

## COMMENTARY

# Comment on “Potential profile near the virtual cathode in presence of charged dust”

Mangilal Choudhary

I. Physikalisches Institut, Justus–Liebig  
Universität Giessen, Giessen, Germany

## Correspondence

Mangilal Choudhary, Physikalisches Institut,  
Justus–Liebig Universität Giessen,  
Henrich–Buff–Ring 16, D 35392 Giessen,  
Germany.  
Email: mangilal.choudhary@  
physik.uni-giessen.de

## Abstract

The characteristics of the virtual cathode and its potential profile in the presence of negatively charged dust particles have been reported by Rathod et al. They have studied the role of charged dust particles in the formation of virtual cathode near the emitting surface. Two conditions of the dust charge number,  $Z_d = 1$  and  $Z_d = 1,000$  are used to study the role of dust density ( $n_d$ ) for the formation of virtual cathode. This work is original and will be more interesting in case of using the correct model equations and realistic dusty plasma conditions.

## KEYWORDS

double layer, dust charging, emitting cathode, plasma sheath, virtual cathode

In a very recent paper, Rathod et al.<sup>[1]</sup> have studied the potential profile near the virtual cathode in the presence of charged dust. The virtual cathode formation in a plasma sheath region of an emitting cathode is an interesting topic and has been studied theoretically and experimentally.<sup>[2–4]</sup> In the manuscript, authors have studied the role of charged dust particles to the potential profile of a virtual cathode. They introduce dust particles in the cathode sheath region of an emitting electrode to incorporate the role of charged dust grains in virtual cathode formation. The set of equations are used to get solution of potential distribution in the sheath region including the dust density ( $n_d$ ), dust charge number ( $Z_d$ ), the density of emitted electrons ( $n_{ee}^0$ ), etc. From the set of Equations<sup>[1]</sup> (Equation 1–20), authors derive the conditions for the existence of virtual cathode in presence of the charged dust grains. The virtual cathode forms when  $\phi_{vc} - \phi_w < 0$ , where  $\phi_{vc}$  and  $\phi_w$  are potential at virtual cathode and emitting wall respectively. So the difference  $\phi_{vc} - \phi_w$  is given as (Equation 21 of the original manuscript)

$$\phi_{vc} - \phi_w = \frac{k_B T_w}{e} \ln \left( \frac{Z_d n_d \alpha}{n_{ee}^0 \beta} \right) \quad (1)$$

where  $T_w$  is temperature of cathode or emitting surface,  $\alpha = n_{rd}/n_0$ ,  $\beta = Z_d n_d/n_0$  and  $n_{ee}^0$  is the density of secondary emitted electrons at the surface. The details about the  $n_{rd}$  and  $n_{ee}^0$  is given in the original manuscript. It has been claimed after citing this equation that  $\beta$  acts an important aspect in the formation of a virtual cathode. It means that dust density, as well as dust charge, have an important role in the formation of virtual cathode.

Authors in original manuscript have plotted this potential difference,  $\phi_{vc} - \phi_w$ , against  $T_w$  for the dusty plasma parameters (a)  $Z_d = 1$ ,  $n_d = 10^3$  to  $10^6$  cm<sup>-3</sup> and (b)  $Z_d = 1000$ ,  $n_d = 10^1$  to  $10^3$  cm<sup>-3</sup> in Figures 5 and 6, respectively. It is clear from Equation (1) that  $\phi_{vc} - \phi_w$  varies linearly with the wall temperature  $T_w$  for the given discharge and dusty parameters. In Figures 5 and 6, I see either a zero or almost steady variation in  $\phi_{vc} - \phi_w$  with increasing  $T_w$  from lower to a threshold value ( $T_{th} > 52,000$  K), where a double layer like potential structure or virtual cathode is formed. An almost steady or zero variation of  $\phi_{vc} - \phi_w$  against  $T_w$  below the threshold temperature does not follow the Equation (1) which is used to understand the role of dust

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2019 The Authors. *Contributions to Plasma Physics* published by Wiley-VCH Verlag GmbH & Co. KGaA

grains in the virtual cathode formation.<sup>[1]</sup> The density of emitted electrons ( $n_{ee}^0$ ) can be estimated by expressions  $n_{ee}^0 = J_{rd}/ev_w$ , where  $j_{rd} = AT_w^2 \exp(-W_f/k_B T_w)$  and  $v_w = \sqrt{2k_B T_w/\pi m_e}$ . Here  $A = 1.2 \times 10^6 \text{ Am}^{-2} \text{ K}^{-2}$  and  $W_f \sim 4.5 \text{ eV}$  are the Richardson constant and work function of the tungsten wall.<sup>[1]</sup> Since the density of emitted electrons is function of the cathode or wall temperature, it increases with increasing  $T_w$ . In the temperature regime of 100–52,500 K,  $n_{ee}^0$  varies from  $10^{15}$  to  $10^{28} \text{ m}^{-3}$ . At threshold temperature, density of secondary emitted electrons is order of  $10^{28} \text{ m}^{-3}$  which is tremendously higher than the primary plasma density,  $n_0 \sim 10^{14} \text{ m}^{-3}$  in the sheath region. Therefore, the numerical experiments performed under such conditions seem non-realistic.

It has been claimed that dust density is a function of the potential distribution,<sup>[1]</sup> which is true in the case of dusty plasma experiments. There is a lack of density variation function with the potential in the manuscript. However, figure captions of Figures 5 and 6 show that an equilibrium dust density ( $n_{d0}$ ) is used to plot the potential difference against  $T_w$ . It is assumed that Equation (1) is used to find the  $\phi_{vc} - \phi_w$  against  $T_w$  for different dust densities and charge numbers to claim the formation of a double layer like structure or virtual cathode in Figures 5 and 6. According to Equation (1) as well the basic concepts of dusty plasma, there should be a trend of  $\phi_{vc} - \phi_w$  against  $T_w$  for different dust densities. In Figure 5, a huge potential difference ( $\phi_{vc} - \phi_w$ ) from  $\sim \pm 100 \text{ V}$  to  $\pm 4,000 \text{ V}$  at  $T_w > 50,000 \text{ K}$  for a singly charged dust ( $Z_d = 1$ ) of density  $n_{d0} = 10^3$  to  $10^5 \text{ cm}^{-3}$  is observed. Such a huge difference in  $\phi_{vc} - \phi_w$  with a small dust density variation is questionable. In Figure 6,  $\phi_{vc} - \phi_w$  is plotted against  $T_w$  for dust with charge number  $Z_d = 1,000$  and density,  $n_{d0} = 10^1$  to  $10^3 \text{ cm}^{-3}$ . For lower dust density ( $n_{d0} = 10^1 \text{ cm}^{-3}$ ),  $\phi_{vc} - \phi_w$  has a transition around 75,000 K with an asymmetric potential difference ( $\sim -300 \text{ V}$ ) and it increases to  $\sim -1,000 \text{ V}$  at higher wall temperature  $T_w \sim 100,000 \text{ K}$  for a slight variation of  $\alpha$ . A different trend of  $\phi_{vc} - \phi_w$  with  $T_w$  is presented for higher dust density,  $n_{d0} = 10^2$ – $10^3 \text{ cm}^{-3}$ . In dusty plasma with emitted cathode or wall, dust grains absorb the secondary emitted electrons and reduce the density of free electrons in the sheath region. The free electron density in the sheath region decreases with increasing the dust density. The loss of free electrons is compensated by the secondary emitted electrons. Therefore, the threshold value of cathode temperature is expected to change when dust density is changed. Thus, one can expect a similar trend of  $\phi_{vc} - \phi_w$  with different threshold wall temperatures in the case of different dust density of fixed charge.

Materials in nature have their melting point. In the original manuscript, tungsten cathode is considered for the simulation work. They provided the external heating using some electric power source. Since tungsten has melting point around 4,000 K, it melts when  $T_w > 4,000 \text{ K}$ . It is observed that virtual cathode forms between 50,000 and 100,000 K for various dusty plasma conditions.<sup>[1]</sup> Such very high wall temperature using the electric power supply in the numerical or laboratory experiment is unexpected. In realistic condition, the wall or cathode temperature should be lower than the melting point of material.

Another problem concerning this article is the use of unrealistic dusty plasma conditions to get the solution for the virtual cathode. Authors have used the experimental plasma parameters to obtain realistic results. Since the study is focused on the dusty plasma, therefore, the experimental dust parameters such as dust particle size and charges on dust particle should be considered in the manuscript. In plasma, the charging mechanism of dust particles depends on the background plasma parameters. The charge number  $Z_d$  varies between  $10^2$  and  $10^5$  in the case of 100 nano to tenth of micron-sized particles in the laboratory plasma.<sup>[5]</sup> When the charge number  $Z_d = 1$ , it means a single electron charge on a dust particle, which does not seem realistic in context of dusty plasma ( $Z_d = 1,000$ ). The inertia of dust does not play any role to determine the potential distribution of sheath region; therefore, charges on it would change the characteristics of virtual cathode near the emitting surfaces. Considering the dust charge,  $q_d = e^-$  is nothing but an electron charge. Hence the dust density can be assumed as primary electron density. In such a case, the solution for the virtual cathode should be similar to that of observed in the ambient plasma.<sup>[3,4]</sup>

I would suggest considering real dusty plasma parameters instead of some random conditions for the realistic approach to study the virtual cathode in the dusty plasma. Authors should also look at the formulations as well as plottings carefully to realize the numerical observed results in laboratory.

## REFERENCES

- [1] D. Rathod, S. K. Dash, A. Sarma, *Contrib Plasm Phys* **2019**, 59, e201900007.
- [2] R. F. Kemp, J. M. Sellen, *Rev Sci Instrum* **1966**, 37, 455.
- [3] S. P. Tierno, J. M. Donoso, J. L. Domenech-Garret, L. Conde, *Phys Plasmas* **2016**, 23, 013503.
- [4] W. Li, J. X. Ma, J.-j. Li, Z.-a. Wei, *Phys Plasmas* **2012**, 19, 113511.
- [5] V. E. Fortov, A. P. Nefedov, V. I. Molotkov, M. Y. Poustylnik, V. M. Torchinsky, *Phys Rev Lett* **2001**, 87, 205002.

**How to cite this article:** Choudhary M. Comment on “Potential profile near the virtual cathode in presence of charged dust”. *Contributions to Plasma Physics*. 2020;60:e201900137. <https://doi.org/10.1002/ctpp.201900137>