Influence of Sample and Ion Beam potential on the Mirror Effect phenomenon at Low accelerated Voltage

Muayyed Jabar Zoory¹, Emad Hameed Ahmed¹ and Saad khalid rahi¹

¹Department of Physics / College of Science / Mustansiriyah Univ., Iraq-Baghdad.
E-mail:muayyedjz@yahoo.com , muayyedjz@uomustansiriyah.edu.iq .

Abstract. Here, the behavior of scanning ion was treated by a simple mathematical control as a function of beam potential and sample potential. The motion equation of the vertically incident ion was derived using energy conservation law. The importance of mathematical derivation comes connecting the irradiation parameters of the scanning beam on one hand and the parameters on the other hand. This achievement was performed through adopting the charged-disk model. The results showed that the current of ion beam has a significant influence on the produced image by ion mirror effect in comparison with other beam parameters that can be used in controlling the ion mirror effect images at minimum values of scanning potential.

Keywords: Mirror Effect, Beam Ion potential, Ion Beam Current, scanning voltage low. Trapped charge.

1. Introduction
The electronic and optical devices have become an analytical technology now days which cannot be ignored in many technological fields. In spite of its shortage with regard to scientific development, it has witnessed a huge progress and massive jump in short duration [1].
The first and simplest application of electron optics is the microscope which built in 1931 by Ernst Ruska and Maxknoll and considered the first use of lenses in image magnification [2].
The technique of focusing ion beam (FIB) device has essentially developed in the period between the late 1970s and early 1980s, the first device was commercially produced during more than one to two decades and the modern systems of focusing ion beams (FIB) device has become widely available in the advanced scientific researchers [3-7].
The mechanism of images production by scanning electron microscope (SEM) and focusing ion beams (FIB) devices are performed through detecting the secondary electrons which start out from the sample as a result of interaction between the initial ray (electrons and ions) and the sample atoms [8]. In fact, the secondary electrons that run away from the sample carry huge information of the chemical and physical properties. Actually, the freed electrons do not have kinetic energy enough to escape from the sample surface. On the other hand, some of incoming electrons or ions are trapped on this surface, therefore, during raster process, both kinds of electrons or ions stay and sharply accumulate forming a layer of charged particles on the sample surface. If this layer of charges was not removed, the sample imaging process would vanish until it stops; at this stage, the layer becomes as a mirror able to regressively reflect charges to the back according to Coulomb's law. The reflected and regressive charges would be extruded inside the cavity of chamber walls causing emitting new secondary electrons whose detection leads to imagining the area inside the cavity; this phenomenon is called the mirror effect. When the initial ray consists of electrons called the electron mirror effect while called the ion mirror effect in case the ions from the initial ray [8-11].
However that, much effort and time has been devoted to make sure of the mirror effect phenomenon does not occur [11, 12]. So in the present work will focus on how to overcome the mirror effect phenomenon.

2. Theoretical Aspect

2.1. Disc Charge Approximation

The electric potential accompanying the electric charge depends basically on the charge quantity, the geometrical distribution of charges, the distance between the center of this distribution and the point at which the potential is needed to measure. Thus, the electric potential is associated the restricted charge which must be determined to understand the behavior of scanning beams of ions. A model was proposed for representing the restricted charges distribution which be adopted in current work namely the approximation of charges distribution of disk shape (see figure 1). This approximation would be verified in this part as for the image's production according to ion mirror effect phenomenon in focusing ion beams device (FIB).

The sample potential and ion beam potential results from the disc distribution at the point P which is given by Eqs. [13]:

\[
U_s(Z) = \frac{Q_t}{2\pi R_s^2 \varepsilon_0} \left[ \sqrt{z^2 + R_s^2} - z \right] 
\]

(1)

\[
U_b(WD - Z) = \frac{I_b t}{2\pi R_b^2 \varepsilon_0} \left[ \sqrt{(WD - z)^2 + R_b^2} - (WD - z) \right] 
\]

(2)

Actually, \( Q_t \) is the restricted charge on the sample surface through a disc of radius \( R_s \) this because of irradiation process where \( I_b \) is the ions beam current that is the number (charges of the surface beam) \( (U_b) \) per unit time \( (t) \) that passes through any point along a beam travelling a distance, \( R_b \) is the radius of beam and \( W \) is the work distance, see the figure 1.

![Figure 1. Schematic representation of ions beam falling down on irradiated sample.](image-url)
2.2. **Energy conservation law**

Apparently, equation (1) represents the resistant potential which enables to blocking the scanning ions from reaching the sample surface. In more precise words, there is a force, (Coulomb force), of a magnitude (\(- e \nabla U_b(Z)\)) affecting the incoming ions (incident ions), thus trying to anchor or trap them from moving toward the sample. On the other hand, equation (2) reveals another coulomb force of a magnitude (\(- e \nabla U_b(WD - Z)\)) which is impairing the first one (eq. (1)) and even pushing the incoming ions away the aperture of ion column of the focusing ion beam device. In operation process of ion beams focusing device, the scanning beam of accelerated ions of potential (\(V_{sc}\)) for making ions interact by any traditional atomic interactions according to the accelerated potential values (\(V_{sc}\)). In this case, there are additional reasons for scanning ions to the approach more toward the sample. As a result, when the sum of accelerated voltages (\(V_{sc}\)) and potentials of ion beam (\(U_b(WD - Z)\)) become equal to the sample potential (\(U_s(Z)\)), the incoming ions would stop moving at a specific point on the axis (\(Z\)). For this reason, these ions rebound back toward room walls of the focalizing ionic beam device. In view of the mirror effect, these ions are reflected at a point that usually locates in vacuum areas. Thus, the energy conservation law at the reflection points is given by the following relation [14, 15].

\[
\frac{q_b t}{2nR_b^2e} \left[ \sqrt{Z^2 + R_b^2} - Z \right] - \frac{i_b t}{2nR_b^2e} \left[ \sqrt{(WD - Z)^2 + R_b^2} - (WD - Z) \right] = V_{sc} \tag{3}
\]

The equation (3) obviously states that equilibrium of coulomb force transfers to benefit from the ion beams values which basically depends on the values of radius (\(R_b\)), current (\(I_b\)) and the scanning potential (\(V_{sc}\)) on one hand and the trapped charges (\(Q_s\)) and radius of the charging disc (\(R_s\)) on the other hand.

3. **Results and discussion**

This part studies the ion beams current parameter to dispose the ion mirror effect. The study is conducted on the sample (PMMA) by using Muayyed’s results [12] where the restricted charge quantity on the sample was 508 PC and the value of \(R_s=R_n=0.457\ \text{mm}\) and the work distance (\(WD\))=30 mm which were constant during the study.

3.1. **Influence of the beam currents (\(I_b\)) parameter**

As it's known at the scanning voltage (\(V_{sc} =6\text{kV}\)), it is so difficult to overcome the ion mirror effect because this generated voltage is not enough to vanquish the emerging voltage by the restricted charge on the sample [16].

Table (1) shows how the inversion points with variation of beam currents for the scanning voltage (\(V_{sc} =6\text{kV}\)). When the ion beam current increase the inversion point (\(Z\)) decreases, in another words, the ion beam becomes nearer to the sample surface which means the ion mirror effect could disappear with increasing the ion beam current.

3.2. **Study the Sample potential (\(U_s\)) and Beam Ion potential (\(U_b\))**

Figure (2) display how the sample potential changes along with the optical axis-\(z\) where the sample potential (\(U_s\)) is at the maximum value at the sample and begins decreasing as it is far away from the sample. As well as, figure (2) elucidated the variation of emerging potential of the ions beam (\(U_b\)) used for imaging the mirror phenomenon along the optical axis-\(z\) where the potential of ions beam (\(U_b\)) starts lowering when getting away from Coulomb's aperture of the ion to the sample surface. The intersection points between the emerging potential of the sample and the ion beam potential for different imaging currents of inversion points of these points represent the maximum distance which ion beam can reach before recoiling back as a result of the sample potential. It can be noticed that the ion beam current used for imaging increases and becomes much closer to the sample.

Anyway, for more explanation, figure (3) reflects the inversion points for different ion beams currents at scanning voltage (\(V_{sc} =6\text{kV}\)), it is clear that when the charge quantity on the sample (\(Q_s\)) becomes equal charge quantity resulting from ion beam of the surface beam (\(Q_b\)) i.e. (\(Q_b=Q_s\)), which means (\(Q_b/Q_s=1\)).
Figure 2. Represents the sample potential ($U_s$) and the ions beam potential ($U_b$) for different beams currents of energy ($V_s=6kV$) along the optical axis.

3.3. Estimation of the trapped charge

Table 1 clarifies how the currents of the ion beam used for imaging change with the ratio ($Q_b/Q_t$). It can be concluded from the table 1 that the value of ion beam current can be used for disposing of the ion mirror effect. It was found that the current value needed to rid from ion mirror effect for the sample (PMMA) at the scanning voltage ($V_{sc} = 6kV$) equal to the ($I_b = 0.14$ nA) (as the index of the red ribbon). It is now possible to estimate the trapped charge by the ion beam current needed to disappear the mirror effect at the acceleration voltage $V_{low}$. ($Q_b\approx Q_t\approx I_b t=0.56$ pc).

From figure 3 it is possible to distinguish the ion beam current necessary to overcome the mirror effect through the intersection point shown in the red circle.

| Beam Current(nA) | Reflection Point (mm) | $Q_t$(pc) | $Q_b=4*I_{ac}$(pc) | $Q_b/Q_t$ |
|------------------|-----------------------|-----------|--------------------|-----------|
| 0.11             | 0.69                  | 0.508     | 0.044              | 0.086614  |
| 0.0022           | 0.695                 | 0.508     | 0.0088             | 0.017323  |
| 0.016            | 0.692                 | 0.508     | 0.064              | 0.125984  |
| 0.033            | 0.689                 | 0.508     | 0.132              | 0.259843  |
| 0.08             | 0.682                 | 0.508     | 0.32               | 0.629921  |
| **0.14**         | **0.672**             | **0.508** | **0.56**           | **1.102362** |
| 0.27             | 0.651                 | 0.508     | 1.08               | 2.125984  |
| 0.7              | 0.59                  | 0.508     | 2.8                | 5.511811  |
| 1.1              | 0.54                  | 0.508     | 4.4                | 8.661417  |
| 1.6              | 0.485                 | 0.508     | 6.4                | 12.59843  |
| 4.7              | 0.258                 | 0.508     | 18.8               | 37.00787  |
Figure 3. Explains change of inversion points (Z (mm)) and the currents beams (I_b (nA)) with (Q_b/Q_t).

4. Conclusions
The obtained results of the present work proved that the veracity of using terms of the charged-disk approximation on the electron mirror effect and ion mirror effect are equal. The reason is that the charged disk approximation leads to the same results in both phenomena (electron mirror effect and ion mirror effect). The results also showed that the required current to rid of the mirror effect can be determined at any potential used in imaging through drawing the intersection of the sample and Beam ion potentials. This result enables of using this approximation as an excellent means to dispose of the electron mirror effect and ion mirror effect which occurs inside the scanning electron microscope and the focusing ion beam device, respectively.

In addition to this, the results also showed that it is possible to estimate trapped charge on the dielectric sample at the acceleration voltage Low.

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