3D Hydrogen Microscopy Using The High Energy Proton Probe SNAKE

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Several techniques for quantitative hydrogen imaging have been developed. However, it is still a challenge to measure 2D or 3D hydrogen profiles on a micrometer scale. The new ion microprobe SNAKE (Superconducting Nanoscope for Applied nuclear (Kern-) physics Experiments) at the Munich tandem accelerator [1,2] offers the possibility of quantitative 3-dimensional scanning of hydrogen distributions with a lateral resolution of one micrometer or below utilising high energy proton-proton scattering [3]. The high proton energies in the range of 8-30 MeV make this method available to unsupported targets up to some 100 μm thickness.

Hydrogen detection is performed utilising the elastic scattering of high energy protons from hydrogen nuclei which are situated in the target. At SNAKE the scattered projectile and recoiled target protons are detected in coincidence in forward direction using a large area silicon strip detector [4] which covers a significant part (2.3 sr) of the total solid angle in order to detect nearly all of the valuable proton-proton scattering events. The granularity of the detector enables redundant discrimination for proton-proton scattering events reducing background below 10^{-6} even at high count rates (e.g. 10 kHz). Major advantage of pp-scattering is the lowest possible irradiation damage in ion beam analysis of hydrogen because the nuclear scattering cross section by a factor of 500 for 20 MeV protons compared to a pure Rutherford cross section. [5]. Thus, a sensitivity in the range of parts per million hydrogen atoms is obtained.

A 2D lateral hydrogen image of the target material is obtained by scanning the focused proton beam across the sample and by marking every proton-proton signal in a map with the actual beam position. The sum energy of each proton pair simultaneously gives a depth information. The achievable depth resolution was found to be better than 5 mm even at probing depths of some 100 mm. [5]

In order to demonstrate the potential of the method, hydrogen distributions of a mayfly's g (*Ephomeroptera Heptageniidae*) are shown in fig. 1b and 1c. The wing was dried and mounted without any further preparation at the target position of SNAKE. Fig. 1b shows the hydrogen image from proton-proton scattering scanning a focussed 10 MeV proton beam at 2.6 mm step size across the rectangular area marked in the principal drawing of the wing in fig. 1a. A branching point of the capillary supply and support system of the wing which lies within the investigated area can clearly be recognised in this hydrogen image. The image directly shows the hydrogen content of the wing. The double peak structure seen at the main capillary results from the characteristic projected image of a hollow tube.

The third dimension of the hydrogen distribution was recorded simultaneously with the 2D map of fig. 1b. A cross section of the hydrogen distribution of the capillary is shown in fig. 1c. It is obtained by evaluating the sum energy spectrum of the detected proton pairs at each position of the base line AB where the pixels of the marked area in fig. 1b are projected onto. The energy loss spectrum was transformed into a depth scale using tabulated values of stopping forces for the relevant proton energies.

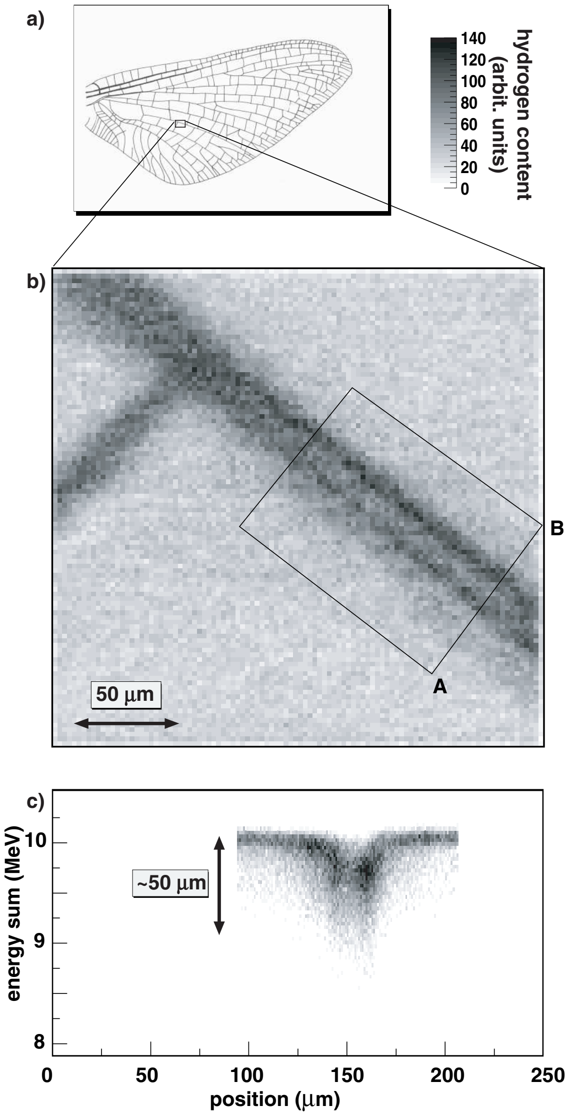

Fig. 1: a) Schematic drawing of a mayfly's wing. b)2D map of the hydrogen content of marked area in fig. 1a. c) Hydrogen cross sectional profile of the marked area of fig. 1b projected onto the base line AB (see text).

The analysis can be extended by a simultaneously performed 2D mapping of other elements e.g. using PIXE (Particle Induced X-ray Emission) [6] for analysis of heavy elements. For analysis of thick targets with proton energies larger than 20 MeV a new detector setup with 1000 μm thick position sensitive detectors in a honeycomb arrangement is under construction.

References

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