A position sensitive time of flight setup for heavy ion elastic recoil detection analysis

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Abstract:
The measurement of elemental concentrations as a function of depth is vital for the understanding of the physical properties and thereby quality of thin, functional layers produced and utilized in e.g. microelectronics and in the semiconductor technology. In this work, a position sensitive time of flight setup (TOF-E) for the quantitative analysis by high energetic (EP = 0.2 MeV·A) heavy ions is presented.
ion elastic recoil detection (ERD) was developed and installed at the scattering chamber of the Q3D magnetic spectograph located at the Munich Tandem Accelerator. The spectrometer is utilized for the quantification of the high resolution, single element depth profiles obtained with the Q3D magnetic spectograph and as stand alone ERD detection system for the simultaneous analysis of all elements from $1 \leq M \leq 178$ with high depth resolution. A high energy- and thereby depth resolution can only be achieved by the correction of kinematic effects of the scattering process. Thus, the first timing detector, as well as the ionization chamber based energy detector were designed to additionally offer a position sensitivity. Using an electrostatic lens which images the secondary electrons created by the recoil ions on penetration of a thin carbon foil in forward emission direction, a position resolution of 0.6 mm (FWHM) was achieved by the first time detector. In combination with a position resolution of the energy detector of 2.4 mm (FWHM), which is acquired by a drift time measurement of the ionization electrons within the gas volume, the true scattering angle of each recoil ion can be determined with an angular resolution of 2.5 mrad (FWHM). This allows to reduce the contributions of the kinematic effects on the energy resolution from 3.3% to 0.4%. By the detection of secondary electrons in backward emission direction within the first timing detector and within a second timing detector, an overall time resolution of 280 ps (FWHM) was achieved. In standard ERD measurements this allows, utilizing a 40 MeV $^{197}$Au projectile beam at an incident angle of 4° to achieve a surface energy resolution from the time of flight information of 0.76% and thereby a depth resolution of 2.3 nm (FWHM). Furthermore, the setup allows elemental separation up to a mass of 40 with a mass resolution of $\Delta M < 1$. At high projectile energies ($EP \approx 1.3$ MeV·A), the setup also offers the ability to perform ERD analysis utilizing a TOF-$\Delta E$-ERes technique. The benefit of this technique is given by combining the inherent mass sensitivity of the TOF-E method with the sensitivity of the $\Delta E$-ERes method to the nuclear charge. Both together allow to create unique filter conditions for background suppression and an overall sensitivity enhancement. This was demonstrated for the difficult case of the detection of low nitrogen amounts within diamond. A sensitivity of 10 ppm was achieved with this technique, which is better by two orders of magnitude compared to conventional $\Delta E$-ERes analysis. In addition to that, the method also allows for isotope separation in a medium heavy mass range of $12 \leq M \leq 40$, which is not possible with the $\Delta E$-ERes method.