 SPIN ROTATOR

This device was designed to compensate for the (g-2) precession of the spin during the recirculation in the microtron [6, 7].

The rotator mainly consists of two electrostatic deflectors T1, T2 and four double–solenoids DS1 .. DS4 (see figure 2). During the first electrostatic deflection the originally longitudinal polarization is transformed into a transverse polarization. Then the spin may be rotated by driving the two double solenoids DS1, DS2 asymmetrically. This first rotation corresponds to a rotation of the polarization vector in the accelerator plane. After another electrostatic deflection the second pair of double-solenoids can be used for another rotation. By this means the spin can be oriented in any desired direction. The two coils of each double solenoid are driven 'back to back'. By this way it is possible to keep the focusing properties of the solenoids constant, because the spin rotation angle for a solenoid is $\propto \int Bdz$ and the focusing length is $\propto 1/\int B^2dz$. The degree of polarization of the beam is measured by Mott scattering at position Mo in figure 2. A value of P = 34.5 ± 2 % is observed typically with a GaAsP–cathode in the gun.

The absolute value and the orientation of polarization of the accelerated beam is measured by a Møller polarimeter which is installed directly before the target position. Any spinorientation at this point (most experiments ask for a longitudinally polarized beam) may be adjusted by the rotator sketched in figure 2. Readjustments during a run are scarcely necessary due to the very good energy stability of the MAMI-accelerator ($\frac{\Delta E}{E} < 10^{-4}$). No correction of the spin rotation angle was required for more than half a year in the above mentioned experiments $D(\vec{e}, e'\vec{n})$ and $^3\vec{H}e(\vec{e}, e'n)$.

Table 1: MAMI source of polarized electrons. Summary of source parameters

| PARAMETER | VALUE | REMARKS |
|---|---|---|
| quantum efficiency | $0.5 - 0.9\,\%$ | |
| polarization | 0.34 | longitudinal at 855 MeV |
| field emission | $< 10\,\text{nA}$ | after in situ prep. at 100 kV |
| emittance | $0.5\,\pi \cdot mm \cdot mrad$ | 0.29 mm diameter of laserspot |
| av. current density | $70\,mA/cm^2$ | at $50\,\mu A$ av. current |
| cont. operation time | $> 200$ h | at $20\,\mu$A |
| operation time @ $50\,\mu$A | $> 100$ h | with movement of laser-spot |

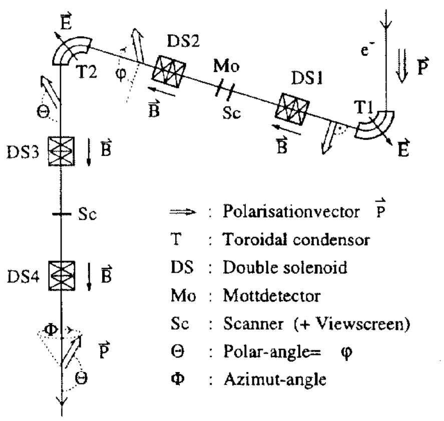


Figure 2: Spin rotator for 100keV electrons.

So far no depolarization during the acceleration has been detected, the polarization measurements at 100 keV (injection-energy) and 855 MeV are in agreement within the errors of the two polarimeters.

## 5 OUTLOOK

During 1993 the electron gun has been duplicated, so that now two electron sources are available for operation. A load lock system will be added to one source by the end of 1994. With this system we plan to achieve operation with currents of 200 $\mu A$ d.c. and 40% of polarization for run times longer than 500 hours.

In the past three years it has been proved that semiconductor photoemission is capable to produce beams with polarizations up to 80% [8]. This result was achieved by using strained GaAs [9, 10]. We will use photocathodes of the same type by the end of the year.

## 6 REFERENCES


[1] M. Meyerhoff, D. Eyl, A. Frey, H. G. Andresen, J. R. M. Annand, K. Aulenbacher, J. Becker, J. Blume-Werry, T. Dombo, P. Drescher, J. E. Ducret, H. Fischer, P. Grabmayr, S. Hall, P. Hartmann, T. Hehl, W. Heil, J. Hoffmann, J. D. Kellie, F. Klein, M. Leduc, H. Möller, C. Nachtigall, M. Ostrick, E. W. Otten, R. O. Owens, S. Plützer, E. Reichert, D. Rohe, M. Schäfer, L. D. Scharer, H. Schmieden, K.-H. Steffens, R. Surkau, and T. Walcher, "First measurement of the electric formfactor of the neutron in the exclusive quasielastic scattering of polarized electrons from polarized $^3$He," *Phys. Lett. B*, vol. 327, pp. 201–207, 1994.

[2] W. Hartmann, D. Conrath, W. Gasteyer, H.-J. Gessinger, W. Heil, H. Kessler, L. Koch, E. Reichert, H. G. Andresen, T. Kettner, B. Wagner, J. Ahrens, J. Jethwa, and F. P. Schäfer, "A source of polarized electrons based on photoemission of GaAsP," *Nucl. Instr. and Meth.*, vol. A286, p. 1, 1990.

[3] R. L. Bell, *Negative Electron Devices.* Oxford: Clarendon Press, 1973.

[4] W. B. Herrmannsfeldt, *Electron trajectory program, SLAC–report 166.* Stanford, USA: SLAC, 1979.

[5] K. Aulenbacher, *Eine Quelle longitudinalpolarisierter Elektronen für das MAMI–Beschleunigersystem.* PhD–thesis, Institut für Physik der Joh. Gutenberg Universität Mainz, 1994.

[6] K.-H. Steffens, *Konzeption und Optimierung eines 100keV Injektionssystems zur Erzeugung eines longitudinal polarisierten Elektronenstrahles an MAMI.* PhD–thesis, Institut für Kernphysik der Joh. Gutenberg Universität Mainz, 1993.

[7] K. H. Steffens, H. G. Andresen, J. Blume-Werry, F. Klein, K. Aulenbacher, and E. Reichert, "A spinrotator for producing a longitudinally polarized electron beam with MAMI.," *Nucl. Instr. Meth.*, vol. A325, pp. 378–383, 1993.

[8] L. Klaisner, "Polarized electron source for the Stanford Linear Collider," in *Proceedings of the Workshop on Photocathodes for Polarized Electron Sources for Accelerarors, Stanford, September 8 – 10, 1993; SLAC–report 432* (M. Chatwell, J. Clendenin, T. Maruyama, and D. Schultz, eds.), (Stanford, USA), pp. 101–121, SLAC, 1994.

[9] T. Nakanishi, A. Aoyagi, H. Horinaka, Y. Kamiya, T. Kato, S. Nakamura, T. Saka, and M. Tsubata, "Large enhancement of spinpolarization observed by photoelectrons from strained GaAs layer," *Phys. Lett. A*, vol. 158, p. 345, 1991.

[10] T. Maruyama and E. L. Garwin, "Observation of strain enhanced electron spin polarization in photoemission from InGaAs," *Phys. Rev. Lett.*, vol. 66, p. 2376, 1991.