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PRELIMINARY EXPERIMENTS OF TAPERED GLASS CAPILLARY OPTICS USED AS FOCUSING SYSTEMS FOR MEV ION BEAMS

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In lucrare sunt prezentate experimente care evidenţiază efectul de focalizare a structurilor de sticlă cu capilaritate conică a fasciculelor de ioni de He cu energia de ordinul MeV. Capilarele conice au o lungimea totală de cca. 50mm iar diametrele de intrare/ieşire este de 2mm respectiv câteva zeci de microni. Ionii incidenţi pe acest dispozitiv sunt reflectaţi pe pereţii interiori de câteva ori suferind aşa numitul proces de canalizare pe suprafaţă o fracţie de cca. 1% fiind transmisă la ieşire fără a pierde energie. În anumite condiţii această fracţie a fasciculului transmis este de 10 până la 1000 ori mai mare decât cea corespunzătoare raportului dintre suprafeţele de intrare/ieşire. Comparabil cu facilităţile convenţionale de obţinere a micro fasciculelor, această metodă este simplă şi necostisitoare deschizând noi căi pentru aplicaţiile fasciculelor accelerate (Ion Beam Applications) cum sunt microanalizele şi noi tehnici de implantare ionică.

We present experiments which proofs the focusing effects of fine glass capillary for MeV He ion beams. Tapered capillaries have an overall length of 50mm and inlet/outlet diameters of 2mm, and few tens of microns respectively. The incident ions to such device are reflected by the inner wall several times suffering the so called process of surface channeling and coming at the exit in a fraction of app. 1% without having significant energy loss. If some conditions are accomplished, this fraction of transmitted beam is 10 up to 1000 times greater than that according to the ratio of inlet/outlet areas. Compared with the conventional micro-beam facilities, this method is certainly simple and low cost, opening easy way for sub-micron Ion Beam Applications (IBA) as are analyses and new ion implantation techniques.

1. Introduction

Beams having cross section with diameters in the range of 1-100µm or so called micro-beams are more and more used in elemental and structural characterization of materials with micron-sized surface structure. Such micro-beams are normally obtained with expensive and sophisticated ion optics using electric or magnetic lenses and multiple collimators coupled to electrostatic

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accelerators which fulfill the requirements of high energetic resolution (keV) and low angular divergences for delivered beams.

Today, a great interest in obtaining micro-beams by simple and low cost solutions is for the focusing effect of the beams passing through a tapered glass capillary.

The interaction between energetic ion beams and the solid surface varies in the nature according to many parameters. For light ions incident on smooth solid surfaces at grazing angles of about 10mrad the interaction is roughly of three types. The ions that approach close enough to the target nuclei are elastically scattered losing significant amount of their energy and changing their direction. Other process is for ions that may be reflected by the surface potential barrier without significant loss in energy. There are also intermediate cases in which ions have energy losses and directional changes by interacting with inner shell electrons. The dominant interaction depends on ion and surface species, the ion energy and its angle of incidence on the surface, the surface geometry and others.

In studies reported in [1] it was observed that for beams of 8keV Ar^{8+} the intensity of transmitted beam trough a tapered capillary need some tens of seconds from the beginning until it reach its maximum. This result could be explained as follow (see Fig. 1 a and b): the observed saturation time suggests that the incident ions entering the capillary are charging up the inner wall (Fig.1a) and after this accumulated charge is big enough to prevent other collisions of ions with the inner wall, the beam will travel more or less parallel toward the exit (fig. 1b)

Fig. 1 Model of guiding effect for low energy ions

Also in the experiments reported in [1], measurements of charge distribution for the transmitted beam showed that the initial charge state of ions is conserved after the saturation time which indicates that transmitted ions never touch the inner wall of the capillary.

There were also reported studies [2] of scattering characteristics for a 2.5MeV proton beams incident on a smooth Au thin film on SiO_2 substrate with small incident angles. The experimental angular distribution resulted for reflected protons showed that for incidence angle below 4mrad the beam is totally reflected and for larger incident angle, the reflected beam has a rather broad profile peaking at:

$$\theta=(1.8^{o}\pm0.2^{o})\cdot\varphi$$

where φ is the incidence angle and θ is the scattering angle.

From other reported experiments [1-4] seems that if for highly charged ions having energies of few keV, the focusing effect is produced by electrostatic charge of the inner wall and corresponding guiding of the beam, for high energy beams (MeV), the focusing is mainly based on small angle scattering of the beam interacting with surface nuclei.

Some experimental results [4] related to focusing of high energy beams (2MeV He^{+}, and 7.6MeV N^{2+} ions) using tapered glass capillaries showed that obtained transmission efficiencies could be of 10 up to 1000 times greater than the corresponding ratio of inlet to outlet areas, and this is depending of many parameters as are taper angle, tilt angle of incident beam, energy loss of ions in capillary material the quality of inner surface of walls and so on. Also, some of these experiments suggested that to focus high energy beams, the use of heavy metals surfaces for inner walls of focusing optics could be preferable to insulating ones.

The ion beam optics based on these principles are using taper angles designed to be less than critical angle of channeling so that the ion beam can penetrate the inner space in a very good analogy to general channeling phenomena of ions in single crystals.

Such new kind of focusing optics with fine glass capillaries based on quite simple interaction of glancing ion beam and a smooth inner wall have been experimented at U-120 Cyclotron using different glass pipes slightly tapered to become narrower in their inner diameter towards the outlet. In this paper we report the first set of experimental results with beams of 3MeV He ions transmitted trough glass tapered capillaries having cross section area of 80 up to 150μm in diameter.

2. Experimental

Experiments were carried out at U-120 Cyclotron in National Institute for Physics and Nuclear Engineering – Horia Hulubei using beams of He^{+} ions accelerated in sub harmonic up to 3MeV and transported through beam line used for RBS analyses.

The experimental setup based on principle scheme from fig.1 has been installed inside the existing reaction chamber dedicated for RBS analyses.

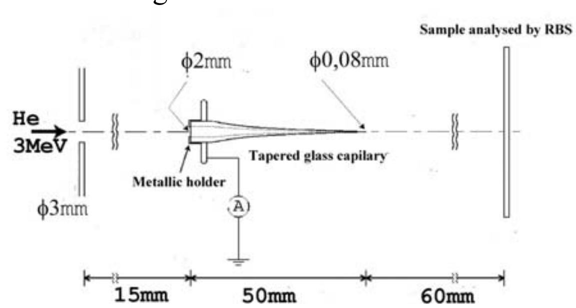

Fig. 1 Principle scheme of experimental setup for the transmission of 3MeV He beam through a tapered glass capillary.

The experiments have been performed by using two tapered capillaries, both having the inner diameter at the inlet of 2mm and inner diameters at the outlet of 0.15mm and 0.08mm respectively. In Fig.2 are shown the glass conical capillary and its fixture provided inside of RBS chamber.

Fig. 2 Conical glass capillary and its mounting fixture used in beam focusing experiments

3. Results and discussions

At the beginning, using a retractable phosphor screen instead of the sample from fig. 1 and a second one placed at 360mm distance from the outlet of glass capillary, we optimized the beam transmission looking for the maximum light intensity emitted by these screens as it could be seen in Fig. 3 and by adjusting different settings of ion optics (lenses, steering magnets) in order to set the right angle of alignment of the incident beam with the conical capillary.

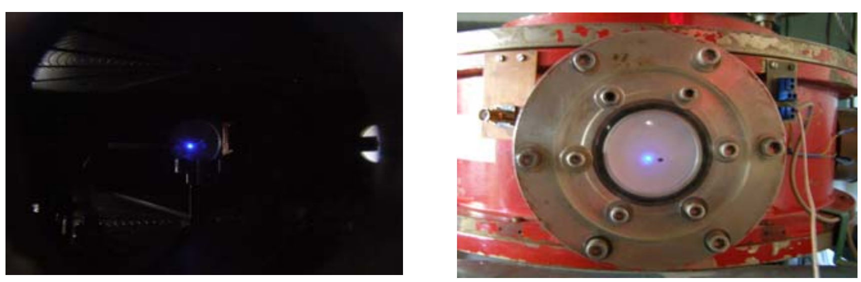

Fig. 3 Visualization of transmitted beam at 60mm (left) and 360mm (right) distance from the output of glass capillary.

According to a rough estimate of the diameter for lighting spot at 360mm distance being less than 2mm, the corresponding divergence of the transmitted beam is less than 0.5mrad.

To quantitatively estimate the focusing effect, we performed beam intensities measurements at the exit of Φ3mm collimator and at the exit of glass conical capillaries, the obtained values being listed in the table below. (The current values given by a Keithley type electrometer with an incertitude of less than ±5% are affected by an additional incertitude of app. ±15% corresponding to the effects of electron secondary emission at the target).

I_{IN}[nA]		J_{IN}[nA/mm^2]	I_{OUT}[nA]	J_{OUT}[nA/mm^2]	Gain[J_{OUT}/J_{IN}]
Collimator 3mm	60	8,48	60	8,48	1
Capillary 2/0,15mm	26,66*	8,48	6	339,5	40
Capillary 2/0,08mm	26,66*	8,48	3	596,8	70,38

*** Beam intensities at the input of capillaries are reduced proportional to the cross sections ratio (4/9).**

From this table results that in our experiments the obtained gains expressed as ratio of output to the input current densities are showing clearly the focusing effect but these gains are smaller than reported values [1]. This difference could be the consequence of both, initial divergence of the incoming beam, small misalignment between the beam and the conical capillary, as well as not optimum taper angle for this one.

In order to measure the degradation of the energy for transmitted beam we performed RBS (Rutherford Backscattering Spectrometry) experiments [5] analyzing samples having known composition and structure. In a common representation of two RBS spectra obtained for a thick gold sample with direct and transmitted beams (see Fig. 4) the high energy edges of these spectra are coincident and that is proofing the conservation of the initial energy of the beam.

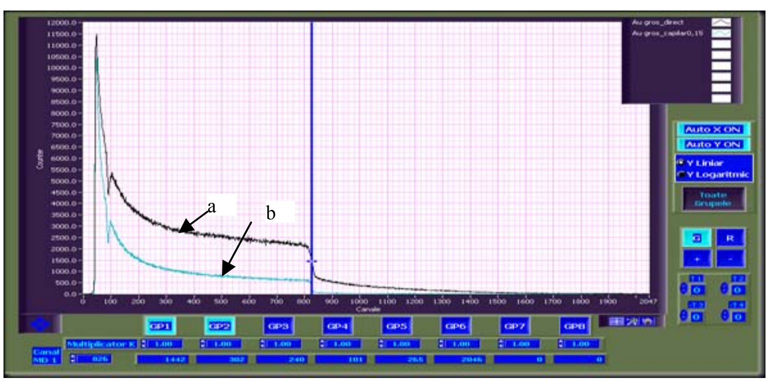

Fig. 4. RBS spectra for a thick Au sample obtained with direct (a) and transmitted (b) beam.

Since no data concerning the energy dispersion of transmitted beam trough conical capillary are available from these spectra, we used the transmitted beam to analyze a second layered sample consisting of a 100nm Au deposited on 16nm Cr the substrate being Si. The experimental spectrum obtained using a 3MeV He ions beam transmitted trough a conical capillary with 0.08mm output diameter is shown in fig. 5.

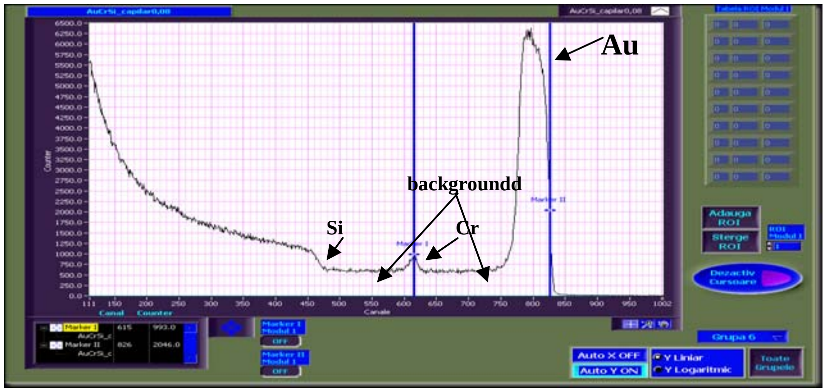

Fig. 5. Experimental RBS spectrum for a layered sample of Au_{100nm}-Cr_{16nm}-Si_{thick} obtained with 3MeV He ions transmitted trough a conical capillary (Φ_{out}=0.08mm).

From this last RBS experiment we concluded that:

- a fraction of the beam estimated from the ratio of spectrum area for “Au” and “background” to be app. 50% has an energy dispersion of 1.2MeV;
- the main beam is conserving its initial energy and energy dispersion being possible to use in RBS analyses with 10nm depth resolutions and 80x80μm investigated area.

4. Conclusions

These preliminary experiments and results open unexpected opportunities for upgrading the existing research infrastructure at U-120 Cyclotron dedicated to material analysis and characterization. The use of such simple and low cost ion optics to obtain micro beams will make possible not only to investigate surface micro structured samples and performing channeling experiments but also, by extracting the focused beam in air, will be possible to study with nuclear methods [6] samples which are not compatible with the high vacuum existing in regular reaction chambers as are biological tissues or cells.

R E F E R E N C E S

[1]. *Ikeda Tokihiro et al, ,,* Production of a microbeam of slow highly charged ions with a tapered glass capillary, APPLIED PHYSICS LETTERS 89, 163502 ,2006

[2]. *J. A. van Kan*, Dr. Thesis Vrije Universiteit Amsterdam 1996

[3]. *T. Nebiki et al.*, Taper angle dependence of the focusing effect of high energy heavy ion beams by glass capillaries Nuclear Instruments and Methods in Physics Research B 266 ,(2008) 1324–1327

[4]. *Tokihiro Ikeda et al,* Focusing of charged particle beams with various glass-made optics XXV International Conference on Photonic, Electronic and Atomic Collisions IOP Publishing.

[5]. *Wei-Kan Chu, James W. Mayer, Marc-A. Nicolet,* Backscattering Spectrometry, Academic Press New York San Francisco London, 1978

[6]. *Jun Hasegawa, Shigeki Shiba, Hitoshi Fukuda, Yoshiyuki Ogur,i* A compact micro-beam system using a tapered glass capillary for proton-induced X-ray radiography, Nuclear Instruments and Methods in Physics Research B 266, (2008) 2125–2129.