Recent developments in nuclear methods in support of semiconductor characterization

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Rutherford Backscattering Spectrometry (RBS) is widely applied for the quantitative compositional analysis of thin films in microelectronics. The most well-known applications are multi-elemental films (SiGe, CoSi, TiN, SiN, etc…) deposited on Si or oxide substrates. The shrinking device dimensions and the new materials used in more advanced technologies also create the need for accurate and reliable characterization of very thin films. Although in the past nuclear techniques have primarily been used for thicker films, we will demonstrate that by an appropriate choice of analysis conditions, instrumentation and data interpretation it is possible to analyze layers as thin of 2-3 nm. Whereas standard RBS analysis is performed at 2 MeV, a reduction in energy can be quite advantageous. Indeed the stopping of He-atoms in a substrate peaks around 500 KeV and declines for higher energies. Hence a reduction in energy will lead to a higher energy per nm traversed and thus a better depth resolution. Another interesting property of the analysis at reduced energies, is the increased scattering cross section ($\sim 1/E^2$) leading at the same time to a higher sensitivity.

Whereas RBS is still a perfect tool for rapid day by day characterization of semiconductor materials and films, the sensitivity and accuracy for light elements is limited due to the low cross-sections for these elements. One way to improve this is to use a more forward scattering geometry leading to significantly enhanced scattering cross sections. One problem, which remains is that the signal for light elements is still superimposed on the matrix signal. The use of nuclear reaction analysis (NRA) can easily circumvent this problem. While, due to the irregular cross-sections, the quantitative use of this technique (NRA) was limited for the analysis of thick samples, this represents no longer a problem for ultra thin film analysis and these peaked cross-sections lead to enhanced sensitivity. Typical examples are the analysis of N in oxynitrides, B(and F) in B(F_2)-implants,…

Last but not least high resolution Elastic Recoil detection is finding its way into the semiconductor applications in view of its ability to probe (simultaneously) light elements in a heavy matrix. Using a judicious choice of the detection system, sub-nm depth resolution has been demonstrated for N in oxynitrides, high k materials and B at SiO_2/Si interfaces.

In a first example we demonstrate the increased sensitivity by the study of the growth high-K materials based on ALCVD and MOCVD. Simply by lowering the energy of the probing beam from the conventional 2 MeV to 1 MeV and selecting the appropriate geometry the sensitivity improved by almost a factor of 10. Under these circumstances, we can analyse the non-linear deposition rate of high k (Zr/Hf) and low k (TiN) in the early phased of film deposition using ALCVD, its relation to the surface preparation, etc

Extra depth resolution improvements can be obtained by enhancing the energy detection system. Whereas the conventional Si-detector has a resolution in the order of 10 keV, magnetic or electrostatic spectrometers may lead to extreme detector resolutions of less than 1 keV. Variations in beam energies (100- 500 keV) and practical implementation exist leading to different nomenclature (Medium Energy Ion Scattering, High-resolution RBS) with however as common characteristic the nm depth-resolution. The latter is demonstrated in the analysis of thin high-k films. Moreover, a combination of NRA and (H-)RBS leads to a very detailed quantitative analysis of those layers.

In a second example, we demonstrate the use of NRA in combination with Secondary Ion Mass Spectroscopy (SIMS). Although fairly limited in depth resolution, NRA can provide essentially background –free detection of Boron in a (α,p) reaction on ^{10}B with a sensitivity of 1E13 Boron/cm2. As for low energy, high dose implants, dopant concentrations may exceed several at%, quantification of SIMS-profiles might become questionable. Combining the details of the SIMS profiles with the integral measurements of NRA provides then an excellent way to certify the SIMS profiles and to study effects such as self-sputtering during ion implantation, dose loss during annealing etc..

An important issue in this area is the accurate determination of the near-surface distribution of shallow implants and at interfaces. Unfortunately SIMS is plagued in this region by transient effects and ionization and sputter yield changes making it for instance very difficult (nearly impossible) to measure a B-peak segregated at the SiO2/Si-interface or to determine the dopant distribution in the first nm. Using the sub-nm depth resolution capabilities of MEIS (for As in Si) and of high energy Elastic Recoil detection (for B at the SiO2/Si interface) substantial differences with SIMS profiles in the near surface region could be demonstrated and provided insight in the fundamental mechanisms leading to the SIMS distortions.

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