Investigation of Linear Polarization for a Specimen Insulator of Scanning Electron Microscope in Sense of Mirror Efectronic Phenomenon

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Abstract

An analytical procedure has been carried out to measure the charge that may be trapped in an insulator sample of scanning electron microscope. It mainly concerns the determination of the deduced polarization charges by means of mirror effect phenomenon. Several relations related to such issue have been modified so as to be applicable for regarding charges due to polarization in linear and isotropic material. Consequently, the potential arises as a result for both trapped free and polarization charges which is set up. Actually the well-known magnification factor method is adopted to be a case study to implement the introduced approach. Results have clearly showed that the polarization charge significantly influences the Coulomb's force that incoming electrons suffer from. Furthermore, the variation in the sample potential mainly depends on the dielectric constant of the specimen material.

Keywords: SEM, Mirror effect, Charging process, Insulators samples, Electron beams.

Introduction

A wide investigation has been accomplished concerning electron trapping in insulators due to its own importance when a dielectric material is inspected by means of scanning electron microscope (SEM). However, this importance comes from the phenomenon which is occurred inside SEM chamber. One of the most spectacular observations related to the electron charging is the well-known mirror effect. Mirror effects occur when a primary electron beam scans an insulating sample and the charges on its surface accumulate to a high density. When the energy of the electrical field becomes higher than the primary beam one, it prevents the charged particles from reaching the sample surface, reflecting them somewhere else in the vacuum chamber whose walls act as a mirror. The inner part of the specimen chamber can be therefore imaged. The phenomenon was explained in terms of something very close to what happens to photons interacting with an optical mirror [1].

Actually, the inspection process behind insulator irradiation by a charged beam is a very complicated problem. This complication arises from several physical and geometrical situations for the sample to being. Where, the sample may be coated by a metallic material or not, grounded with the stage or not, separated from the stage by special distance or not… etc [2]. Consequently, various experimental techniques had been presented for measuring the trapped charges that are suitable for specific situation. Most of the experimental techniques, including the thermal pulse method, the pressure wave propagation method, the Kerr electro-optic method, and the mirror image method, measure the total trapped charge and its distribution in the insulator [3].

Concerning with mirror image method, one can mention several literatures which adopted this method to investigate the charging process and so the trapped charges. For example, this technique is employed for the investigation of charging in different cuts of a α-SiO2 [4]. Also it combined with the classical scattering theory to represent a modified method to calculate the total trapped charge [5]. Other authors developed this method to measure the charge distribution volume in insulators [6] where an electrostatic potential expression is derived by assuming the dipolar approximation and hemispheroid distribution. Dielectric samples with different relative permittivities are employed in charging experiments to justify this approach. Furthermore, scanning electron microscope mirror method was used for studying a cloud of charge stored near the surface of an insulator. The effect of the finite size of the experimental chamber, of the thickness of the sample, and of relativistic corrections was discussed. Moreover, it had been made a detailed computation of the electron orbits in the presence of extended sources, and then tests the commonly made assumption that the method measures the radius of curvature of the equipotentials [7]. In addition to that, observation of Pseudo–Mirror Effect had been reported and gave an explanation concerning the factors that could be influenced [8]. Other authors had presented a reviewed investigation for the charging effects occurring when an insulating material is subjected to electron irradiation by means of SEM. However, they proposed a method to deduce the trapped charge inside the insulator (whether it is coated or not) and so the corresponding internal or external electric field [9]. The Electron Mirror Effect (EME), images was discussed by using the passive Solid State Backscattered Detector (SSBSD), where a non-conductive Polyethylene Terephthalate (PET) sample was irradiated by high energy electrons [10].

On the other hand, a basic model to calculate the inversion point of electrons of the primary beam launched against the dielectric in connection with simple measurements is presented [11]. This investigation had showed the importance of the analytical properties of EME and Ion Mirror Effect (IME) associates with the investigation of insulator charged surfaces, the whole family of experiments can play a relevant role in the understanding of the basic features of electrodynamics of charged particles in a simple and controllable way. The behavior of an accelerated probing electron that orientated towards a charged insulator sample and hence producing mirror images is investigated analytically [12]. Where, the distribution of the trapped charges at the sample surface is approximated as a point charge. Hence, analytical derivation for the path equation of this electron has been introduced. Thereafter a comprehensive investigation is carried out to inspect the influence of trapped charge, scanning potential, working distance and dielectric constant on the images by means of this model [13]. Indeed all of the mentioned studies used the conventional way for calculating trapped charges. So no one of them had considered the effect of the polarization charge. Therefore the essential goal of this manuscript is to investigate the influence of this kind of charge on the properties of the mirror images. So, attention will be focused on the mechanism by which charges accumulates on the sample surface by means of the free and polarized charges.

Theoretical Structure

Conductors and dielectrics materials response differently in an electric field. The main difference between them lies in the availability of free electrons in the atomic outermost shells. Although the charges in a dielectric are not able to move about freely, they are bound by finite forces and one may certainly expect a displacement when an external force is applied [14]. On the other hand, when a dielectric material is subjected to an electron charging process, there will be an excess in the negative charges over that the material own. Indeed, these extra charges accumulate more and more (i.e. trapped at the dielectric surface) during the charging process till the saturation limit. These trapped charges behave as a source of an electrostatic field (potential) which eventually leads to polarizing the dielectric material under consideration. Thus, the electrostatic flux density being now gained additional resource due to the linear polarization ($\vec{P}$)over their counterpart in free space ($\varepsilon_o \vec{E}$) which can be written as [15]:

$$\vec{D} = \varepsilon_o \vec{E} + \vec{P} \qquad (1)$$

For isotropic and linear medium, the and have a linear relationship at every point in the dielectric material and hence equation (1) becomes [16];

$$\vec{D} = \varepsilon \vec{E} \qquad (2)$$

Where is the material permittivity (dielectric constant), which is the sum of the free space permittivity ( ) and the electric susceptibility, and is the relative permittivity.

Several assumptions have been proposed to describe the distribution of the trapped charge at the surface of a dielectric material. Among most of them is the so called point charge approximation. According to that, the electrostatic potential at a point r, due to a charge Qe trapped at a surface of a dielectric material of a permittivity is given by the following relation [4];

$$V_{sc} = \frac{KQ_e}{4\pi\varepsilon_o r} \qquad (3)$$

Where is permittivity constant which is equivalent to .The essential condition by means of equation (3) is derived, the grounded walls of the vacuum chamber are supposed to be far enough from the sample to be considered at the infinite. In that sense equations (3) draw spherical equipotential surfaces whose their center is the origin of the trapped charge distribution. However, when the sample is entirely isolated from the stage an experimental approach, called magnification factor method, can be used to determine the number of charges that may be trapped at the sample surface. Consequently, equation (3) can be reformulated in terms of the magnification factor (d/d'), working distance (L) and the scanning potential (at which the mirror image is captured) as shown by the following relation [17];

$$Q_e = 16\pi\varepsilon_o \frac{L}{K}\frac{d}{d'}V_{sc} \tag{4}$$

Where d' is the output diameter of the column and d is its counterpart in the image received by means of mirror effect and L is the working distance. In fact, equation (4) is derived assuming that the incoming electrons undergo a Rutherford's scattering from the charges that trapped at the sample surface where the radius of the equipotential surface had been taken the expression [17];

$$\frac{1}{r} = \frac{d'}{d}\frac{1}{4L} \tag{5}$$

If the point charge KQe was situated in a vacuum, the electric field would be a pure radial field. But since E, D, and P are all parallel to one another at each point, the radial nature of the field is not changed by the presence of the medium. However, Gauss's law could be applied and the Gaussian surface can be chosen to be a spherical surface of radius r which is located concentrically about KQe. For convenience, KQe will be located at the origin. Then Gauss' law leads to the following form;

$$\vec{D} = \frac{KQ_e}{4\pi r^2}\hat{r} \tag{6}$$

The electric field and polarization may now be evaluated quite easily using equations (1) and (2) to get respectively;

$$\vec{E} = \frac{KQ_e}{4\pi\varepsilon_o\varepsilon_r r^2}\hat{r} \tag{7}$$

And;

$$\vec{P} = \left(1 - \frac{1}{\varepsilon_r}\right)\frac{KQ_e}{4\pi r^2}\hat{r} \tag{8}$$

It is seen that the polarization vanishes when the dielectric material is absent. Indeed this may justify the validity of the followed procedure. Anyway, the polarization has the unit of the flux density which is Coulomb per unit area. So polarization charge can be deduced by integrating equation over the Gaussian surface enclosing this charge. The result, however, is as in the following formula;

$$Q_p = -\left(1 - \frac{1}{\varepsilon_r}\right)KQ_e \tag{9}$$

The minus sign appears in equation (9) is a direct consequence of the opposite directions for the polarization vector and the outward unit normal to the Gaussian surface. Now, one is able to determine the total charges (Qt) surrounded by the Gaussian surface, which are the sum of the free electron embedded in the dielectric (Qe) due to the charging process, and the polarization charge (Qp) due to the polarization as follows;

$$Q_t = Q_e + Q_p = Q_e\left[1 - \left(\frac{\varepsilon_r - 1}{\varepsilon_r}\right)K\right] \tag{10}$$

However, equation (10) can be rewritten in sense of equation (4) as follows;

$$Q_t = 16\pi\varepsilon_o \frac{L}{K}\frac{d}{d'}V_{sc}\left[1 - \left(\frac{\varepsilon_r - 1}{\varepsilon_r}\right)K\right] \tag{11}$$

Actually, a significant conclusion can be predicted from equation (11) in which will be led to equation (4) when the polarization is over.

Results and Discussions

In order to grant the approach presented in last section a practical importance, some of the experimental data that are published in reference [2] have been adopted. According to this literature, a sample of PET is irradiated by an electron beam of different accelerating potentials with different periods of time. The electron mirror images have been received at a scanning potential 300 V for all of the followed experiments as shown in figures 1a and 2a. The method of magnification factor is used to determine the trapped charge at the surface of PET material and so equation (4) is applied for the measurement process at the values L=15 mm and d'=2.26 mm. It is worth to mention that the net trapped charge in this manner only describe the trapped electrons (free charges) in insulator material, which have been plotted as a function of the column apparent diameter in figures 1b and 2b for irradiation potentials 30 kV and 20 kV respectively.

It is quite reasonable to realize that as long as the irradiation process proceed for a long period of time and also a raise-up acceleration potential the number of free-trapped charges increases consequently. Figures 3 and 4 show the variation of the trapped charges in the presence of polarization together with the case when it is absent for comparison purposes. It is seen that when the polarization is taken into account the total number of trapped charges decreases. Actually one should keep in mind that there is no direct relationship between the total number of trapped charges and the polarization.

Indeed this may seem to be paradox, but the careful inspection of both of equations (4 and 11) reveal that the quantity Qt is calculated as a dependent variable of the sample potential which in this case equals to the scanning potential Vsc.Strictly speaking, the scanning potential (at the reflection) has a direct proportional with the charges that are being accumulated at the sample surface. Therefore, when Vsc increases the Qt increases too and vice versa. Defiantly, the presence of polarization leads to decrease the electric field (due to the trapped charges) by amount equals to as can be seen from equation (7). As a consequence the correspondence potential decreases by a same amount and hence this leads to decrease the trapped charges requested to met Vsc.

Furthermore, figure 5 represents the deviation between Qe calculated from equation (4) and its counterpart which is calculated from equation (11) as a function of d. Obviously, the difference between them gradually increases as long as more free charges are accumulate at the insulator surface. This behavior clearly interprets that polarization get growth during the implantation of a free electron at the surface of PET material. Beside that, the deviation between Qe and Qt increases with the increase of the irradiation potential. The reason behind that is the increase in the Qe (due to the increases of the incoming electron velocity) which makes these electrons to go further under the surface of PET material.

Conclusions

It is seen that the polarization charge has a considerable effect on the sample potential inside a chamber of SEM. Therefore, it must be taken into account in any calculation operation concerns with physical phenomenon that may occur in this apparatus. Additionally, this type of charge significantly alters the electrostatic field due to a dielectric material of high response for the electric field. Hence, whenever an insulator material of high susceptibility being examined by a SEM, the polarization charge has to be regarded.

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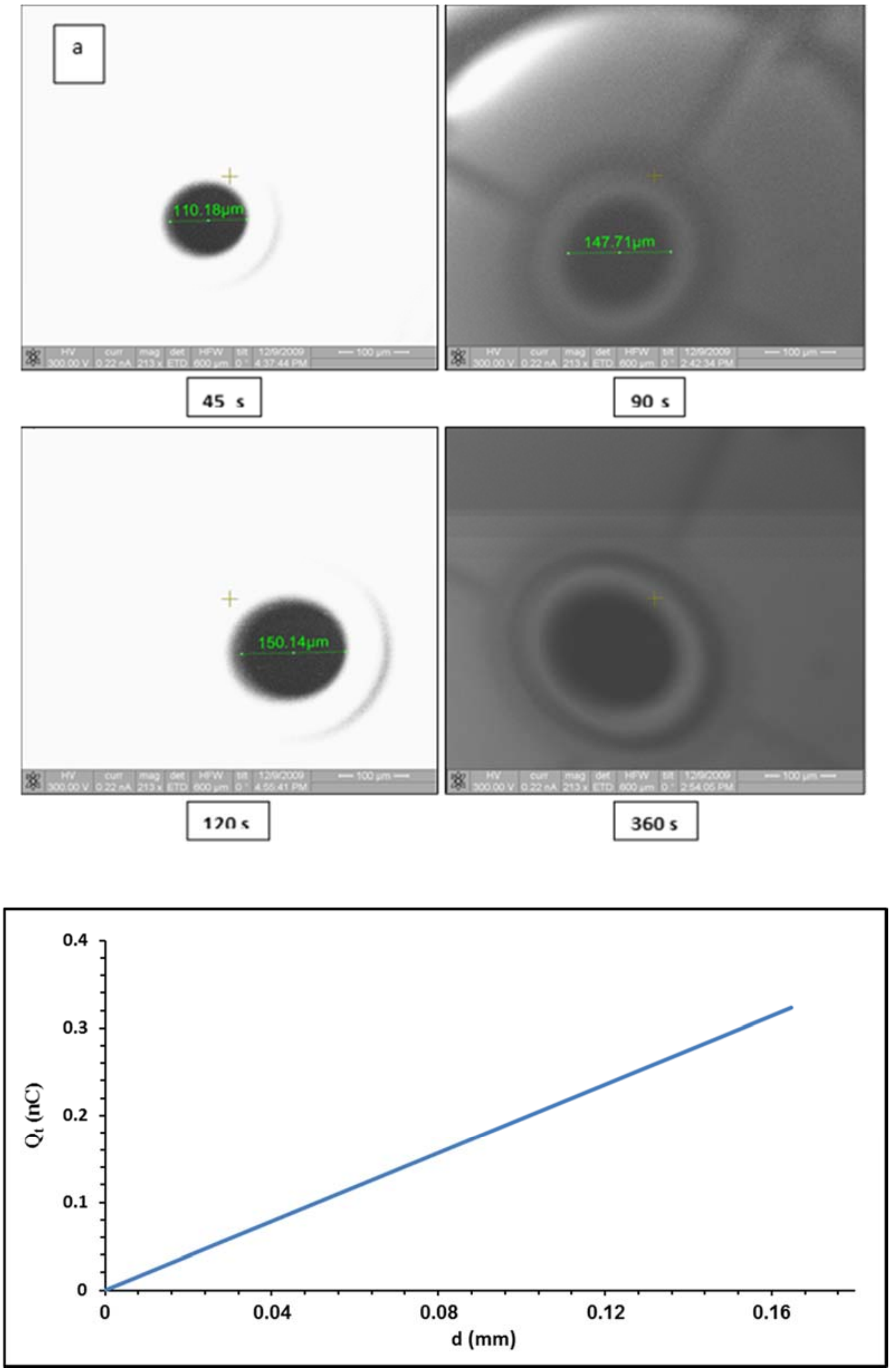
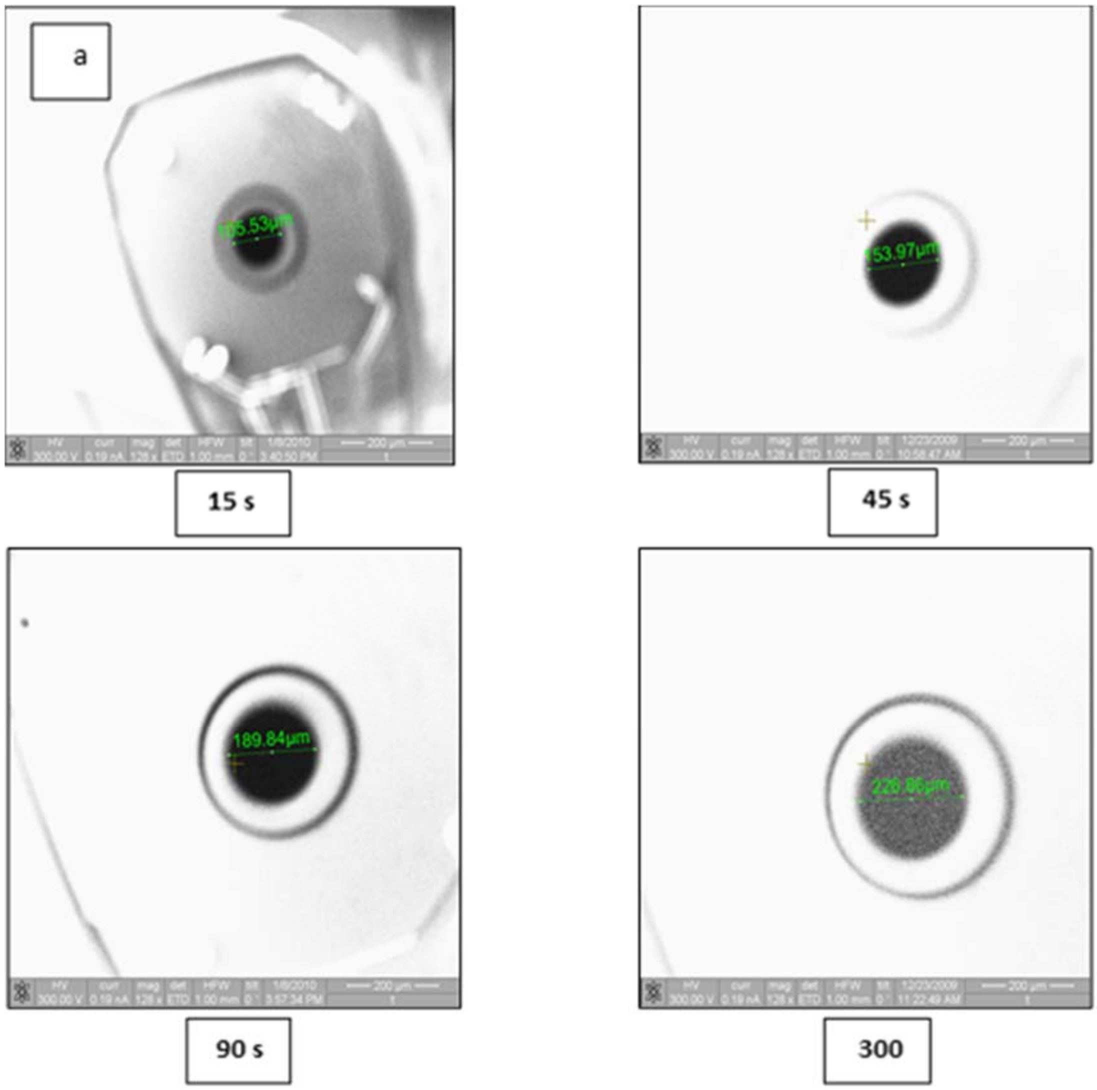


Figure No.(1): (a) Electron mirror images record at different irradiation times with irradiation potential of Vi=30 kV and magnification 213 [2], (b)The trapped electrons Qt versus the inner diameter of SEM column output diaphragm as imaged by the electron mirror



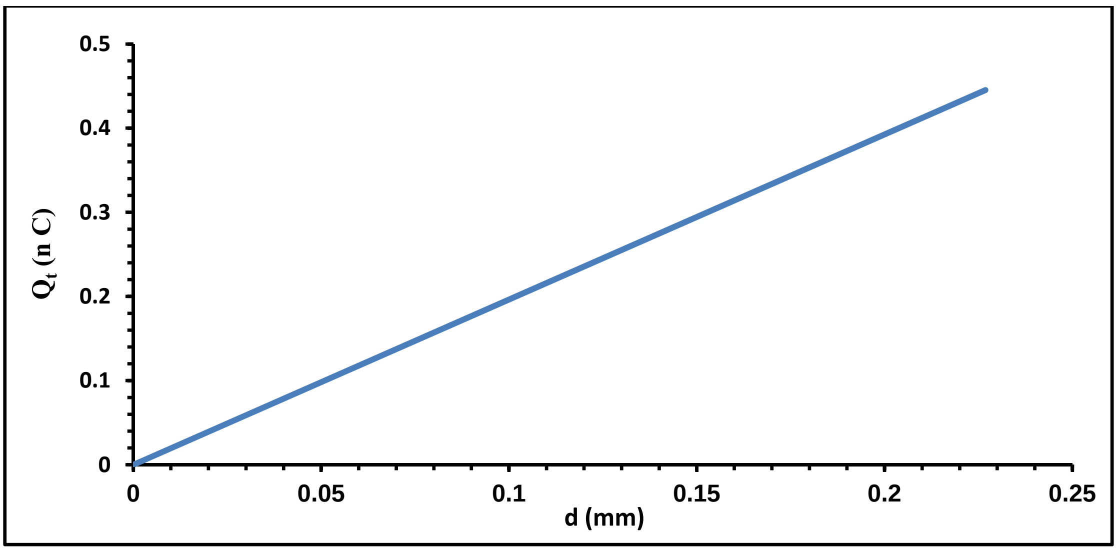


Figure No.(2): (a) Electron mirror images record at different irradiation times with irradiation potential of Vi=20 kV and magn.=128 [2], (b)The trapped electrons Qt versus the inner diameter of SEM column output diaphragm as imaged by the electron mirror

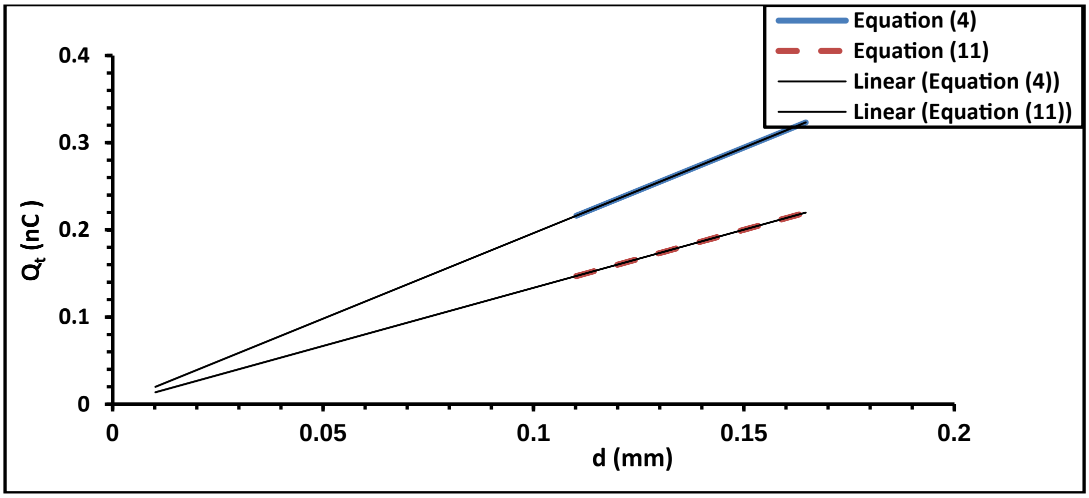


Figure No.(3): The total trapped charges Qt versus the inner diameter of SEM column output diaphragm for Vi= 30 kV

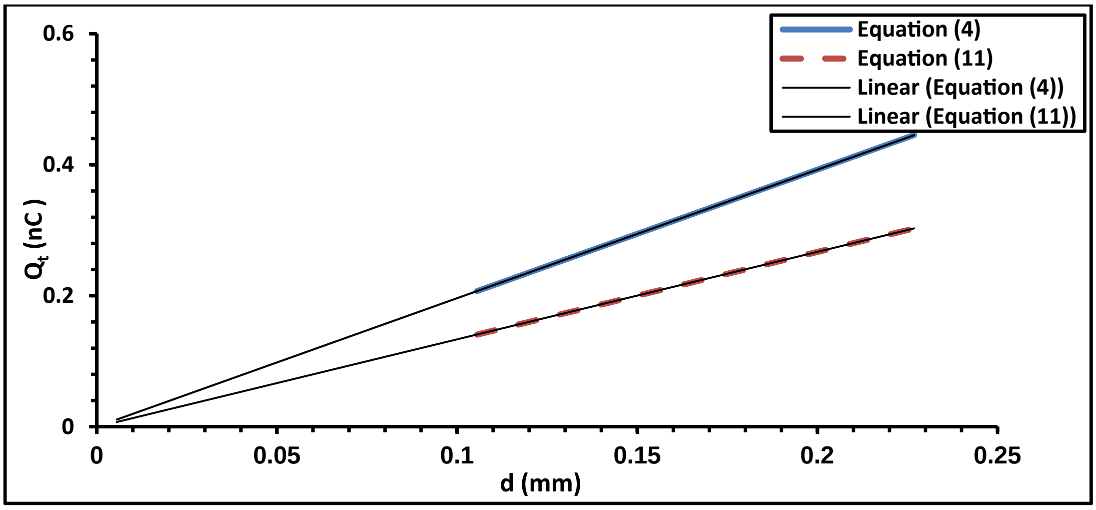


Figure No.(4): The total trapped charges Qt versus the inner diameter of SEM column output diaphragm for Vi= 20 kV

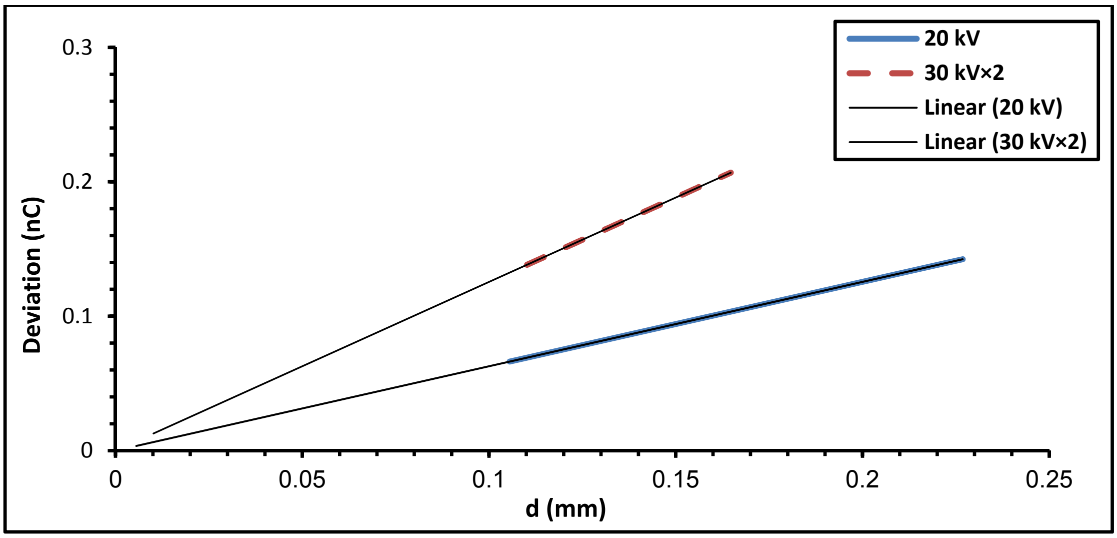


Figure No.(5): The deviation between Qe and Qt versus d for two different irradiation potentials

دراسة الاستقطاب الخطي لعينة مادة عازلة للمجهر الالكتروني الماسح في منظور ظاهرة المرآة الالكترونية

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الخلاصة

تم انجاز اجراء تحليلي لقياس الشحنة التي يمكن أن تحقن في نموذج لمادة عازلة في المجهر الالكتروني الماسح. يعتمد هذا الاجراء بالأساس على تحديد شحنة الاستقطاب بوساطة ظاهرة المرآة الالكترونية. من خلال ذلك تم تطوير عدة علاقات مرتبطة بهذا الموضوع لتكون قابلة للتطبيق فيما يتعلق بالطبع شحنات الاستقطاب للمواد الخطية والموحدة الخواص، بالنتيجة تم تحديد الجهد الذي ينشأ كنتيجة لتأثير كل من الشحنات المحقونة الحرة والشحنات المستقطبة. بالحقيقة تم تبني طريقة عامل التكبير كدراسة افرادية لانجاز الاجراء المقدم في هذا البحث. أوضحت النتائج بشكل جلي ان شحنة الاستقطاب تؤثر في قوة كولوم التي تعاني منها الكترونات المسح فضلاً عن ذلك فان التغيير في جهد العينة يعتمد بصورة رئيسة على ثابت العزل لمادة العينة.

الكلمات المفتاحية: المجهر الالكتروني الماسح، التأثير المرآتي، عمليات الشحن، نموذج عوازل، الحزمة الالكترونية.