Optik 127 (2016) 6978–6981

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Investigation of scanning electron beam parameters in terms of the disk-charged approximation for the sample potential

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ARTICLE INFO

Article history:
Received 12 March 2016
Accepted 9 May 2016

Keywords:
Scanning electron microscope
Electron mirror images beam current
Trapped charges
Disc-charged potential.

ABSTRACT

A theoretical investigation of electron behavior inside the scanning electron microscope chamber for the mirror image operation mode has been carried out. The equation of motion of this head-incident electron is derived in terms of the energy conservation law. By solving this equation the influence of beam parameters are investigated. Results have shown that a good comprehend and interpret for the physical behaviors of scanning electron can be extracted. It is found that the beam current may be used to control mirror images only in the lower values of scanning potential. Also the size of scanning beam has no effect on mirror image as long as the beam current is kept fixed.

1. Introduction

One of the most important challenges facing the operation of the scanning electron microscope (SEM) is the phenomenon of the mirror effect appears when examining insulating materials. These effects arise from the accumulation of electrons at the specimen surface during the irradiation process [1] yielding an electric field that may be strong enough to deflect incident electrons in the same way a convex mirror scatters light [2]. Consequently, further electrons approaching the specimen suffer a repulsive coulomb force and therefore electrons of low energy reflect at different with respect to the line of incidence as determined by the beam parameters [3]. The reflected electrons collide with chamber walls of the SEM that in turn liberates new electrons. When they arrive at the detectors, images from the chamber space surrounding the specimen are recorded rather than the sample itself [4].

Mirror effects have drawn much interest since their observation in the 70s of the last century because of their ability of analyzing insulating materials [5]. Quite a number of works have been carried out either to use this phenomenon as a tool for investigation, or to analyze the characteristics of this phenomenon itself [6–11]. Recently it has been found that the scanning beam current could be used as a control for enhancing or deforming mirror effects [12]. Furthermore, the SEM beam may be considered to be an excellent tool for computing trapped charges [13] and analyzing polarization and mechanical stress [14].

The tracing of scanning electrons beam is a mathematically complicated process that may be overcome by using energy conservation method [14]. In the present work this method is adopted for a new setting of the beam and sample potentials as compared to one of our previous works [14]. In addition a scanning potential is added to the conservation method for further investigation.

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http://dx.doi.org/10.1016/j.ijleo.2016.05.017
0030-4026/

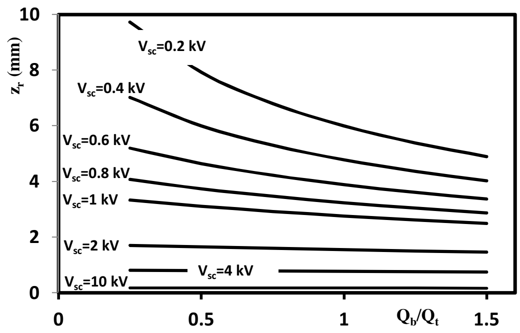

Fig. 1. Reflection point position z_r as a function of the quotient Q_b/Q_t for different values of scanning potential.

2. Method

For a beam of electrons of radius R_b and current I_b directed towards the center of an irradiated area of an insulating sample of radius R_s that containing a trapped charge Q_t the equation [14]

$$\frac{Q_t}{I_b t}\left(\frac{R_b}{R_S}\right)^2\left\{(z^2+R_S^2)^{1/2}-z\right\}-\left\{((W-z)^2+R_b^2)^{1/2}-(W-z)\right\}=0 \tag{1}$$

describes the energy conservation of incident electrons.Here W is the working distance and z is the position along the optical axis at which the electron is reflected back. Eq. (1) has been derived assuming that electrons are uniformly distributed over the incident beam cross sectional area. A similar assumption is made for the electrons that have accumulated on the surface of the sample. The potential distributions of the beam electrons and the electrons on the specimen surface have the following general form [14]

$$U(r)=\frac{It}{2\pi\varepsilon_0 R^2}\left\{(\vec{r}^2+R^2)^{1/2}-\vec{r}\right\} \tag{2}$$

where It, R and r are respectively represent Q_t, R_s and z for the surface potential, or $I_b t$, R_b and $(W\text{-}z)$ for the beam potential, respectively.

However, Eq. (1) does not take into account the scanning potential V_{sc} that has a significant influence on the mirror images. If V_{sc} is added to the beam potential, the energy-conservation law becomes

$$\frac{Qt}{I_b t}\left(\frac{R_b}{R_s}\right)^2\left\{\left(z^2+R_S^2\right)^{1/2}-z\right\}-\left\{((W-z)^2+R_b^2)^{1/2}-(W-z)\right\}-\frac{2\pi\epsilon_0 R_b V_{sc}}{I_b t}=0 \tag{3}$$

It may be realized that the balance in the Coulomb force has shifted to the advantage of the electron beam by an amount mainly dependent on R_b and It. The effect of these parameters on the reflection and hence the mirror images is examined.

By solving Eq. (3) via the Newton-Raphson method. The parameters R_b, R_S, W and V_{sc} are fixed at 0.5 mm, 15 mm and 10 kV respectively. For the quotient Q_b/Q_t we used 0.25, 0.5, 0.75, 1.0, 1.25 and 1.5. The calculations are then conducted for values of the scanning potential 4, 2, 1, 0.8, 0.6, 0.4, and 0.2 kV.

3. Results and discussion

The variation of the position of the reflection-point for several values of the scanning potential as a function of Q_b/Q_t is plotted in Fig. 1. It is seen that the reflection point move away from the column diaphragm towards the sample as Q_b/Q_t is increased. In other words, there is an increase in the ability of incident electrons to come closer to the sample whenever the beam current is increased. Obviously this characteristic becomes insignificant at higher V_{sc} indicating that the beam current I_b can only be used to control mirror images at low values of the V_{sc}. Otherwise the adjustment of electron mirror images should be carried out by means of V_{sc} itself.

In order to focus on the curve of the inflection point that belong to V_{sc} = 10 kV is plotted again at an enlarged scale in Fig. 2. It can be seen that the increase of Q_b/Q_t is still pushing the inflection point towards the sample surface. But the rate of decline of z_r practically insignificant because the point of reflection z_r declines by just ∼10% from its original position whereas the corresponding rise in the beam-current reaches to ∼500%.This result confirms that the increase in V_{sc} leads to reduces the ability of the beam current in the reflection process of electrons.

Keeping the quotient Q_b/Q_t fixed at the value 1.5 the reflection point versus the radius of scanning beam is plotted in Fig. 3 for various values of scanning potential. Indeed the process by which the beam radius changes while the beam current maintained fixed may leads, from first glance, to a false confusion. This should never happen anymore for two reasons. First of them is that implementation of this task can be done according to the theoretical point of view. In other word I_b in Eq. (3) can kept fixed while R_b changes. The second one, however, is that such a mission is practically applicable. Actually it