Journal of Electrostatics 74 (2015) 102–107

Contents lists available at ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

Beam analysis of scanning electron microscope according to the mirror effect phenomenon

Hassan N. Al-Obaidi*

Department of Physics, College of Education, Al-Mustansiriah University, Baghdad, Iraq

ARTICLE INFO

Article history:
Received 25 July 2014
Received in revised form
23 November 2014
Accepted 9 January 2015
Available online 23 January 2015

Keywords:
Electron optics
Scanning electron microscope
Electron beam current
Electron mirror images
Insulator charging

ABSTRACT

In a scanning electron microscope the influence of electronic beam parameters on the electron-mirror images has been investigated. A simple theoretical model for scanning electron beam behavior in terms of beam and surface potentials is presented. The derived expression relates the scanning beam parameters and parameters of an irradiation region. Influence of a beam (the size and current), scanning potential, working distance, trapped charge and the irradiated area on electron mirror images are defined. Results show that the electron beam current has a considerable effect on the deduced mirror images in comparison with the other beam parameters. So it could be adapted for adjusting the phenomena of mirror effect. Moreover, the trapped charges have been calculated and the results examined in comparison with experimental data.

Introduction

The scanning electron microscope SEM is now one of the most indispensable devices for collecting data details for materials in the range of nano-scale. In addition, the applications of this tool may spread to many branches and scientific disciplines that make a lot of these application overlap with each other. The electron beam parameters are the main factors that define the technical characteristics of a SEM apparatus. In other word, the lens system that produces and controls the beam of electrons are the cardinal elements that specify the quality of any SEM. However, the electron beam current, size (or a diameter), angle of inclination and the depth of its focus are the usual parameters that define a charged particle beam [17]. This information is important both for the development and upgrading of the construction of a SEM, and for the use of the microscope in scientific research and industries. Information regarding the geometrical characteristics of the electronic beam is of particular importance in connection with the development of new methods for measurements of linear dimensions of the relief elements in the micro or nanometer range, being on a surface of a solid [15].

It is worth to mention that the beam current is the most important parameter that influence the electronic beam diameter [9], and so it is a very important instrument parameter. Strictly speaking, low beam current and small spot size are usually required for high resolution, while the high beam current and large spot diameters are ultimately useful for good contrast [7]. So, a condenser lens in a SEM should be operated in compensative way such that it balances these two parameters according to the specific application. The above argument is valid only for normal use of a SEM to imaging conductive, or either a metal-coated insulator, samples. However, when a sample of a dielectric material (or either not grounded conducting sample) is adopted for inspection by means of the SEM, the mirror effects occur inside the SEM chamber, see for example [16,10].

Substantially, this phenomenon arises due to the accumulation of charges, electrons in the SEM [2] and ions in Focused Ion Beams FIB [8], at the sample surface during the irradiation process. Consequently, an electric potential will be born and begins to growth over the irradiated region up to the state of saturation [1]. In turn this potential makes the scanning electrons (electron of lower potential) reflect-back toward the upper chamber space. Therefore, the screen of SEM apparatus will reveal an image that refers to the ceiling of the SEM chamber rather than the sample. Electron mirror images have gained more advertencies since its invention in the seventies of the last century. However, it is now attracting a great deal of attention, especially when some authors argued that it can

* Tel.: +964 7901264694.
E-mail addresses: hassanmail2006@yahoo.com, hassan_nouri@uomustansiriyah.edu.iq.

http://dx.doi.org/10.1016/j.elstat.2015.01.004
0304-3886/

be used as a tool to determine some of the characteristics of insulator materials [13,1].

Indeed many operation parameters control the image which is deduced by means of mirror effects. Among most of them are the irradiation potential, current and time [5,6], scanning potential [1], scanning current [3], working distance [14] and the dielectric constant [13] of the insulator material under consideration. Recently it has been shown that the beam current could be used either to enhance, or to eliminate, the phenomena of mirror effect [3]. The ideas that have been used in the op cit will be developed in the present work to get a deeper understanding for the characteristics of the electron beam in the sense of mirror effect.

On the other hand, it is well known that an electron beam trajectory through any charge particle system is one of the problems that attract a great interest in the field of charged particle optics. The knowledge of the electron path coordinates inside the system space requires a solution for the electron equation of motion, i.e., the paraxial ray equation. Indeed this equation is the only tool by which the charged particle path can be determined and hence the quality of the related system is evaluated [4]. Furthermore, the solution of this equation is not a straightforward task due to the mathematical nature that may require analytical and/or numerical manipulation [12]. More recently the behavior of electrons inside the chamber of the SEM is investigated concerning the mirror effect phenomena [3]. This investigation is carried out a via complicated mathematical procedure. So it is useful to search for a way that can determine the path of the charged particle, albeit roughly, especially inside the chamber of the SEM apparatus. Consequently, the present work tries to get information about the electron reflection coordinates without the need to solve the paraxial ray equation.

Theoretical manipulation

It is well known that the flow of electrons that go through the hole in the anode, of the electron gun, and continue down the column to the specimen makes up the beam current. Accordingly, one can assume that these electrons may be distributed uniformly within the beam and so the face of this beam being a disk of a radius R_b that carry charges of an amount Q_b, see Fig. 1.

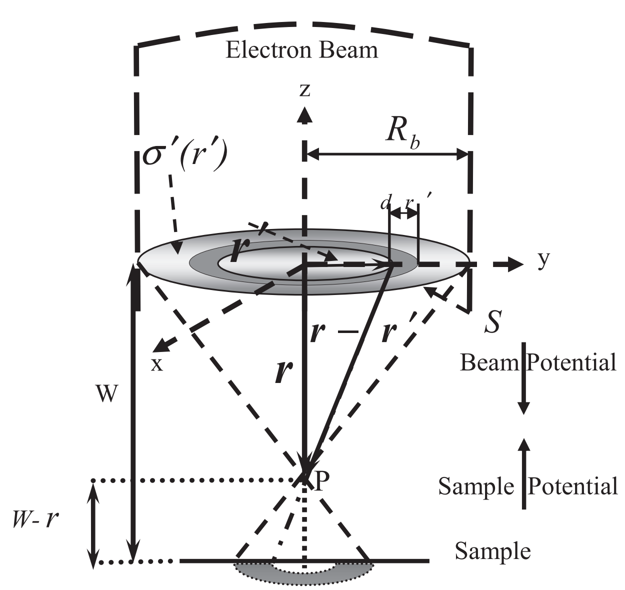

Fig. 1. A schematic representation for a beam of electrons landing on a sample that is previously irradiated.

The aim, however, is to find the electric potential $U_b(r)$ at a point P located at a distance r from the beam's disk. According to the basic ideas of electromagnetism the potential $U_b(r)$ can be written as [11];

$$U_b(r) = \frac{1}{4\pi\varepsilon_0} \int_S \frac{\sigma'(r')da'}{|r - r'|} \tag{1}$$

where $\sigma'(r')$ is the surface charge density embedded in the disk, da' is an infinitesimal area of the disk which is bounded by the surface S. Using the cylindrical coordinates and keeping in mind that charges are uniformly distributed across the disk surface, Equation (1) can be written as;

$$U_b(r) = \frac{\sigma'}{2\varepsilon_0} \int_0^{R_b} \left(\vec{r}^{\,2} + r'^2\right)^{-1/2} r' dr' \tag{2}$$

where the disk of electrons is assumed to be at a right angle with respect to the beam axis. The integration of Equation (2) leads to the following formula;

$$U_b(r) = \frac{\sigma'}{2\varepsilon_0} \left\{ \left(\vec{r}^{\,2} + R_b^2\right)^{1/2} - \vec{r} \right\} \tag{3}$$

Since the surface charge density is assumed to be uniform, thus; $\sigma'(\vec{r}\,') = Q_b/S$, where $S = \pi R_b^2$. According to the current definition, the total electrons (Q_b) (embedded in the surface S) can be expressed in terms of the beam current (I_b) as; $Q_b = I_b t$. Where t is the unit of time per which the electrons (Q_b) will pass through any point (x, y, z) within the beam space. Thus, Equation (3) may converts to the following form;

$$U_b(r) = \frac{I_b t}{2\pi\varepsilon_0 R_b^2} \left\{ \left(\vec{r}^{\,2} + R_b^2\right)^{1/2} - \vec{r} \right\} \tag{4}$$

Since the above manipulation is mainly concerned with finding beam potential along the beam axis (see Fig. 1) Equation (4) can be written as;

$$U_b(W - z) = \frac{I_b t}{2\pi\varepsilon_0 R_b^2} \left\{ \left((W - z)^2 + R_b^2\right)^{1/2} - (W - z) \right\} \tag{5}$$

where W is the working distance. It can be seen that the beam's current and diameter are the only beam parameters that influence the beam potential. Therefore the number of accelerated electrons, that construct the beam, and its own spatial distribution are the main characteristics of any electron beam. Actually, this beam specification is fixed along the distance from the beam surface till the sample.

When an electron beam is used to irradiate an area of radius R_s for an insulator material, an amount of charges Q_t will be accumulated at this area. By using a similar manipulation treatment, to that followed with the electron beam, one can reach the following form for the electric potential at the sample surface due to these trapped charges;

$$U_S(z) = \frac{Q_t}{2\pi\varepsilon_0 R_S^2} \left\{ \left(z^2 + R_S^2\right)^{1/2} - z \right\} \tag{6}$$

Indeed Equations (5) and (6) are exactly similar since theirs owns potential is deduced according to the same framework. However, when the potential at the sample surface becomes equivalent to that of the electron beam, the incident electrons have an opportunity to reflect back at certain points from the optical axis-z. Definitely, this