

Enhanced thin film analysis via High Resolution RBS using the NEC CARBS system

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Abstract. Advancements in thin film deposition techniques can now produce films of only a few monolayers in thicknesses, with multiple applications emerging in the nano technology field. This maturing manufacturing technique is driving the need for diagnostics tools able to accurately measure depth profiles. To meet this need, the Compact Automated Rutherford Back-Scattering (CARBS) system is under development at National Electrostatics Corp. (NEC) for nanometer thin film analysis using High-resolution RBS (HRBS) within a 4 x 4meter footprint. We present the recent development of the system and demonstrate a study of HRBS applied to a 30nm CoAl alloy film. We compare the performance of the CARBS system with the conventional NEC HRBS end station and discuss the advantages of HRBS over SIMS method.

The advancements in production of monolayer level films [1] require diagnostic tools with accuracy of a few Angstroms. The several MeV beam energies typically applied in Rutherford Backscattering Spectroscopy (RBS) result in the penetration depth of up to a few micrometers. As a result, the effective depth resolution is in the range of a few tens of nanometers [2,3]. This makes RBS analysis not sensitive enough to resolve the fine structure within a film. Figure 1 demonstrates a RBS spectrum measured with 1.9MeV He+ beam in the RBS Facilities at MPI of Microstructure Physics. A sputter-deposited film made at MPI of Microstructure Physics consisting of 3nm MgO capping, 30nm CoAl alloy on the MgO substrate is taken as a demo system. To remove the charging due to insulating MgO capping an additional 30 nm thick carbon layer was extra deposited before RBS measurement. The RBS spectrum measured with 169 degrees and 90 degrees scattering angle allows to resolve Co and Al peaks and provides an accurate measure for the Co-Al elemental ratio within a film but gives no information on the homogeneity of the film. Obviously, the beam energy has to be reduced to get a more detailed shape of Co and Al peaks. The RBS spectrum measured with He+ beam 400keV is shown in Figure 1 and provides an improved depth profile and reveals an important concentration gradient within the film (Figure 1 – middle). The further improvement in the depth resolution is limited by the energy resolution of the standard Si implanted detectors (Ametek, 15 keV). To achieve the desired energy and depth resolution the High-Resolution RBS technique has been developed in the last decades [4]. This technique utilizes a magnetic spectrometer with MCP detector and allows to reduce the energy resolution up to 1 keV.

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One of the first dedicated HRBS systems is the NEC CARBS. Here we present the recent improvements in the CARBS system and discuss the performance as compared with the standard NEC HRBS end station. We show HRBS analysis of the introduced CoAl sample and discuss the improvement in the performance. Finally, we compare the HRBS sensitivity for depth profiling with those of SIMS method.

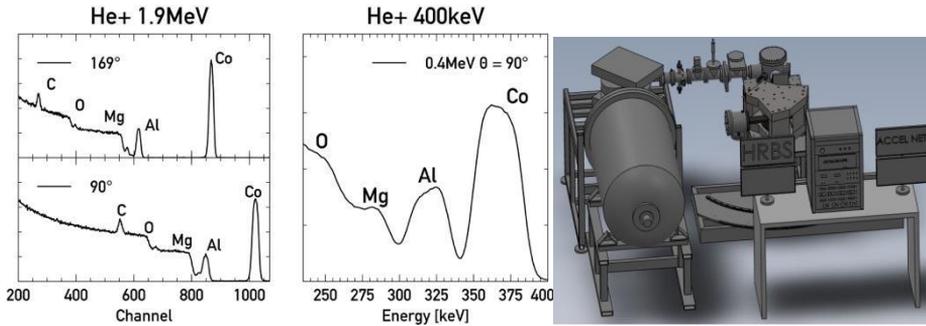


Fig. 1. RBS spectra of the test sample (MgO/30nm CoAl/30nmMgO/30nm Carbon) as measured at different scattering angles θ with the 1.9MeV (left) and 400keV (middle) He+ beam using Si implanted detector with 15keV energy resolution. Right - overview of the NEC CARBS system

The NEC CARBS system is shown in figure 1 (right). The 0.5MV Pelletron® accelerator is equipped with the RF source to deliver 1mm in diameter He+ and H+ beams of 50 to 100nA on target. Mass and energy analysis is accomplished with a 90° magnet followed by beam size measurement, definition, and diagnostics. The analysis chamber has the base pressure of 1.3E-5 Pa and allows for sample positioning with a 5-axis manipulator. The high-resolution magnet separates the scattered beam for acquisition with the detector. The latter is a 100 x 15mm micro channel plate (MCP) with resistive anode encoder (RAE) with ~50um spatial resolution in the horizontal plane. Data collection and system operation are automatically completed by the HRBS and AccelNET computers. Scattering angles between 45° and 125° are available without breaking the vacuum. Additionally, a standard RBS detector is available and can be positioned remotely.

The requirement to meet in the HRBS is the best possible energy resolution. In conflict with improving the energy resolution is obtaining a reasonable detector solid angle. This is due to increasing kinematic energy spread in the scattered beam with increasing solid angle. Typical HRBS systems have a solid angle of 0.4mStr. This results in an angular spread of $\pm 0.7^\circ$ which induces a kinematic energy spread. The energy spread becomes greater than $\pm 1\text{keV}$ for Silicon and lighter elements and is a maximum for H in Forward Recoil Spectroscopy affecting the final energy resolution. To minimize this effect of the energy spreading due to the solid angle effects we performed OPRA/TOSCA [4] simulations and redesign the new magnet poles. From the magnet simulation, the focal points of the scattered He+ are perpendicular to the central ion trajectory and used for correct detector placement see Figure 2 (right), and optimize the beam focusing at the MCP detector. The new magnetic poles [5] allow to optimize the focus of the incoming particles on the one-dimensional detectors such that the scattered particles of the same energy are perfectly aligned vertically at the detector. Moreover, with the optimized detector placement the total energy width is ~28% of the central ray energy (~22% previously). To take advantage of the energy resolution of the magnet the MCP/RAE detector pulse processing electronics time resolution is set for ~10ns [6]. Figure 2 (left) confirms the ultimate 1keV HRBS energy resolution of the CARBS system as measured with the HfO₂ film on Si [7].

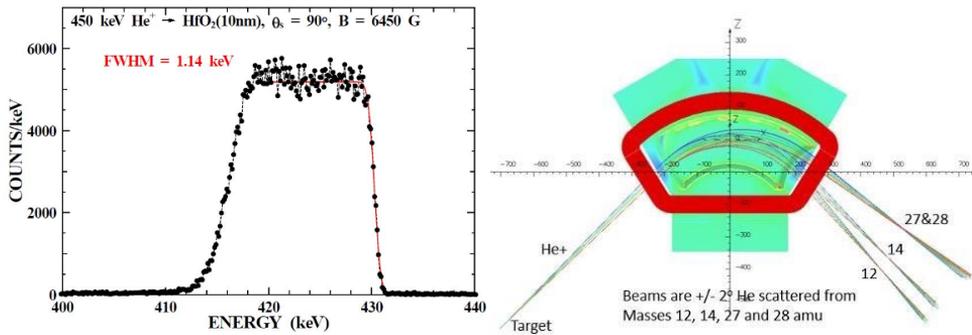


Fig. 2. Right: Simulation of the magnetic Focusing of He⁺ scattered from indicated masses. Left: Hf edge of the 10nm HfO₂ film on the Si substrate as measured with HRBS. The edge width of 1.14keV defines the ultimate energy resolution of the CARBS system

We have performed the comparison of the HRBS performance between the standard NEC RC43 end station at the Max Planck Institute of Microstructure Physics and the new CARBS endstation using an introduced test sample (MgO substrate/ 345ACoAl/ 35A MgO/308A Carbon). Figure 3 (top) shows the HRBS spectra around Co and Al peaks as measured by the two systems. The resulting profile allows the detection of the concentration gradient within the film. The elemental ratio is estimated using SimNRA code and is varying from Co 0.68 Al 1 on the surface towards Co 0.73 Al 1 in the middle of the film and Co 0.81 Al 1 on the interface with substrate. A classical RBS analysis applied for that sample provides only the averaged composition of Co 0.75 Al 1. Although the shape of the peak measured by the two systems is similar, the improvements in the CARBS EndStation allows it to achieve a broader energy window for the same parameters as seen from the broader line shapes.

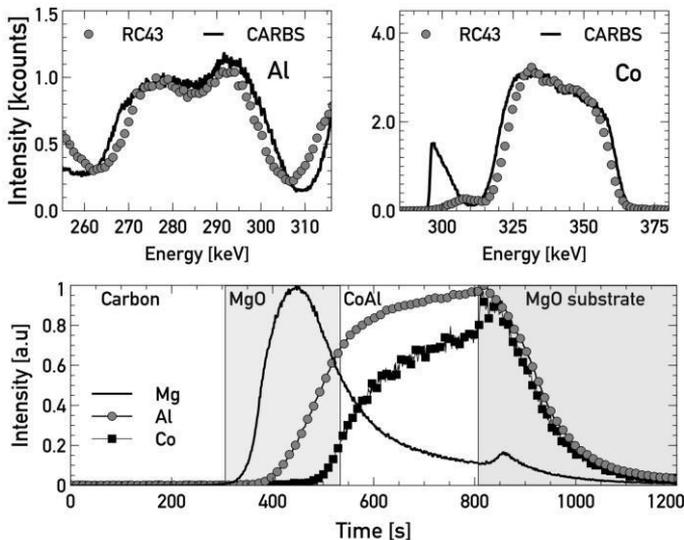


Fig. 3. Top - HRBS data of the Co and Al peaks as measured with RC43 and CARBS systems. Bottom - SIMS data as measured with 3keV Xe⁺ beam

For comparison, we performed the SIMS analysis of the same sample using a 3keV Xe⁺ beam. The SIMS depth profile is shown in Figure 3 (bottom). Different layers of the sample are marked for clear navigation. The intensities go down for the etching time above 800s as sputtering of the insulating MgO substrate slows down significantly due to charging effects. Compared to the HRBS data the accurate evaluation of the elemental stoichiometry within the CoAl film (time range 500 - 800 s) is not feasible.

To conclude, we have presented a comparisitional demonstration of the recent improvements to the NEC CARBS System for HRBS. The development of the magnetic poles in the detector using accurate numerical simulations and updated electronics with higher time resolution allows to achieve very high energy resolution of 1 keV, an increased energy window while remaining in the compact layout. We applied HRBS analysis to study a thin CoAl film for accurate depth profiling and show the advantages of CARBS system as compared to conventional NEC RC43 end station. Finally, we discuss the advantages of HRBS method as compared to SIMS.

Literature

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