Various beams for RBS at IFIN-HH

H. Schubert, D. Dudu, I. Vata
Horia Hulubei National Institute of Physics and Nuclear Engineering - IFIN HH; Str. Atomistilor no.407, P.O. BOX MG-6, Bucharest - Magurele, ROMANIA

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.

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](image)

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)](image)

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
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:

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:

<table>
<thead>
<tr>
<th>No.</th>
<th>Ion</th>
<th>Energy (keV)</th>
<th>Cross section [mm²]</th>
<th>Beam intensity [mA]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>He⁺</td>
<td>2.7-8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>H⁺</td>
<td>1.25-2.5</td>
<td></td>
<td>0.25-25</td>
</tr>
<tr>
<td>3</td>
<td>Mg⁺</td>
<td>3</td>
<td></td>
<td>3-100</td>
</tr>
<tr>
<td>4</td>
<td>Al⁺</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>H₂⁺</td>
<td>1.25-2.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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:

![Beam handling with a glass capillary](Image)

**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:

<table>
<thead>
<tr>
<th>Capillary</th>
<th>L_{1} [inA]</th>
<th>J_{1} [inA/m²]</th>
<th>L_{2} [inA]</th>
<th>J_{2} [inA/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3mm</td>
<td>0</td>
<td>8.48</td>
<td>0</td>
<td>8.48</td>
</tr>
<tr>
<td>2.0/0.15mm</td>
<td>26.66</td>
<td>8.18</td>
<td>6</td>
<td>339.3</td>
</tr>
<tr>
<td>2.0/0.08mm</td>
<td>76.66</td>
<td>8.48</td>
<td>4</td>
<td>576.8</td>
</tr>
</tbody>
</table>

*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.


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}Cry_{16nm}Si_{30nm} obtained with 3MeV He ions transmitted through a conical capillary (D_{max}=0.08mm). 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

![Energy spectrum of transmitted beam](Image)

*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 μm 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!

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

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.

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

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

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 Ne7+ 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 Ar8+ 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)