Charge State Distributions of Channeled Ions in Cooling/Heating Regime II

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The mean charge states of ions behind crystals significantly depend on whether the ions move in channeling or random direction, as has been shown in several experiments [1,5]. It was argued 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" [3,4], which cannot be explained by the prevailing theory of ion channeling. In our experiments reported last year [5] with Ag ions transmitted through a 3.4μm thin Si(001) foil at two different energies, one could clearly see that in 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 looks like a correlation between shifts of channeling to random charge states and the appearance of cooling/heating. However, this correlation may in fact be a correlation with ion energy only, because cooling was observed at high energy, but heating at low energy. So it was the scope of the experiments reported here to look closer at this correlation.

1. Experiment

This second series of experiments was done with 100 MeV Ag ions transmitted through different crystals, where a 1.0μm thin Ni (001) crystal has shown heating, but a 1.0μm Pt (001) crystal points out cooling for the channeled ions. [6]

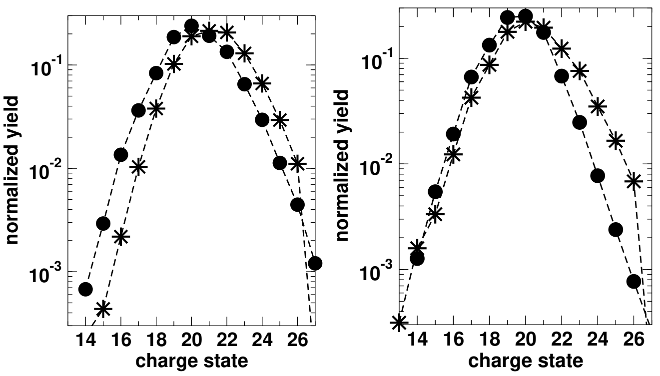

Fig. 1: Charge state distributions of axially channeled Ag ions with 100 MeV behind a 1.0μm Ni(left) and a 1.0μm Pt(right) crystal foil in (001) orientation: (left) heating with Ni crystal, (right) cooling with Pt crystal. Filled circles: channeling, stars: random direction.

In figure 1 one can see, that in both cases the axially channeled ions have a lower charge state than random ions, despite the difference in cooling/heating. This finding gives strong evidence that there is no general correlation between shifts in charge state distributions and the appearance of cooling/heating, but rather a clear correlation with the ion energy.

2. Simulation

The presented experimental findings suggest that the observed shifts in charge state distributions are more likely a function of the ion energy than of the appearance of cooling/heating. As to our knowledge there exists no theoretical approach to the question about the energy depedence of channeling vs. random charge states. In order to check our conjecture, we have advanced an n-body Classical Trajectory Monte-Carlo (nCTMC) type simulation, and we herewith present first results. Fig. 2 shows simulated mean charge states of Y ions after transmission of a Si crystal, resembling the experiments reported ealier with Ag ions. In correspondence to these measurements the charge state of best channeled ions is higher (lower) at high (low) energy than the average over all impact parameters. As a possible explanation we assume the folowing picture: at high ion velocity, the capture radius is so small, that electrons can only effectively be captured when the ion moves close to strings, but ionization of ionic bound electrons is still possible in the middle of the channel due to electron impact ionization. In contrast, at low velocity capture of electrons is possible even at large impact parameters, with the electron impact ionization being so strong now that low charge states can only survive far away from strings where the electron density is lower.

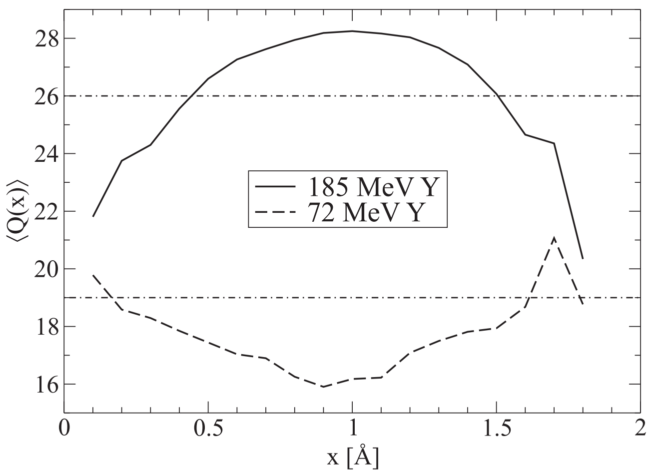

Fig. 2: Simulated mean charge states of Y ions as a function of the transverse position between two atomic strings at two different energies: 185 MeV (solid line) and 72 MeV (dashed line). The corresponding tabulated random charge states for the two energies behind a thin C-foil (horizontal lines) are 26.0 and 19.0, respectively.

References

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