Quality Assurance in an Ion Implantation Laboratory

The classical method of Rutherford backscattering spectrometry (RBS) can now be used as a new primary direct reference method [1] for measuring Quantity of Material in thin films, and in particular to support quality assurance for ion implantation laboratories. The University of Surrey Ion Beam Centre has been using this full method systematically over the last three years to validate the accuracy of its 200 kV (Danfysik) general-purpose ion implanter at better than 2% (see Colaux *et al*, 2015 [2] a paper featured by the Royal Society of Chemistry), and has recently been accredited to the ISO 17025 standard to supply certified implants to customers.

Ion implantation is an enabling technology both for the huge semiconductor industry world-wide, and also for manipulating the chemistry of near-surface layers of modern functional materials. Accurate implantation [3] is important, for example, for ion implanted standards (for secondary ion mass spectrometry, SIMS), and much scientific work requires very good control of the fluence in the ion beam.

The quality assurance method used for certifying the implanted dose by RBS obtains absolute accuracies with a standard measurement uncertainty approaching 1%. The comparable uncertainty for the indicated fluence on the implanter is similar, and does not involve the system calibration (used for industrial implanters) which is capable only of relative accuracy.

The work depends on accurate determination of the electronic gain [4] of the spectrometric system and of the energy loss behaviour of silicon [5] (used as an intrinsic measurement standard). The robustness of the method was first demonstrated in a multi-lab comparison [6] between Surrey, Budapest, and Lisbon.

The beam energy [7] is also obtained directly with very high accuracy, enabling absolute calibration of the terminal voltage of the accelerator in a collaboration between Surrey and Namur, which incidentally established the energy of the 7156 keV level of the ^{20}Ne nucleus with a significantly reduced uncertainty compared to the compilations [8].

RBS is "non-destructive", that is, the sample is not significantly changed unless the energy deposited by the beam causes changes (such as cross-linking in polymers or other beam-damage [9] effects). This means that it can be used as part of a multi-technique analysis [10], or for real-time process [11] measurements, or to characterise valuable (such as works of art [12]) or irreplaceable (such as forensic [13]) samples.

RBS is also reference-free, and makes no assumptions about the sample, essential for primary reference methods. This is the first time that an Ion Beam Analysis laboratory has obtained ISO 17025 accreditation of its technical competence in carrying out RBS at this accuracy.

Cited Literature

[1] M.J.T. Milton, T.J. Quinn, Primary methods for the measurement of amount of substance, *Metrologia*, **38** (2001) 289-296; DOI: 10.1088/0026-1394/38/4/1.

[2] Julien L. Colaux, Chris Jeynes, Keith C. Heasman, Russell M. Gwilliam, Certified ion implantation fluence by high accuracy RBS, *Analyst* **140** (2015) 3251-3261; DOI: 10.1039/C4AN02316A.

[3] Werner H. Gries, Ion-implanted surface analysis reference materials: Certification of dose densities from 10^{16} to 10^{13} cm^{-2}, *Surface and Interface Analysis*, **24** (1996) 431-447; DOI: 10.1002/(SICI)1096-9918(199607)24:7<431::AID-SIA133>3.0.CO;2-C.

[4] Julien L. Colaux, Chris Jeynes, Accurate electronics calibration for particle backscattering spectrometry, *Analytical Methods*, **7** (2015) 3096-3104; DOI: 10.1039/C4AY02988G.

[5] J.L. Colaux, C. Jeynes, High accuracy traceable Rutherford backscattering spectrometry of ion implanted samples, *Analytical Methods*, **6** (2014) 120-129; DOI: 10.1039/C3AY41398E.

[6] C. Jeynes, N.P. Barradas, E. Szilágyi, Accurate determination of quantity of material in thin films by Rutherford Backscattering Spectrometry, *Analytical Chemistry*, **84** (2012) 6061–6069; DOI: 10.1021/ac300904c.

[7] J.L. Colaux, G. Terwagne, C. Jeynes, On the traceably accurate voltage calibration of electrostatic accelerators, *Nuclear Instruments & Methods B*, **349** (2015) 173-183; DOI: 10.1016/j.nimb.2015.02.048.

[8] D.R. Tilley, C.M. Cheves, J.H. Kelley, S. Raman, H.R. Weller, Energy levels of light nuclei, A = 20, *Nuclear Physics A*, **636** (1998) 249-364; DOI: 10.1016/S0375-9474(98)00129-8.

[9] D. Benzeggouta, I. Vickridge (Eds), Handbook on Best Practice for Minimising Beam Induced Damage during IBA (2013); arXiv:1303.3171 [cond-mat.mtrl-sci].

[10] N.P. Barradas, S.A. Almeida, C. Jeynes, A.P. Knights, S.R.P. Silva, B.J. Sealy, RBS and ERDA study of ion beam synthesised amorphous gallium nitride, *Nuclear Instruments & Methods B*, **148** (1999) 463-467; DOI: 10.1016/S0168-583X(98)00702-2.

[11] J. Rennie, S.R. Elliott, C. Jeynes, Rutherford backscattering study of the photodissolution of Ag in amorphous $GeSe_2$, *Applied Physics Letters*, **48** (1986) 1430; DOI: 10.1063/1.96879.

[12] Carlos Pascual-Izarra, Nuno P. Barradas, Miguel A. Reis, Chris Jeynes, Michel Menu, Bertrand Lavedrine, Jean Jacques Ezrati, Stefan Röhrs, Towards truly simultaneous PIXE and RBS analysis of layered objects in cultural heritage, *Nuclear Instruments & Methods B*, **261** (2007) 426-429; DOI: 10.1016/j/nimb.2007.04.259.

[13] Matthew E. Christopher, John-William Warmenhoven, Francesco S. Romolo, Matteo Donghi, Roger P. Webb, Christopher Jeynes, Neil I. Ward, Karen J. Kirkby, Melanie J. Bailey, A new quantitative method for gunshot residue analysis by ion beam analysis, *Analyst*, **138** (2013) 4649-4655; DOI: 10.1039/C3AN00597F.