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Precision Measurements of Mott-scattering asymmetry and Quantum Efficiency in Photocathodes for Polarised Electron Beam Experiments

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At the new, energy-recovering superconducting accelerator MESA at Mainz, spin-polarised electrons are required in the P2 experiment. Here the requirements increase considerably compared to the experiments at the microtron MAMI at Mainz. A very sensitive part of photocathodes lies in the specially prepared surface, characterised by its negative electron affinity. This surface is highly sensitive to residual gases in vacuum that cause ion back bombardment. Traditionally, this negative electron affinity is achieved through a preparation involving caesium and oxygen. Beam current losses induce a degradation of quantum efficiency and, in addition, the spin polarisation undergoes significant change. The exploration of the intricate relationship between polarization and quantum efficiency bears considerable importance, especially for the P2 experiment. Our aim is to clarify this connection and its implications, offering insights into managing spin polarisation and quantum efficiency in photocathodes.

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1. Motivation

At Mainz a new energy recovery superconducting accelerator called MESA is under construction [1]. This new accelerator will be able to perform in two different modes, feeding two different experiments. One experiment will use the energy recovery mode (ERL-Mode) while using unpolarized electrons with currents up to 1 mA at 105 MeV. The other experiment called P2 [2] will use the full energy of 155 MeV but with polarized electron beams in the external beam operation. P2 aims to measure precisely the weak mixing angle and is therefore a key experiment to the MESA project.

1.1 Generation of polarized electrons

Spin polarized electrons are produced from GaAs-based photocathode-heterostructures. Moreover, the NEA state is mandatory to achieve sufficient polarization since well defined S-like electronic states exist only at the bottom of the conduction band. NEA state requires covering the surface with dipoles which may be formed by $Cs:O_2$ or $Cs:NF_3$. A drift of beam polarization, as depicted in fig. 1 is observed for $Cs:O_2$ covered surfaces in our experiments at the Mainz Mikrotron (MAMI).

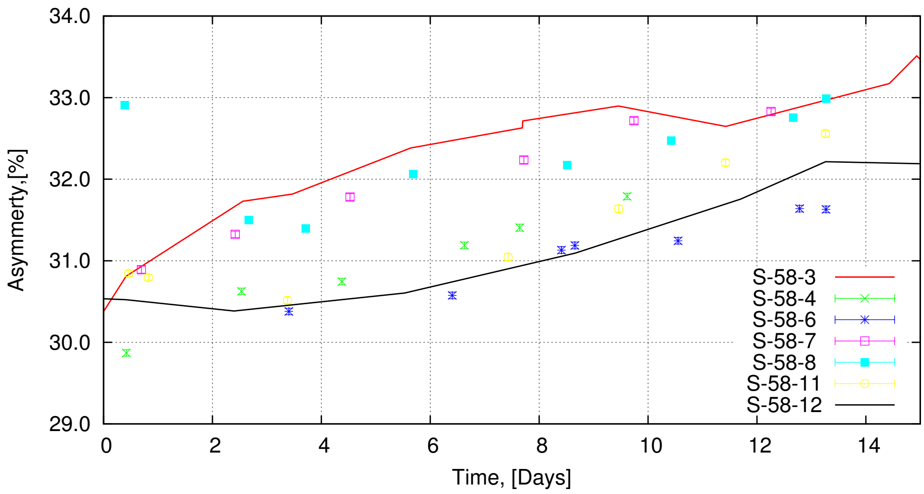

Figure 1: The Mott-scattering asymmetry changes during operation. These Mott scattering measurements have been taken at the MAMI accelerator. These measurements have been made with the same photocathode at different reactivations as indicated by the last two digits in the legend. The first and last usage of the photocathode corresponds to the solid lines. Taken from [3].

The purpose of this work is to observe if such changes also occur for $Cs:NF_3$ NEA surfaces. To do so we have modified one of our apparatuses, the so-called "Polarisierte Kanone-2" (PKA2) test apparatus, for both NEA options. In order to observe the drift of polarization a stable measurement is necessary. We describe the modifications of PKA2 in the following. The idea is to exchange the oxygen in the NEA surface with nitrogen trifluoride (NF_3) and to look at relative time dependent changes of the Mott-scattering asymmetry. The quantum efficiency tends to be more stable with NF_3 than with oxygen [4].

2. Experimental Setup

A schematic view of the whole apparatus is presented in fig. 2, on the right side a more detailed sketch of the load lock and on the left side the presentation of the beamline.

Fresh photocathodes can be introduced via load lock system where the NF_3 dosing system with leak valve is implemented as indicated in right side of fig. 2. The NF_3 dosing system was retrofitted to the existing load lock of the preparation chamber of the test apparatus. This was possible without great effort and has no disadvantages for the preparation process since the conductance of the open valve is large. Due to the small volume of the load lock acceptable vacuum conditions have been achieved after baking. From load lock photocathodes and the oxidizing agent, e.g NF_3 or oxygen gas are transported into the preparation chamber. The infrastructure of photocathode preparation consists of a laser (674 nm) with cesium dispenser and a small ring anode. The partial pressure of NF_3 and O_2 can be measured with a mass analyzer which is directly connected to the preparation chamber. After the preparation the photocathode is introduced into the source chamber which allows producing the 100 keV beam. The electrons travel through about 5 m beam transport line with several beam focusing elements into the Mott polarimeter. A successful activation with NF_3 has already been done and served to produce the data discussed below. Mott scattering refers to the back scattering process of polarized particles on unpolarized nuclei. Typically gold nuclei in thin foils are used as target and a spin rotating system in order to rotate the polarization vector orthogonal to the scattering plane since the initial polarization direction is parallel to the beam momentum. In this experiment a Wienfilter [5] is used to rotate the spin of the electrons. Since

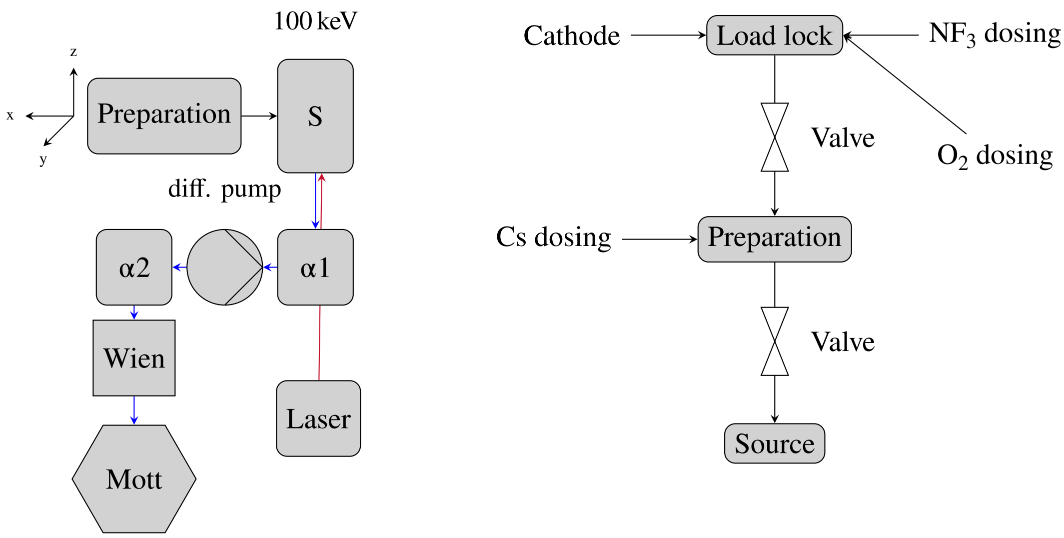

Figure 2: A schematic view of the experimental setup. On the right a scheme of the load lock and preparation chamber is presented with indications of dosing system positions. On the left is a sketch of the whole system. After a photocathode is introduced into the system and undergone the preparation process it can be transferred into the source (S). Laser light will excite electrons which will travel through the beamline, bend with an alpha magnet into the x-axis, passing through a differential pumping stage before passing the second alpha magnet. This will bend the beam into the y axis and into the Mott scattering polarimeter after it passed the spin rotation system (Wienfilter) to change the spin direction of the beam from longitudinal to transversal.

using a 100 keV source, the back scattering angle for Mott scattering is fixed at 120 °. The Sherman function which describes the proportionality of the Mott-scattering asymmetry to the polarization, has the maximum absolute value close to this angle for this electron energy.

3. Results and discussion

This setup permitted measurement of the Mott-scattering asymmetry of photocathodes with different preparation methods: a superlattice photocathode was activated with Cs:NF_3 and the very same sample was reactivated with Cs:O_2 in order to compare the results. To facilitate comparison between different activation methods and photocathodes it was chosen to convert the quantum efficiency into the escape probability as introduced in [6]. In the case of superlattice photocathodes the quantum efficiency is proportional to the escape probability.

It is shown in fig. 3 that both activation methods do not change the behaviour of the Mott-scattering asymmetry with respect to the escape probability. The lower the escape probability, the higher the Mott-scattering asymmetry. The maximum Mott-scattering asymmetry observed with both activation methods was approximately 17 % for said superlattice photocathode, although the starting Mott-scattering asymmetry of both activations is quite different.

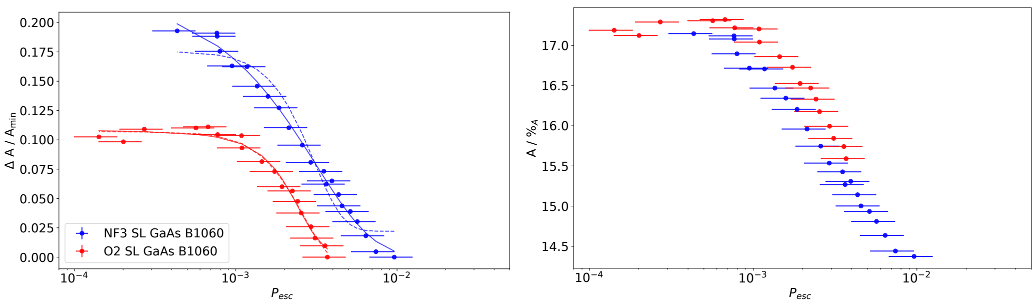

Figure 3: The relative change in Mott-scattering asymmetry as a function of the escape probability (left). The lower the escape probability, the higher the change of Mott-scattering asymmetry. The red points indicate a superlattice photocathode activated with Cs:O_2, while the blue points show the curve for the same superlattice photocathode but activated with Cs:NF_3. Both show the same behavior. (Right) the absolute Mott-scattering asymmetry versus the escape probability. Within the error bar of the escape probability the same Mott-scattering asymmetry for the same photocathode can be expected for the same escape probability. The development of a plateau starting at an escape probability of 10^{-3} is easier to identify by plotting the absolute asymmetries.

This could be explained by energy states within the band bending region which have been found in bulk photocathodes in [7]. They proposed two broad energy states in which electrons, which are on the way to emission, can relax. Electrons that relax into these energy states perhaps lose their polarization due to longer emission times and the known depolarizing effects can act on them. If the escape probability is high than those relaxed electrons can still be emitted and contribute to an overall lower measured Mott-scattering asymmetry. If an electron does not relax into those states it will have a higher Mott-scattering asymmetry. As soon as the escape probability decreases the relaxed electrons cannot be emitted into the vacuum anymore and therefore do not contribute to the overall measured Mott-scattering asymmetry. As a result the Mott-scattering asymmetry rises. This is sketched in fig. 4.

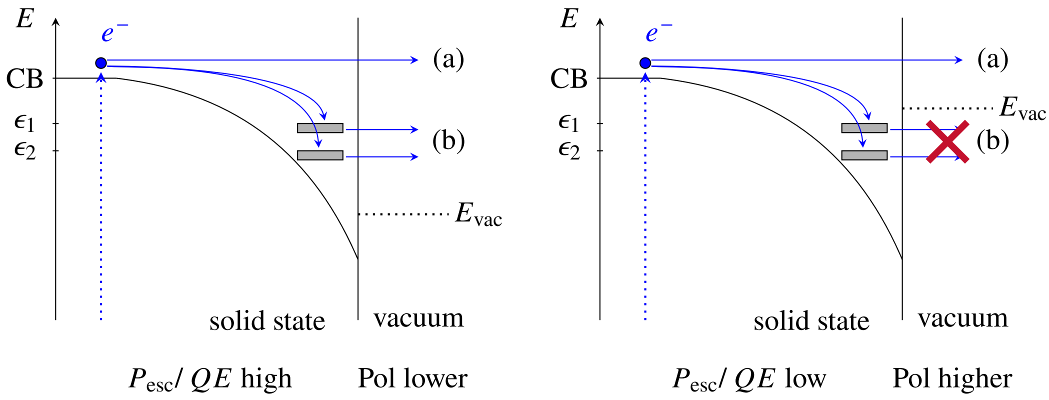

Figure 4: A possible explanation of the observed rise of Mott-scattering asymmetry. (left) the energy states and paths electrons can take during emission into the vacuum are shown. For bulk photocathodes two states have been proposed in the band bending region where electrons can relax into. If the escape probability is still high those relaxed electrons still can be emitted into the vacuum and contribute to an overall measured lower Mott-scattering asymmetry. (Right) the same sketch is shown but here the escape probability is low and the path (b) of the relaxed electron is blocked and therefore only electrons from path (a) can contribute to the overall Mott-scattering asymmetry which now is higher.

4. Summary

Experimental demands on the MESA project have significantly increased compared to the experiments at the existing MAMI at Mainz. A particular experiment, the P2 experiment, aims to measure the weak mixing angle very precisely at the full energy of MESA of 155 MeV. In order to reach the statistical goal they need over 11000 hours of high polarized, high current electron beam. It was investigated how the degradation of quantum efficiency influences the polarization of the electron beam and a strong correlation between a decreasing quantum efficiency and a rising measured Mott-scattering asymmetry was found. This phenomenon has been shown on the same superlattice photocathodes as used in the MAMI and it has been shown to be independent of the activation method of said photocathode. An explanation has been provided stating that energy states in the band bending region provide a possibility for electrons to relax and lose their spin while still contributing to the overall measured Mott-scattering asymmetry if the quantum efficiency is high. For low quantum efficiency it was suggested, that electrons, which relaxed into those states cannot be emitted into the vacuum and therefore do not contribute to the overall measure Mott-scattering asymmetry, hence the polarization rises. This emphasizes the importance of online polarization measurements to achieve the high precision P2 demands.

Acknowledgments

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