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In-air STIM with a capillary microprobe

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ABSTRACT

A nuclear microprobe based on a tapered glass micro-capillary has been developed. The MeV ion beam can be collimated to a diameter of approximately 1 μm without the need of ion optical lenses. Due to the small gas leakage through the capillary opening, the beam can be taken into air without any membrane or special differential pumping. Samples can be raster scanned by means of a piezo-driven *XY* stage. For Scanning Transmission Ion Microscopy (STIM), the energy of the transmitted particles is measured by a miniaturized and radiation hard high resolution gas ionization detector. Technical details are given and examples for STIM imaging and single spot PIXE measurements are shown.

1. Introduction

Conventional MeV ion microprobes are based on highly sophisticated and expensive multiplets of multipole ion-optical lenses requiring a large amount of space [1]. Although significant progress in the performance of magnetic micro-lens systems has been made in past decades, there have been a few ion beam applications at moderate beam spot sizes or with very low beam currents in which the microbeam or millibeam has been obtained by pure collimation. In 1997, Folkard et al. used a straight glass capillary for MeV beam collimation in order to be able to target biological cells by single ions for radiobiological purposes [2]. In 2003 a similar technique was applied at the University of Kochi, Japan in order to extract the particle beam into air through a tapered capillary without using a diaphragm [3,4]. At that time it was noticed that the particle transmission through the capillary was bigger than expected by the collimation geometry. In addition, the broadening of the energy distribution of the beam particles was found to be very modest. This triggered new research activity in the field of capillary guiding and focusing of ion beams for microprobe applications, including in-air PIXE measurements [5–7]. The exact underlying physical mechanism and the extent of the observed focusing effect are still under discussion and are beyond the scope of this article. Nevertheless, the capillary collimation technique offers attractive opportunities for practical application, even without a possible current density enhancement by the capillary. Microbeams with a spot size on the order of 1 μm can be obtained easily and fast at very little expense. Tedious focusing procedures are not necessary and the accelerator beam stability is of no importance for the result. Due to the small gas leakage through the capillary, the beam can be taken into air without any membrane or differential pumping. In addition, the position of the beam spot is obviously given by the outlet of the capillary and positioning of samples is straightforward. Even with a very small current of 1 nA on the 1 mm^2 inlet area of the capillary, which corresponds to a flux of 6000 particles per second and square micron, STIM is well possible without any additional focusing.

In the following, we present the construction details and performance of a capillary in-air microbeam set-up for STIM at the Laboratory of Ion Beam Physics at ETH Zurich.

2. Experimental

The micro-capillaries used for beam collimation are produced from commercially available borosilicate glass tubes (8–10 cm long, 0.9 mm inner and 1.5 mm outer diameter) by a modified puller which allows to produce long and straight capillaries of regular conical shape with nearly constant taper angle of about 1° (Fig. 1).

The in-air capillary microprobe has been set up at the end of the central beam line of the 6 MV EN tandem accelerator. The glass capillary is glued into a small vacuum end flange mounted on a bellow that can be aligned to the beam position and direction by a simple 2-axis goniometer sitting on an *XY* table (Fig. 2). The upstream beamline with an inner diameter of 5 cm is pumped by a 190 l/s turbo pump and the pressure remains in the 10^{-6} mbar range for capillary openings smaller than 10 μm. For STIM measurements, requiring only a few kHz of particles, the beam is not prefocused onto the capillary inlet but there is a 12 m long drift path between the last collimator and the microprobe. For alignment of a new capillary, a cheap silicon PIN diode is positioned in front of the capillary tip and the goniometer is adjusted at reduced beam current to the maximum count rate in the diode. For this purpose, the count rate is made audible via a loudspeaker,

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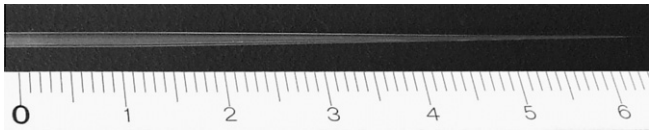

Fig. 1. Borosilicate glass capillary of regular conical shape used for beam collimation. The scale is in cm.

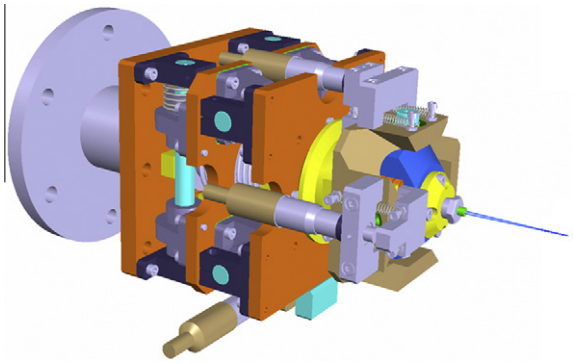

Fig. 2. Drawing of the capillary microprobe. The capillary is sitting on the end of a bellow which can be aligned to the beam by a simple 2-axis goniometer with *XY* adjustment.

which speeds up the procedure considerably. For a sufficiently straight capillary, the alignment does not take more than 5 min. After the beam set-up process, the PIN diode is replaced by a miniaturized high resolution gas ionization detector [8]. This device has an energy resolution which is comparable to the one of a silicon detector and is completely radiation hard, i.e. STIM measurements can be performed for hours at a few tens of kHz count rate on the same micron sized spot on the detector window without the slightest loss of performance [8].

Since the capillary opening is fixed in space, STIM imaging has to be obtained by raster movement of the sample. For this purpose an *XY* cross table of two inertial piezo drives is used as specimen stage. The maximum scanning travel of the piezo drives is 7 mm and the closed loop positioning resolution is 10 nm [9]. *Z* adjustment is accomplished by a manual micrometer stage. For observation of the capillary tip position relative to the sample a digital optical microscope is mounted. Fig. 3 shows a picture of the complete microprobe set-up. The capillary tip region can be flooded by helium in order to reduce energy loss and scattering of the ion beam.

3. Results

So far, the capillary microprobe has been operated with proton and He beams of energies between 1 and 3 MeV. Fig. 4 displays energy spectra of a 1 MeV p beam transmitted through a capillary with 2 μm outlet diameter. The spectra were taken with a PIN diode, both with the capillary under vacuum and in air. With the well collimated and parallel beam the particle flux at the capillary exit corresponds well with the input current density. Only decent enhancement factors between 1 and 3 have been measured for all particle types and energies used. Therefore it can be assumed that under vacuum the particles in the full energy peak (solid line in inset of Fig. 4) have not undergone any significant scattering by the capillary wall. They leave the capillary with the full beam energy and a general broadening of the energy distribution is not detectable with the present PIN diode resolution (10 keV for protons). A low energy tail appears in the spectrum, probably due to scattering with the inner walls. If the beam is taken into air the energy distribution is shifted and broadened by energy loss and straggling in the atmosphere between the capillary exit and the detector as well as by the gas particles entering the capillary. The angular straggling by the gas inside the capillary is probably responsible for the enhanced tail in the energy spectrum (Fig. 4). It widens the very narrow angular distribution of the beam and enables particles that have undergone a scattering to still get to the tip opening.

Fig. 5 (top) shows the STIM image of a part of a mosquito wing produced with a 1 MeV proton beam through a capillary with a tip opening of 8 μm. The raster size was 500 μm times 230 μm with a step size of 5 μm. The dwell time on each of the 100 × 47 pixels was approximately 1 s, the minimum that can presently be obtained by the stage controller and scanning software. The total acquisition time for a STIM frame was about 2 h. In a conventional microprobe with beam scanning the time needed for a STIM image is only minutes [10]. It is expected that by technical improvement of the raster hard- and software the scan speed can be increased by about one order of magnitude.

Fig. 5 (bottom) shows a STIM image of a microscopy gold grid with a mesh size of 85 μm. The lateral resolution in this image is on the order of 10 μm, given by the capillary diameter and the coarse step size used. The quantity plotted in the images is the

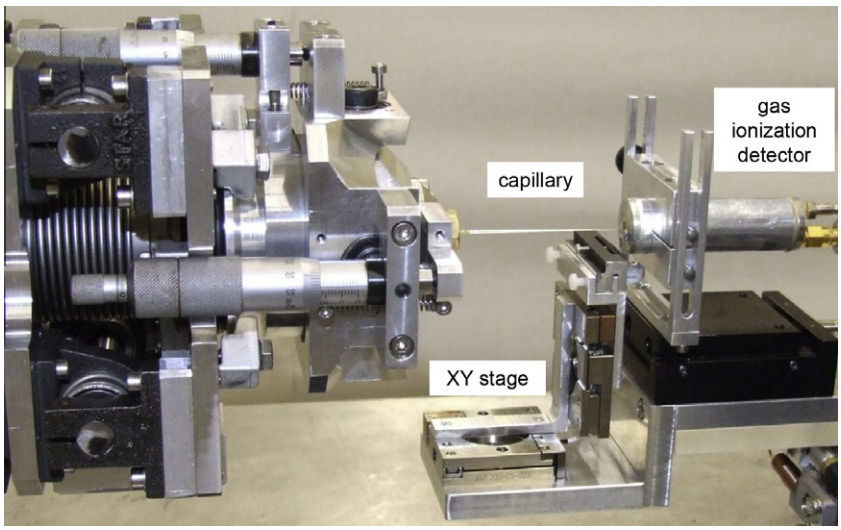

Fig. 3. Photograph of the capillary microprobe set-up with *XY*-stage and gas ionization detector.