Monolayers of Graphite Resolved by Elastic Recoil Detection (ERD)

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The depth of origin of the detected recoils in ERD analysis is obtained from the recoil energy which is shifted from the value expected for recoils scattered at the sample surface by energy losses of the incoming and the recoil ion. Energy separation increases linearly with path length when small flat angles of incidence or exit are used. Therefore, small angles are commonly used in order to get highest depth resolution in ion beam analysis.

The experimental conditions used for the experiments presented here are $\alpha = 4.7°$ flat angle for 60 MeV ^{127}I ions impinging on the (002) surface of a highly oriented pyrolythic graphite (HOPG, mosaic spread 0.4° fwhm). Carbon recoils being in the 5+ charge state are analysed using the Q3D magnetic spectrograph at a scattering angle $\varphi = 10°$ to get high energy resolution. The solid angle of detection was $(120 \times 48) mrad^2 = 5.8 msr$. Such a large solid angle is necessary to reduce ion beam induced damage to an acceptable level. However, the large opening angle within the scattering plane leads to a large kinematic energy spread of several percents which was corrected for up to the third order by the magnetic multipole element situated in the Q3D magnetic spectrograph [1]. The correction resulted in an energy resolution of 5×10^{-4}.

Energy spreads were simulated analytically using the DEPTH code of Szilagyi et al. [2]. All contributions to the total energy resolution in dependence on the analysed depth are plotted in Fig. 1. The calculation shows that the total energy spread is smaller than the expected energy loss per atomic layer near the surface.

The 23+ charge state of ^{127}I was used in the ERD analysis obtained as the equilibrium charge state behind a carbon stripper foil in order to achieve a high stopping power right at the surface and a low energy loss scattering [3]. After stripping, the phase space of the beam was cut using slits in front and behind an analysing magnet in order to keep the necessary energy resolution. The energy spread of the beam was smaller than 2×10^{-4} and the beam divergence within the scattering plane was controlled to be lower than 0.8 mrad.

The graphite was cleavaged in air some minutes before its transfer into the new UHV chamber (KRAKE) at the Q3D ($5 \times 10^{-7} Pa$). Surface contamination was controlled by ERD using a ΔE–E recoil analysis at a scattering angle of 35° performed simultaneously with the high resolution recoil analysis [4]. The coverage of the surface with hydrogen was about 2×10^{12} at/cm^2 and with oxygen smaller than 1×10^{12} at/cm^2 after heating the graphite to 550 K.

The energy spectrum measured for $^{12}C^{5+}$ recoils scattered from the graphite sample using the Q3D magnetic spectrograph is shown in Fig. 2. The energy scale is calibrated as a relative energy shift to the energy of carbon recoils (18.36 MeV) scattered with no energy losses involved at the average scattering angle of 10°. Regular oscillations in the detected counts can be seen which are damped for higher energy shifts. Each peak represents carbon ions scattered from a certain monolayer of graphite. The solid line plotted in Fig. 2 shows a fit of 3 added Gaussian functions and one error function to the measured spectrum. The distance between neighbouring peaks corresponds to the relative energy loss of the ions between adjacent (002)-layers of graphite. It is slightly larger (20%) than the tabulated values. However, such a difference was also measured during the analysis of amorphous carbon films and is due to uncorrect values of the stopping power of the 60 MeV ^{127}I ions in carbon. The peak spacing grew in the expected way when an incident angle of 3.5° was chosen. Alltogether, the measurement clearly demonstrated the resolution of adjacent atomic layers for the first time in ERD analysis.

References

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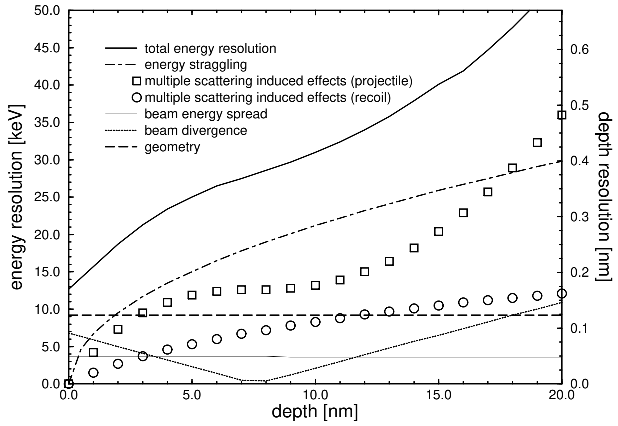

Fig. 1: Calculated total energy resolution (fwhm, solid line, [2]) in ERD analysis of ^{12}C recoils of a pure carbon sample using 60 MeV ^{127}I ions, a scattering angle of 10° and a flat angle to the surface of the incident beam of 3.6°. Specific contributions to the limited resolution are also plotted.

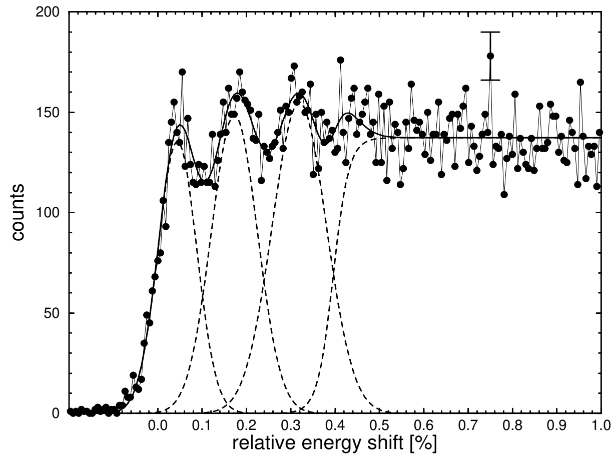

Fig. 2: Energy spectrum of $^{12}C^{5+}$ recoils from a highly oriented pyrolythic graphite analysed with a Q3D magnetic spectrograph. Each of the peaks represents the signal of an individual graphite (002) layer