# 3 - 16 Development of a Momentum Computed Tomography for Sputtered Ions

Zhang Yuezhao, Yu Deyang and Wang Wei

When energetic ions interact with solid surfaces, sputtered ions are produced[1]. The normalized distribution function $F(m,q,v_x,v_y,v_z)$ of the ions mass numbers $m$, charge states $q$ and velocity $(v_x,v_y,v_z)$ in Cartesian coordinate represents kinematical information, and therefore carries important dynamical information of the sputtering process. A new instrument that is able to collect all the outgoing sputtered ions with $2\pi$ solid angle and subsequently can measure $F(m,q,v_x,v_y,v_z)$ is developed. The spectrometer structure is illustrated, the mathematical basis is presented and an algebraic algorithm is employed to calculate $F(m,q,v_x,v_y,v_z)$ numerically.

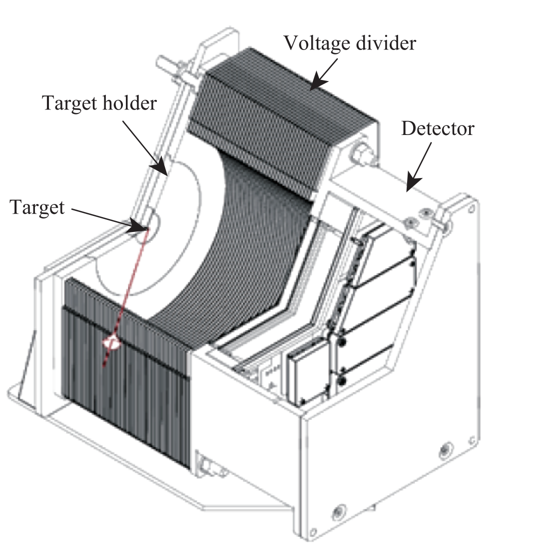



Fig. 1 (color online) Structure of the momentum computed tomography. The spectrometer consists of three parts: the target and the target holder, an array of voltage dividers, and a two dimensional position sensitive detector.

The layout of the spectrometer is shown in Fig. 1. The target is placed in the center of a target holder, which also works as a positive-high-voltage electrode plate. A series of electrode rings are installed next to the target holder, with an interval of 2 mm between two adjacent rings, to form a uniform electric field. A two-dimensional position sensitive MCP detector is fixed at the end of the electrode ring array, right to the front of the target with a distance $d$. The detecting surface of the detector is parallel to the target holder, and it is grounded working also as an electrode plate.

When the ion beam hits the target, the sputtered ions will be driven by the electric field to the detector. As an approximation, we assume that there is only one species of sputtered ions, and use $\rho(p_x,p_y,p_z)$ instead of $F(m,q,v_x,v_y,v_z)$ to represent the momentum distribution of the sputtered ions, where $p_i = mv_i (i \equiv x, y or z)$ are the Cartesian momentum components. From Newtonian mechanics it's easy to derive that under a specific working voltage $U$ of the target holder, a position on the detector corresponds to a specific integral curve in the momentum space,

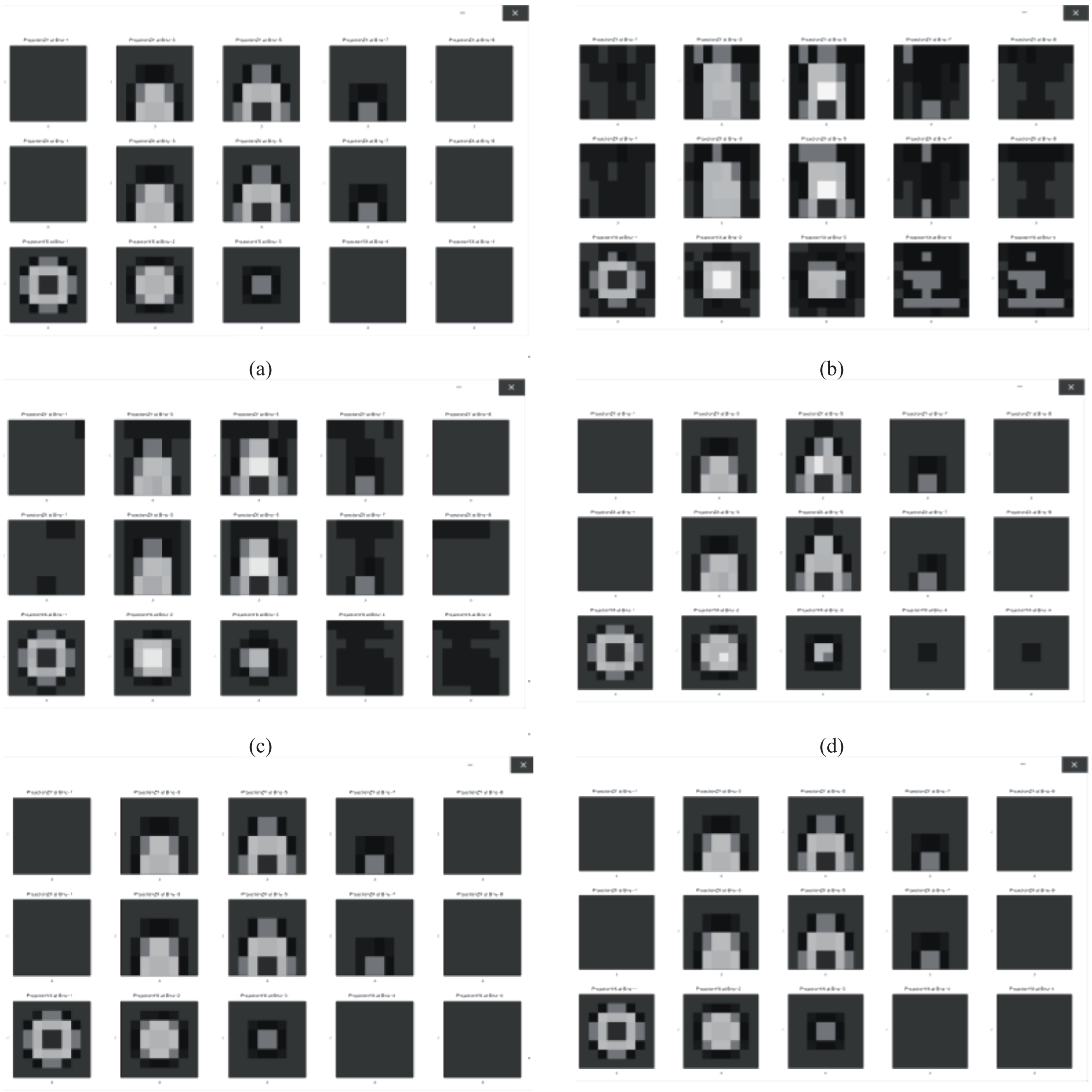
$$p_x^h = \frac{x_h}{2d}\left(\sqrt{p_z^{h2}+2qmU}+p_z^h\right),$$

$$p_y^h = \frac{y_h}{2d}\left(\sqrt{p_z^{h2}+2qmU}+p_z^h\right).$$

Integrating the momentum distribution density along that curve gives the detected count of that position, $C_h = \int_h \rho(p_x,p_y,p_z)\mathrm{d}l$. Discretizing this integration gives us a linear equation, $C_h = \sum_{i=1}^{l_x}\sum_{j=1}^{l_y}\sum_{k=1}^{l_z}\rho(p_{xi},p_{yj},p_{zk})\Delta l_{ijk}^h = \sum_{i=1}^{n}\rho_i\Delta l_{hi}$. Thus a series of detected positions under the working voltage $U$ corresponds to a series of linear equations. Changing the voltage, we get another series of linear equations. Solving this equation set iteratively with Kaczmarz algorithm[2], we can get the numerical solution of $\rho(p_x,p_y,p_z)$, which we refer as the reconstruction process.

Taking Be target for instance and assume the sputtered ions are all $Be^+$, the reconstruction results are shown in Fig. 2. Fig. 2(a) is an arbitrarily generated $Be^+$ momentum distribution in an 8×8×4 mesh grid with a maximum Cartesian momentum component of $\sqrt{2mE_{\max}}$, where $E_{\max} = 1\ 000$ eV. Fig. 2(b), 2(c), 2(d), 2(e) and Fig. 2(f) show the reconstruction results respectively after 1, 2, 3, 4 and 5 iterations as defined in Ref. [2]. The reconstruction seems rather satisfying after 4 iterations and indeed we didn't find significant improvement in further iterations.

In conclusion, a new instrument that can measure the momentum distribution of single-mass and single-charge particles is developed. The spectrometer is currently under test and the first reconstruction results are efficient and satisfying. We further point out that the current theory can be applied to measure the momentum distribution of ions of different masses and different charges, which requires two improvements of the current spectrometer, *i.e.* the detector precision and a nonlinear algorithm to solve a nonlinear equation set.



(a) (b) (c) (d) (e) (f)

Fig. 2 (color online) Reconstruction results of the original momentum distribution in a 8×8×4 mesh grid. (a) the arbitrarily generated original distribution. (b) (c) (d) (e) and (f), respectively the reconstruction result after 1, 2, 3, 4 and 5 iterations with Kaczmarz algorithm.

## References

[1] Rainer Behrisch, W. E., *Sputtering by Particle Bombardment*, ed. (2007): Springer.

[2] S. Kaczmarz, International Journal of Control, 57(6)(1993)1269.