Charge State Distributions of Channeled Ions in Cooling/Heating Regime

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It is well known that mean charge states of ions behind crystals significantly depend on whether the ions move in channeling or random direction through the crystal. For instance, the mean charge state of 60 MeV planar channeled I ions in Au was found to be lower by 2.5e as compared to random directions [1]. In contrast, the mean charge state in case of 40 MeV O ions was higher by about 0.5e [2]. It was reckoned that the reason lies in different impact parameter dependencies for electron capture and loss. This matter is also a key issue for a possible understanding of our effect of "Transverse Cooling and Heating" [3], which cannot be explained by the prevailing theory of ion channeling. However, this measured redistribution of an initially isotropic ion beam after transmission through thin crystalline foils may be explained by a charge exchange model that uses such different impact parameter dependencies.

Thus, it was the scope of this series of experiments to verify the predictions of the charge exchange model in respect to outcoming mean charge states. As cooling (i.e. enhancement of the ion flux along crystal directions) is found at higher velocity, and heating (i.e. reduction of the ion flux) appears at lower velocity, the measurement of the charge state distributions of channeled and non-channeled ions was performed in dependence of the ion velocity. Since one assumes that well channeled ions cannot pick up any more electrons when moving fast, it was expected that the mean charge state of these ions would be larger than the one of random ions. At lower velocity, even well channeled ions can capture electrons (into highly excited states), but may get stripped fast when coming close to the target atoms, hence, in this case the mean charge state of these ions should be lower than the one of random ions.

In order to measure the charge state distributions the Q3D magnetic spectrograph was utilized. Two different scatter geometries were considered: (1) scatter geometry as used in our earlier experiments of cooling/heating, and (2) transmission geometry, where a collimated micro-beam (pencil beam) is directly transmitted through the crystal. The latter possibility turned out to be more useful in respect to a much better energy resolution which enabled us to distinguish the two groups of channeled and non-channeled ions due to their different energy loss.

For the required accuracy of the crystal orientation in respect to the beam and the detector a new goniometer was built in, and a feasible computer based controlling system was developed. The alignment of the crystal was done with the aid of the measured energy spectra, as it is known that the best channeled ions have the least energy loss. Thus, the appearance of a minimal energy loss during aligning indicated the best orientation. Due to the relatively small energy acceptance of the Q3D we could only observe parts of three different charge states at one setting. Therefore, it was necessary to tune the magnetic field in order to probe the complete charge state distribution. This required a beam monitoring for the normalisation of the distributions. In case of the scatter geometry a PIN diode was moved into the beam just before and after each measurement for deducing the beam current.

Fig. 1 shows two charge state distributions of Ag ions behind a 3.4 μm Si(001) crystal in transmission geometry at two different energies corresponding to a cooling, and a heating case, respectively.

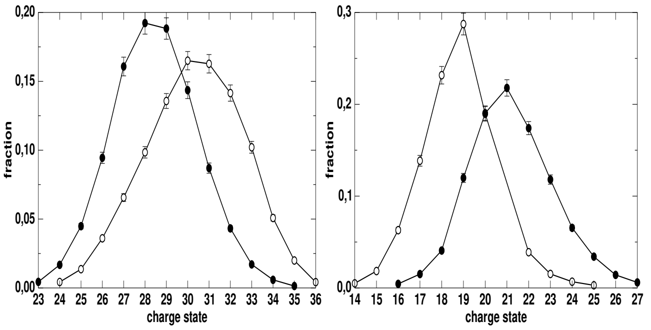

Fig. 1: Charge state distributions of axially channeled Ag ions behind a 3.4μm Si(001) foil: (left) cooling with 240 MeV Ag, (right) heating with 100 MeV Ag. Filled circles: random direction, open circles: channeling.

One can clearly see that in the case of low velocity (i.e. heating regime) the mean charge state of the channeled ions is lower than the one of random ions, and the opposite situation is given for higher velocity (i.e. cooling regime).

This result seems to verify the predictions made by the charge exchange model of cooling/heating [3] stating that the mean capture radius is smaller than the mean loss radius at higher velocity, and vice versa at lower velocity. However, it is not perfectly clear whether the relation between cooling/heating and mean charge state shifts is really a direct correlation. It seems possible that the charge state shift is only a matter of the ion velocity irrespective of the appearance of cooling or heating. This question will be treated with a future experiment that studies charge state distributions of ions at the same velocity but different cooling/heating appearances and different transverse energy distributions (prepared by tilting the crystal in respect to the incoming beam).

References

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