Role of ion impact ionization cross sections in the irradiation of swift heavy ions into condensed matter

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Synopsis We have produced simple functions using ion impact ionization cross sections (σ) for the motion of secondary electrons and the electric filed (E_f) induced from heavy ion irradiation through simulations. Our simulation for the probability of secondary electrons escaping from E_f reproduces the tendency of the measurements. We will also discuss the role of σ in the other swift heavy ion science such as the radiation biology, material science.

In the study of irradiation of swift ions to condensed matter, secondary electrons, which are produced from ion impact ionization, play an important role. In this paper, aiming to understand science of swift heavy ions, we try to describe simple functions using ion impact ionization cross sections (σ) for the motion of secondary electrons and the electric filed induced from heavy ion irradiation [1,2]. This electric field is though to affect the motion of secondary electrons [1 – 3].

Previous measurements [3] showed that some secondary electrons are trapped near the incident ion path. This trap may occur due to electric field [$E_f(r)$] induced from incident ion impact ionization, where r is the distance from the incident ion path. However, except for our simulation model, there were no models that reproduced this trap because $E_f(r)$ was ignored as far as we know. We incorporate $E_f(r)$ in our model by treating the Coulomb interaction between all secondary electrons and all ions produced from σ_{ion}. We believe that our simulation model has become possible in the 21st century because many times and memories are required to execute our simulations even by employing the present super computers. The rapid progress of computers allows us to develop this model.

Using our model, we reproduced [1] the tendencies of the measurement [3] (see Fig.1). Figure 1 (a) shows simulation results of the probabilities (P_e) of the secondary electrons escaping from $E_f(r)$ vs. mean path ($\tau = 1/n\sigma$) between impact ionization events, where n is the number density of molecules in the target. Figure 1 (b) shows ratios of experimental results of P_e of the incident ion of proton to that of proton, He, or Li ion vs. $1/<q^2>$ with $\tau \propto 1/<q^2>$, where $<q^2>$ is the mean square of final charge states of the incident ion. Regardless of target materials, P_e $\tau^{0.5}$, or $P_e \propto 1/\sigma^{0.5}$ is almost satisfied in both our simulations and the experiments [3].

We also produce functions of $E_f(r)$ using σ_{ion}, that is, $E_f(r) \propto \sigma_{ion}/r$ [2]. On the other hand, electric fields formed from a point charge decreases according to $1/r^2$. Namely, the electric field induced from heavy ion irradiation becomes longer range force than that attributed to point charges. This longer range force is expected to trap slow secondary electrons near the incident ion path

We succeeded in the production of simple functions using σ_{ion} for P_e and E_f. We discuss the applications of these functions to the other science fields such as radiation biology and material science due to heavy ion irradiation.

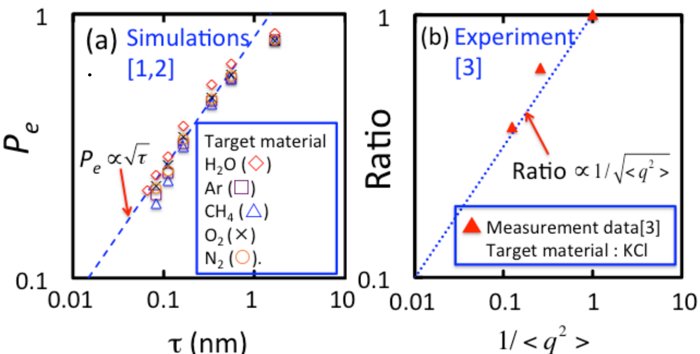

Figure 1. (a) P_e vs. τ for various target materials (b) ratios of P_e vs $1/<q^2>$. The dashed line shows the increase functions according to (a) $\sqrt{\tau}$ and (b) $\sqrt{1/<q^2>}$.

References

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