

Various beams for RBS at IFIN-HH

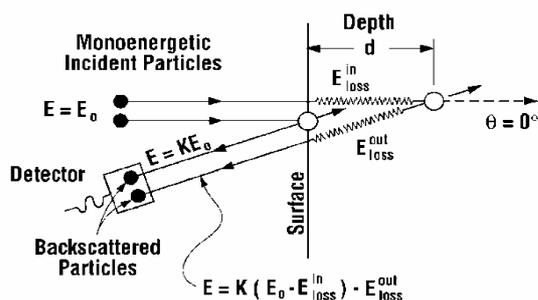
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At IFIN-HH, we are using our Cyclotron for Ion beam analysis, mainly RBS. Rutherford Back Scattering (RBS) is a widely used method for material analysis of thin films and surfaces. We give a brief overview about some results obtained with RBS, before we describe a new method for micro beam creation tested in our laboratory. Focusing the beam with a glass capillary seems to be a possible way, to enlarge our RBS applications to surface mapping and probably even channeling applications. More studies of the focusing effect itself are planned, involving more sophisticated beam analysis methods.

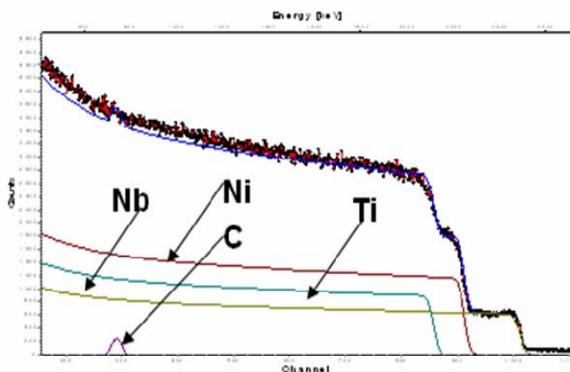
Introduction

Ions of a high kinetic energy (typically 1-3MeV) are directed at the sample. The incident ions are elastically scattered from the atoms in the sample. The number of scattered ions and their energy is measured. The energy loss of a given (in general low mass; He^+) back scattered particle measured at a fixed angle is a function of initial energy, mass (kinematic factor) and depth of the target nucleus.



Picture 1: Principle of RBS

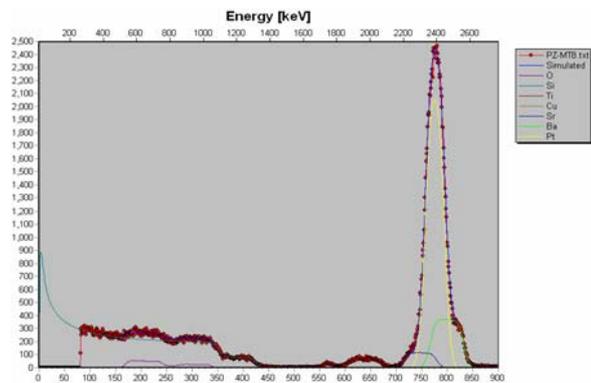
The measured energy spectrum is the sum of all contributions of the constitutive elements inside the probe. This data provides information on the composition of the sample, the distribution of those components and the thickness of the sample.



Picture 2: Example for Elemental composition

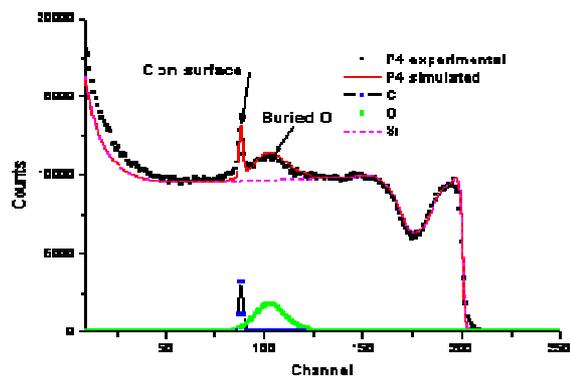
Application Samples

In praxis, the analyzed samples are consisting of different layers and the resulting spectra are more complex. A typical multi-layer sample is shown in picture 3:

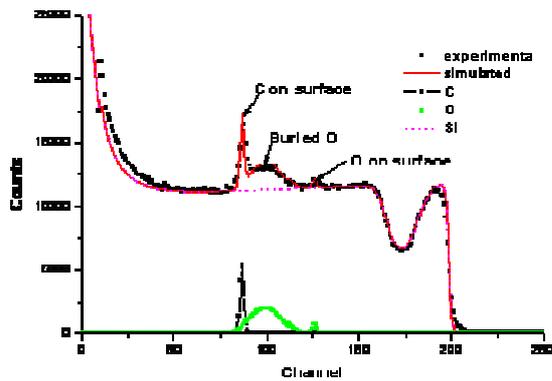


Picture 3: Sample with composed layers

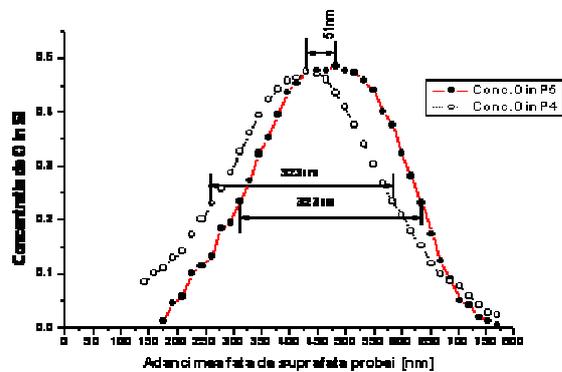
From measurements of depth profiles of probes before and after thermal treatments, diffusion processes can be analyzed. See pictures below:



Picture 4: measured and calculated spectrum of a probe with a buried Oxygen layer in Silicon (P4)



Picture 5: measured and calculated spectrum of the same probe after heat treatment (P5)



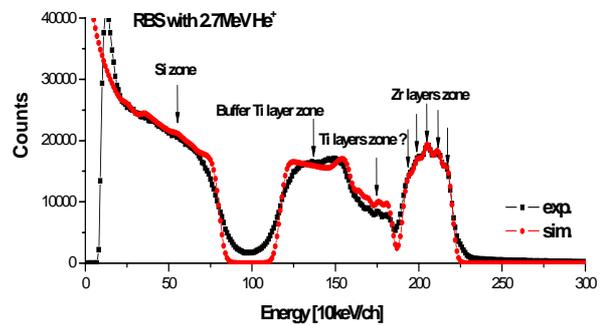
Picture 6: Position and concentration (shape) of the buried oxygen layer in Si before (P4) and after (P5) thermal annealing at 1000°C

The interesting result of this analysis is, that the layer is more or less keeping its shape (~320nm), but is shifted by ~50nm backwards (away from the surface). Similar analyses e.g. for intermediate layers have been performed for different “customers” in the last years. So even a cyclotron is not a dedicated machine for RBS, we can support other institutes and local industry with our analyses in order to improve their products or production processes.

Ambiguity problem / use of different ions

Due to the limited beam quality (energy spread ~1%) of the cyclotron, limited detector resolutions and the complexity of probes, some of the spectrums obtained are not precise enough to be clearly analyzed (fitted) without ambiguity. To resolve this ambiguity problem we can measure with different angles of the incident beam towards the probes’ surface in order to better separate different layers or elements from each other.

But sometimes, we end up with spectrums like this:



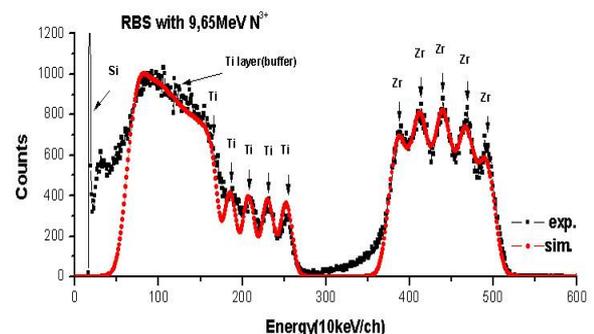
Picture 7: Nano-structured layers measured with He⁺

To analyze such samples a change of incident angle simply is not good enough to achieve acceptable results. Therefore, we were retuning the cyclotron for the use of different ion beams like e.g. Nitrogen:

No.	Ion	Energy (MeV)	Cross section[mm ²]	Beam intensity[nA]
1	⁴ He ⁺	2,7-5	0,25-25	3-100
2	² H ⁺	1,35-2,5		
3	¹⁴ N ⁺²	3		
4	¹⁴ N ⁺³	10		
5	H ₂ ⁺	1,35-2,5		

Table 1: Different beams from the cyclotron

Depending on the elemental composition, we can significantly improve our resolution by using various dedicated ion beams (varying mass (element) and angle of the incident ions). For layers with heavier atoms (obs.: RBS only occurs, if the incident ion has less mass than the target atom), the use of a Nitrogen beam can resolve the probes much better.

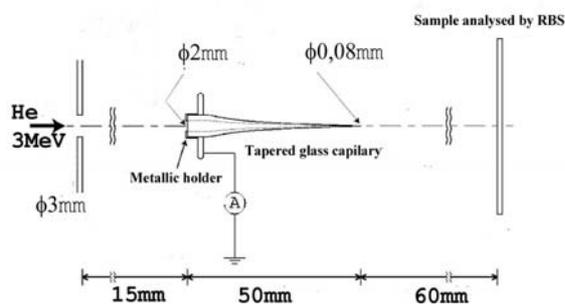


Picture 8: Experimental and simulated spectra of a nano-structured probe of 5 pairs of ZrN/TiN layers having 15 nm/layer deposited on Si with a Ti buffer layer of 300nm

Micro beam

In order to extend the field of application for RBS (and other IBAs), we have been looking for possibilities to achieve micro beams with our cyclotron. Because of the relatively poor beam quality from this cyclotron, standard procedures are not applicable. But we found another way.

By introducing a conical glass capillary into the beam line, we could achieve micro beams with reasonable intensities and acceptable quality (Energy spread, divergence). The principle is shown in Picture 9:



Picture 9: Beam handling with a glass capillary

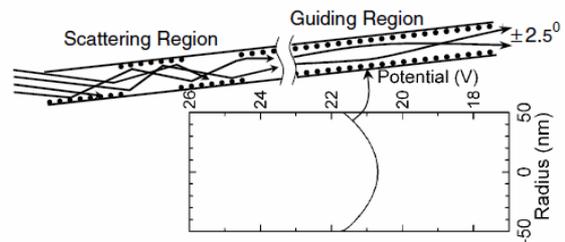
In comparison to a simple collimator (e.g. iris) the (perfect aligned) glass capillary is not only cutting out a part of the beam, but also shows a kind of focusing effect which leads to relative higher intensity of the remaining beam. First results are shown in table 2:

	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

Table 2: Beam parameters and gain factor for different capillaries (* Beam intensities at the input of capillaries are reduced proportional to the cross sections ratio (4/9))

The gain factors of 40 and > 70 indicate clearly, that some kind of focusing occurs inside the capillary. This focusing effect is still topic of (basic) research and probably not yet totally understood. Some possible explanations are given in [1, 2, 3]. Without going into details, it seems there are two possible ways for the beam to pass through the capillary. First is low angle scattering at the surface or near surface atoms of the capillary, which also leads to energy losses of the

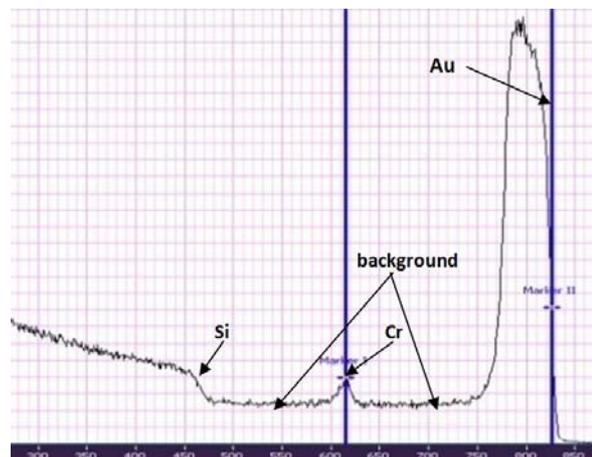
transmitted ions. Second parts of the beam seem to be guided through the capillary without (significant) energy change. How exactly this works is still topic of research.



Picture 10: beam in glass capillary [N. Stolterfoht, et al., Phys. Rev. Lett., 88,133201 (2002)]

First results

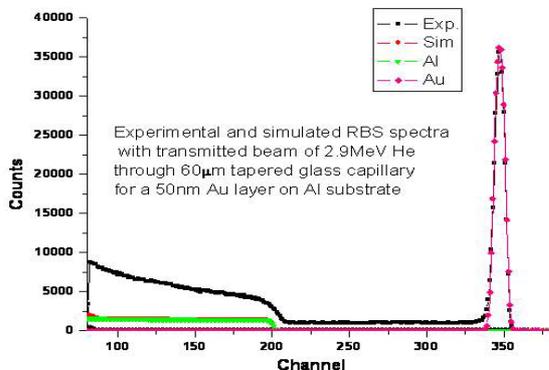
In order to analyze the beam after the capillary, we used one of our standard probes. Picture 11 shows a RBS spectrum for a layered sample of Au_{100nm}-Cr_{16nm}-Si_{thick} obtained with 3MeV He ions transmitted through a conical capillary ($\Phi_{out}=0.08$ mm). The RBS spectrum shows two components of transmitted beam: -an "undisturbed" beam (initial energy and energy dispersion are more or less conserved) -a fraction of the initial beam having a large energy dispersion



Picture 11: Energy spectrum of transmitted beam

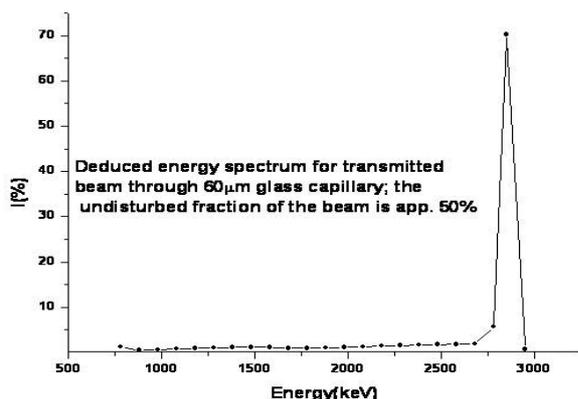
For more precise analysis of the transmitted beam, we were analyzing the reflected He ions from a 2.9MeV beam after passing through a 60 μ m tapered glass capillary, using a 50 nm Gold layer on an Aluminum substrate (see picture 12). It is to mention, that the

cyclotron was running during this experiment for 24 h, with a stability of +/- 2 KeV!



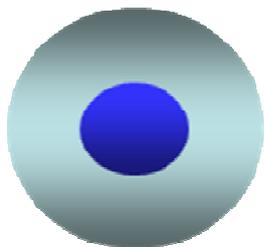
Picture 12: RBS Spectrum

From this spectrum we can deduce an energy spectrum (picture 13) of the transmitted beam, which shows that ~ 50% of the ions in the beam seem to be transmitted without energy loss.

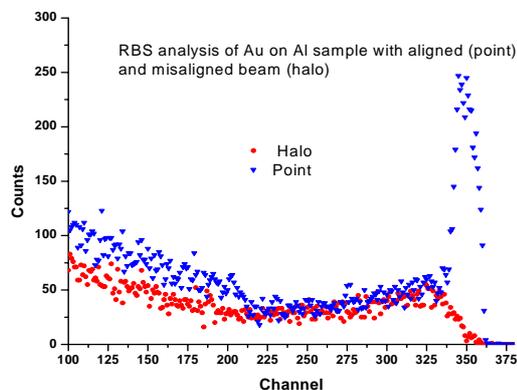


Picture 13: Deduced energy spectrum

Visual examination (phosphor screen) suggests, that the other 50% of the beam, which suffer energy loss also have a bigger divergence as the “undisturbed” beam and form a halo around the “undisturbed” center beam.

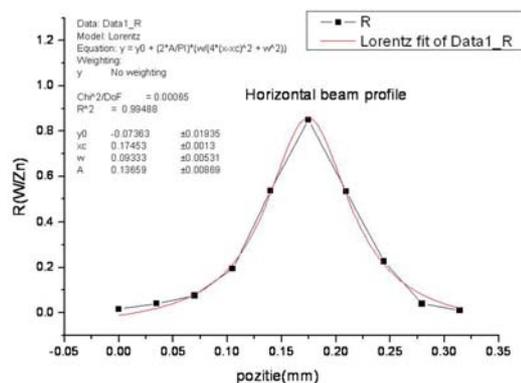


To crosscheck this, we measured two additional spectrums, one with proper alignment of the tube and one with identical setup, but slightly misaligned capillary.



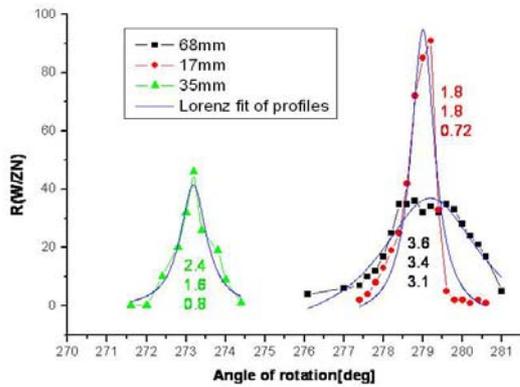
Picture 14: RBS Spectra with an aligned and misaligned capillary

Again with the aligned capillary ~ 50% of the ions in the beam seem to be transmitted without energy loss. To measure the beam profile we used a thin Wolfram wire of 20 µm, mounted on a rotating disk behind the capillary. From the measured RBS spectra we could deduct a beam profile with a width of 80 µm.

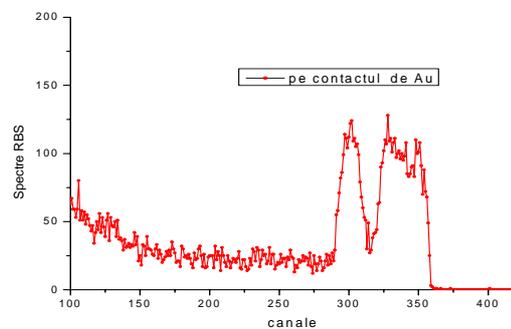
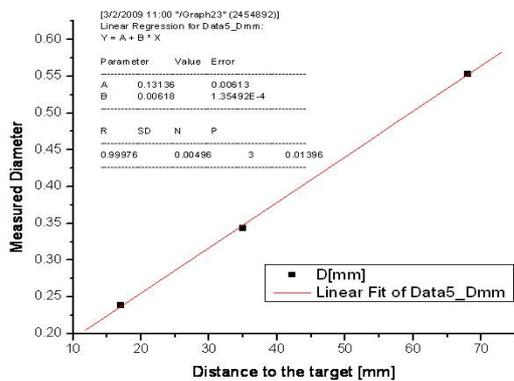
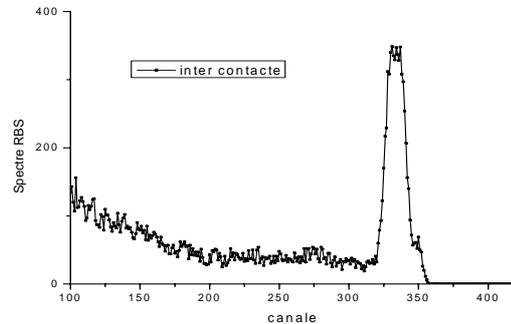


Picture 15: beam profile

By repeating this measurement with different distances (17, 35 and 68 mm) of the wire to the exit of the capillary, we could deduce a divergence of the “undisturbed” center beam of ~ 6 mrad. Visual observation by means of phosphor screens on 60 and 360 mm distance lead to the same result (5,5 -6 mrad).

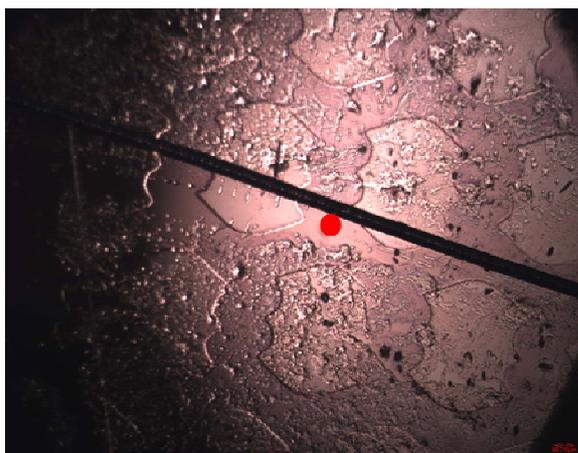


The resulting spectra show that we clearly can resolve the geometric different regions on this chip:



Picture 16 & 17: Measured Divergence of a 200µm capillary

To test the possibility of mapping surfaced with this kind of micro beam, we measured the spectra of a micro-structured semiconductor.



Picture 18: Semiconductor surface (black: wire with 60 µm, red: beam spot of 50 µm)

Conclusion:

Even a cyclotron is not dedicated for RBS, we can achieve interesting results and the capillaries most probably open the door for micro beam applications.

Further steps:

- Standardization of (simple) RBS for our customers (EN17025)
- More detailed studies on capillary focusing and new applications with micro beams
- New analyzing chamber with better adjustment possibilities (arrived in the meantime)
- Channeling experiments
- A new, dedicated accelerator (tandem) is planned

Acknowledgement:

The experiments could not be performed and analyzed without the help of Ion Rusen, Stefan Nitisor, Ofelia Muresan, the operator crew of the cyclotron and some inciting discussions with Eugen Ivanov.

References:

1. low energy ions of Ne^{7+} are guided through capillary tubes even for small angles of misalignment with the beam axis (N. Stolterfoht et al., Phys. Rev. Lett. 88, 133201/2002)
2. the transmitted beam of 8keV Ar^{8+} through a tapered glass capillary need some tens of seconds to reach its maximum of intensity (T. Ikeda et al., Phys. Rev. Lett. 89, 163502/2006)
3. Experiments with beams of MeV ions transmitted through tapered capillaries revealed a focusing effect most probable based on total reflection at small angles (T. Nebiki, et al., J. Vac. Sci. Technol. A 21, 1671 /2003).