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Approximations of Minimum Approach Distance in Electron Mirroring Phenomena

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Abstract

The minimum approaches distance of probing electrons in scanning electron microscope has investigated in accordance to mirror effect phenomenon. The analytical expression for such distance is decomposed using the binomial expansion. With aid of resulted expansion, the distribution of trapped electrons within the sample surface has explored. Results have shown that trapped electron distributes with various forms rather an individual one. The domination of any shape is mainly depend on the minimum approaches distance of probing electrons

Keywords: Electron mirror image, Charging effect, Minimum approach distance, Scanning electron microscope, Insulator samples.

1. Introduction

The phenomenon of charging effect (CE) has get a great deal of attention during the last three decades [1]. Significantly, it is a conventional result for irradiating an insulator material by a charged particles beam in scanning electron microscope (SEM) [2]. Such a materials have an ability to keeps some of the projectile charged particles at underneath its surfaces temporally[3]. Eventually, these accumulated charges make a mirror like, which reflects the next incoming charged particles. Therefore, an image for the insider chamber will received instated of topographic of the sample surface, which usually called electron mirror image (EMI) [4-6].

Physically, there are many parameters specifies the characteristics of CE such as the working distance [7], specimen dielectric constants [8], irradiation beam potential, current and elapsed time [9,10], potential and current of scanning beam [11]. Indeed, all of these parameters control the path of the accelerated probing electron that orientated towards a charged sample. Hence, the produced electron mirror image features only influenced by behavior of the path of these electrons. Latterly, such a behavior is investigated extensively by derive an analytical expression for the path of probing electrons. This path extends along the probing electron travel from the column diaphragm until the chamber ceiling [1]. Current work aims at present a further investigation by implementing an expansion for this analytical expression. Such expansion may reveals how trapped electrons are distributes within the specimen surface. Hence, the actual surface potential could be evaluated and the electrical resistance force for the probing electrons can be find out.

2. Material and Method

Schematically, the path of probing electron can be represented as shown in figure.1. Obviously, an electron of charge e and scanning potential V_{sc} is incident with an angle α toward trapped electrons Q_t that accumulated at the sample surface in SEM. Due to the Coulomb repulse force, the probing electron suffers a deflecting from its original path and so it is plot a parabola curve as revealed in the figure.

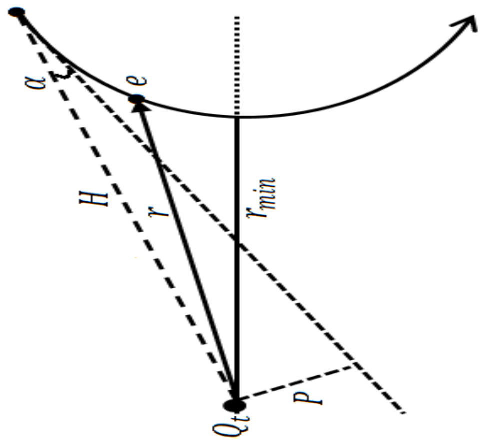

Figure. 1: A schematic diagram for a probing electron path in sense of mirror effect.

However, the minimum distance that such particle approaches from trapped electrons (r_{min}) can be expressed by the following formula [1];

$$r_{min} = \frac{2V_{sc}P^2}{\lambda Q_t\left[\sqrt{1+(2V_{sc}P/\lambda Q_t)^2}-1\right]} \qquad \ldots\ldots\ldots\ldots(1)$$

Where λ is a constant that related free space permittivity (ε_o) and the relative permittivity (ε_r) by the formula; $\lambda = 1/2\pi\varepsilon_o(\varepsilon_r + 1)$. The symbol P represent the impact factor and given by the expression; $P = H\,sin\,\alpha$, and H refer to the working distance.

Assuming that, $R = \frac{2V_{sc}}{\lambda Q_t}$ and regard R to be the radius of Gaussian surface, equation (1) can be re-written as follows;

$$\frac{1}{r_{min}} = \frac{R}{2P^2}\left[\sqrt{1+\left(\frac{2P}{R}\right)^2} - 1\right] \qquad \ldots\ldots\ldots\ldots(2)$$

Using the binomial expansion for the expression inside the root of equation (2), the following formula can be deduced;

$$\frac{1}{r_{min}} = \frac{1}{R}\left\{1 - \left(\frac{P}{R}\right)^2 + 2\left(\frac{P}{R}\right)^4 - 5\left(\frac{P}{R}\right)^6 + 14\left(\frac{P}{R}\right)^8 - \cdots\right\} \qquad \ldots\ldots\ldots\ldots(3)$$

It is worth to mention that, the expansion above has been implemented considering the impact factor lower than the radius of Gaussian surface along the entire path for the probing electron, i.e. $\left(\frac{2P}{R}\right)^2 < 1$. Equation (3), in fact, represent a new form for the equation of mirror plot, which is represented by means of different distribution forms of trapped electrons. Strictly speaking, the first term in this formula shows that the trapped electrons spreading is like a point. However, the following terms second, third, fourth, fifth …refers to the dipole,

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quadrupole, hexapole, octupole … like profile. Consequently, evaluations of these terms may reveals how the minimum approaches distance could influenced by these distribution forms.

3. Results and Discussions

For the following values; Q_t=0.42 nC, H=15 mm, α=0.2°and for a PET sample material (ε_r=3.34), equation (3) has been executed for several values of the operating scanning potential. However, the amount for each term that contributed to create this equation as a function of scanning potential are plotted in figure.2. Obviously, the individual contribution of these terms increases gradually with increasing of scanning potential. Among all of the considered terms, the first one mostly feed the curve ($1/r_{min}$) by its total worth along the interval $2 \leq V_{sc} \lesssim 5$ kV.However for the interval $V_{sc} \gtrsim 5$ kV the first term values becomes greater than the amount of mirror plot curve itself. The reason is quite clear due to the increase of the growth rate for the second and fourth terms (especially the second term) over their counterpart the first one. In other word, when the incident electron approaches to a distances less than ≈0.34 mm from the sample, trapped electrons are no longer appears to be located at a same point. Actually, they look like to be spreads to the benefit to be a dipole distribution form.

Indeed, the result mention above in agreement with that mentioned in previous works, see for example the literatures [1,3 and 12] where the point charge approximation falls to works well as long as scanning potential get rise increases. However, for such distances the second and fourth terms becomes balancing the increases of first terms and hence the curve of ($1/r_{min}$) deviates down from being linear. Keep in mind that, signs of these two terms is negative and so their own growth opposite to that for the remaining regarded terms. Here it should be mention that when the probing electron approaches further toward the sample, the contribution of all of the considered terms increases as revealed in Table-I. Nevertheless, the contribution of the second terms is the dominant one and therefore the mirror plot scaled down. This behavior indicates to an important fact that, trapped electrons formed as various shapes but the foremost one is the dipole profile.

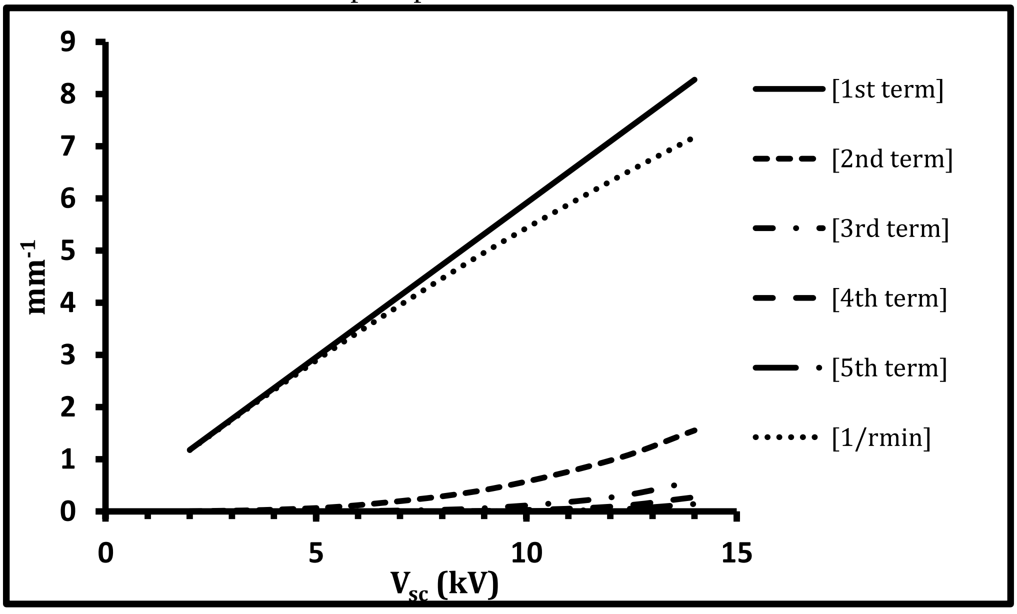

Figure.2: Valuable amount the terms in equation (3) versus the scanning potential.

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However, Table-I directly reveals that the weight amount of the first terms is more than the whole values of the curve($1/r_{min}$) along the considered interval of scanning potential. Actually another remark can be recorded from this table, that is the second terms becomes significantly affects the mirror plot curve for values of scanning potential greater than 5 kV. Furthermore, weight of the considered terms becomes significant as long as the scanning potential is increases.

Table-I: Weight amount of each term in equation (3).

V_{sc} (kV)	terms weight				
	1^{st}	2^{nd}	3^{rd} $\times 10^{-1}$	4^{th} $\times 10^{-1}$	5^{th} $\times 10^{-2}$
2	1.004	0.0038	0.000	0.000	0.000
4	1.015	0.0156	0.005	0.000	0.000
6	1.033	0.0357	0.025	0.002	0.000
9	1.072	0.0832	0.129	0.025	0.050
12	1.121	0.1547	0.427	0.147	0.570
14	1.153	0.2166	0.814	0.382	2.010

4. Conclusion

Results presented in this work gives a clear indication that the trapped electron could takes different formations at the sample surface. In addition, this various distributions almost mixed of several profile but there is often one (or may others) is being dominant. The main parameter that controls these formations is the distance between the incident and trapped electrons. This mean, however, the used scanning potential that drive the probing electrons to a minimum approaches distance.

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