Positronbeam for μm Resolved Coincident Doppler Broadening Spectroscopy at NEPOMUC

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Abstract.
A new high resolution coincidence Doppler spectrometer is under development at the positron beam facility NEPOMUC at the research neutron source FRM II. A Ni(100) remoderation foil will be installed at the new spectrometer in transmission geometry for producing a positron beam with high brightness. Therefore, a magnetic lens for focusing the positrons onto the re-moderator and an electrostatic lens system for focusing the beam onto the sample have to be designed and simulated. The aim is to reach a beam diameter below 10 μm at the sample position for high resolution experiments. The current status of the project will be described and presented.

1. Introduction
Doppler broadening spectroscopy with positrons is a well-established non-destructive tool for the investigation of lattice defects in solids. Therefore, a (C)DB spectrometer is operated at the NEutron induced POsitron source MUniCh (NEPOMUC) which provides a high intensity positron beam of about 10^9 e^+/s. With the spectrometer it is possible to detect lattice defects which are caused for example after irradiation or by plastical deformation. Lateral resolved measurements are possible by focusing the positron beam and moving the sample with two stepper motors. For depth resolved measurements the sample can be biased up to -30 kV. The sample can be heated up to about 800 K in-situ for studying thermal annealing processes in thin layers [1], heavy deformed metal samples [2] or it can be cooled in order to study phase transitions i.e. in ionic liquids [3] and shallow trapping sides [4]. With CDBS the chemical surrounding of vacancies or small metallic segregations can be analysed [5]. In the near future investigations on technical alloys will be performed. The formation and growth of precipitations in aluminium based alloys in early state and the analysis of the elemental distribution in grains and grain boundaries of polycrystalline metallic alloys are of great interest. Therefore the beam diameter of the current instrument has to be reduced considerably.

2. Experimental set-up of the new CDB
At the current spectrometer a focused beam spot on the sample of about 300 μm is reached with apertures and an electrostatic lens system. For reducing the spot size of the beam at the sample
position there are in principle two possibilities. The first one is to use an optimized electrostatic lens system in order to get a better focused beam. However, this method is technically limited due to geometric constraints mainly the minimal distance from the lens to the sample. The second possibility is to apply the technique of re-moderation to enhance the brightness of the beam. The incident positron beam, which occupies a certain phase space volume (PSV), is focused onto a moderator. Due to Liouville’s theorem the transversal momentum must grow in order to keep the PSV constant and to compensate the reduction in real space. By entering the material the momentum of the positrons is reduced due to inelastic scattering and hence the PSV gets smaller. When materials with negative positron work function, i.e. tungsten or nickel, positrons which diffuse to the surface are emitted and can be accelerated with an electrostatic lens system. The result is a smaller positron beam with low energy spread and small angular divergence.

For the transmission re-moderator a Ni(100) foil with a thickness of 100 nm will be used. According to the Makhovian profile (see figure 1), a positron implantation energy of about 5 keV must be applied to maximize the amount of stopped positrons in the Ni(100) foil and to re-emit efficiently re-moderated positrons on the back side of the foil. At two research facilities in Japan this principle of re-moderating a positron beam was successfully realized [6]. The new design of the beam guidance to the CDB spectrometer at NEPOMUC is shown in figure 2. It consists of the magnetic beam guidance (beamline of NEPOMUC), an accelerator stage, the brightness enhancement system with the magnetic lens, the re-moderation foil and the electrostatic lens system. Two piezo sample positioners will be installed in the vacuum chamber enabling a high accuracy positioning of the sample. In order to achieve a minimal spot size of below 10 µm it is planned to mount an aperture for the incident beam and an additional magnetic single pole lens below the sample. For depth profiling the sample potential will be adjustable between about -5 kV and -30 kV. A heater enables the in-situ annealing and surface cleaning of the re-moderation foil. For monitoring the beam diameter at the site of the re-moderation foil a micro channel plate (MCP) can be inserted instead of the foil without breaking the vacuum.

3. Simulation of the new CDB design
At the current project status simulations for the new CDB spectrometer are performed with COMSOL multiphysics. Most important are the simulations for the magnetic lens (see figure 3) and the electrostatic focusing system below the re-moderation foil. The accelerated positrons

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**Figure 1:** Makhovian profiles for positrons in nickel for different implantation energies. An energy of about 5 keV is expected to result in a maximum yield of re-emitted positrons.
Figure 2: Design of the new CDB spectrometer at NEPOMUC. The incident positron beam is guided magnetically from the source to the instrument and is then accelerated to an implantation energy of 5 keV for a maximum re-moderation efficiency. The beam then passes an adjustment coil for illuminating the magnetic lens which focusses the beam onto the re-moderation foil. By three electrostatic lenses the re-moderated positrons are accelerated and formed to a beam which is focused onto the sample. For scanning the sample in 2D, two piezo micropositioners are mounted in the sample chamber. For depth dependent measurements the potential of the sample can be adjusted between -5 kV and -30 kV.

are focused onto the re-moderation foil by a magnetic field of about 500 Gs which is produced by two specially designed pole pieces of the magnetic lens. According to the simulations (see figure B), the beam diameter at the position of the re-moderation foil is reduced by a factor of 10, i.e. starting with a beam diameter of 1.5 mm a beam spot of 150 µm is expected at the Ni-foil. The magnetic field at the Ni(100) foil is reduced by a factor of 100 due to the geometry of the pole pieces. They will be further improved so that the magnetic field will be close to zero at the position of the re-moderation foil and hence cannot affect the electrostatic focusing onto the sample. Simulations of the electrostatic lens system are in progress. It will consist of three or four electrostatic electrodes (see figure 2) to extract the positrons from the re-moderation foil and generate a beam which is focused onto the sample. After additional focusing with a magnetic single pole lens below the sample and additional apertures a reduction in diameter of a factor of 20 is estimated to be achievable leading to a diameter < 10 µm.
4. Outlook
For the new design of the CDB spectrometer at NEPOMUC first simulations for the design of the magnetic lens have been made. Further simulations for the electrostatic lens system are in progress. The simulations deliver promising results of the beam spot diameter at the sample position but they have to be further adapted to the beam parameters of the re-moderated beam of NEPOMUC. At the end of 2013 and the beginning of 2014 the construction of the UHV components and the transmission re-moderator is planned. First experiments for testing the components will be performed at the open beam port of NEPOMUC in 2014. The final setting up of the new CDB spectrometer is planned to be in 2015.

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