8th International Workshop on Mechanisms of Vacuum Arcs

Study on phenomenon of high energy protons bombarding electrode

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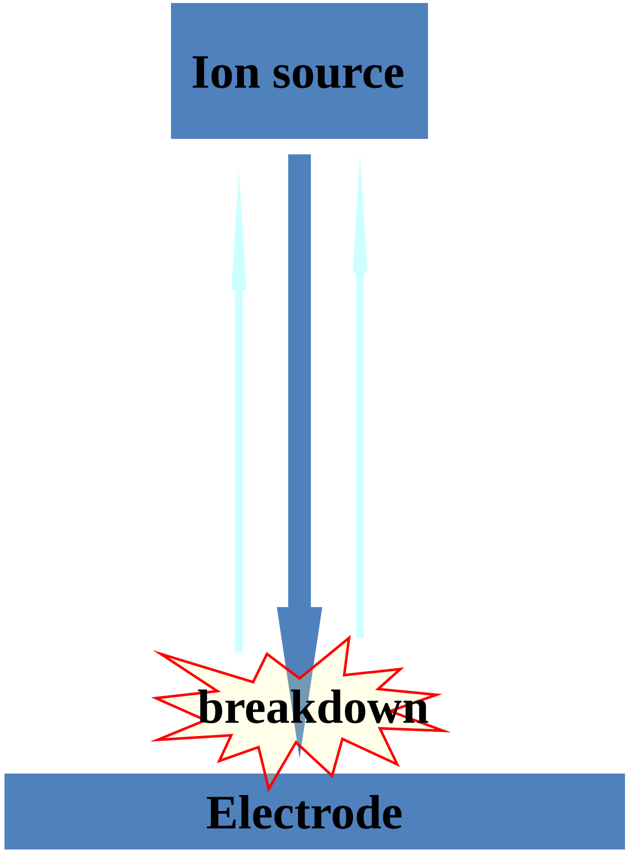
Introduction

- **When ion accelerators or film deposition instruments are operating, it is possible to induce breakdown by ion beam bombarding electrodes.**
- **But the operating voltage is not enough to induced breakdown in these instruments without the ion source working.**
- **Therefore, it is unambiguously that the interaction between high energy ions and electrode can obviously decrease the breakdown voltage in vacuum gaps.**



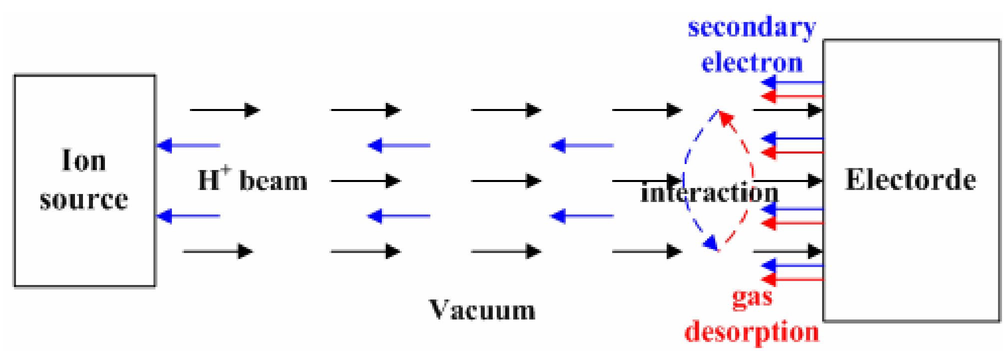
In order to illuminate this physical mechanism, the proton beam bombarding electrode under high voltage condition is selected as a typical physical model.

Simulation model

Simulation setting

Type	setting
Code	PIC-DSMC
Dimensionality	1D
Electrode	Stainless steel
Background	1×10^{-5}Pa, H_2
Ion beam	H^+
Adsorb gas	H_2
Sputter	non
Particle species	e, H, H^+, H^{2s}, H_2, H_2^+
Interval	5mm
Voltage	-50kV

The ion source only emit H^+, the emission flux of H+ is $2\times10^{23}m^{-2}s^{-1}$ and the initial velocity is a local Maxwell distribution at temperature of 0.5eV and the mean velocity of 20000m/s.



Simulation model

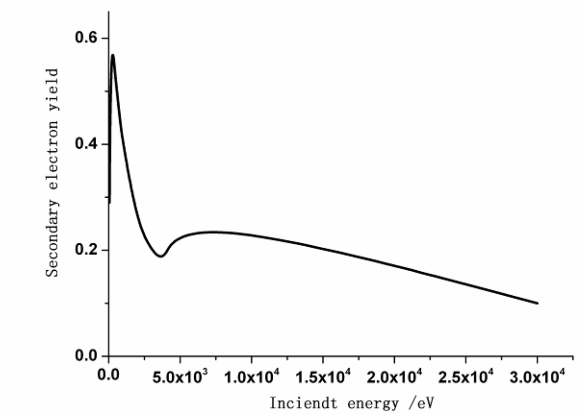
Interactions

Index	Type	Index	Type
1	$e+e \rightarrow e+e$	13	$e+H_2 \rightarrow e+H_2^{L\text{-}bnd} \rightarrow e+H_2$
2	$e+H \rightarrow 2e+H^+$	14	$e+H_2 \rightarrow e+H_2^{W\text{-}bnd} \rightarrow e+H_2$
3	$e+H^{2s} \rightarrow e+H^++e$	15	$e+H_2 \rightarrow e+H+H^{2s}$
4	$H^++H_2 \rightarrow H^++H^++H^++2e$	16	$e+H_2 \rightarrow e+H_2^{J=0\text{-}2} \rightarrow e+H_2$
5	$H^++H_2 \rightarrow H^++H^{2s}+H$	17	$e+H_2 \rightarrow e+H_2^{J=1\text{-}3} \rightarrow e+H_2$
6	$H^++H \rightarrow H^++H^++e$	18	$e+H_2 \rightarrow 2e+H+H^+$
7	$H^++H_2 \rightarrow H^++H_2^++e$	19	$e+H_2 \rightarrow H+H+e$
8	$H^++H_2 \rightarrow H_2^++H$	20	$e+H_2 \rightarrow H^{v1,v2,v3}+e \rightarrow H_2+e$
9	$H^++H \rightarrow H+H^+$	21	$H_2^++H_2 \rightarrow H^++H+H_2$
10	$e+H_2 \rightarrow H_2+e$	22	$H_2^++H \rightarrow H^++H_2$
11	$e+H_2 \rightarrow H_2^++e+e$	23	$e+H_2^+ \rightarrow 2H$
12	$e+H_2 \rightarrow e+H+H^{L\text{-}alp} \rightarrow e+H+H$	24	$e+H_2^+ \rightarrow e+H^++H$

Particles bombard electrode

Type	setting
H, H^{2s}, H_2	Random reflected (coefficient is 1)
H^+	Secondary electron generation (yield is 2.5)
	Adsorbed gas, H_2 (rate are 1000, 10000, 100000)
H_2^+	1.5

Secondary electron generation by bombardment of electrons

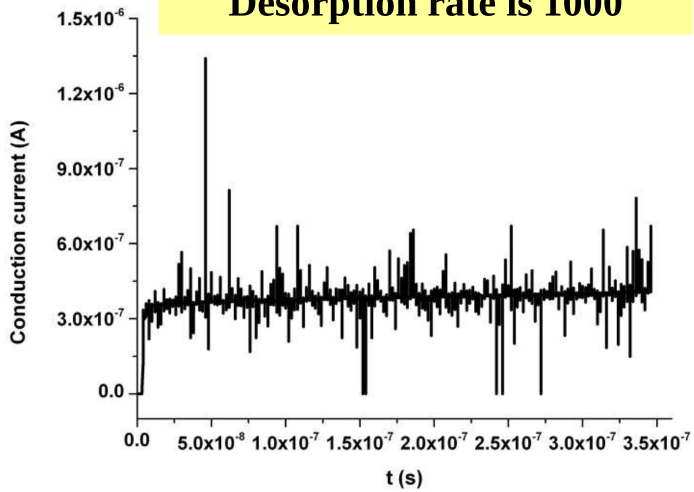


Simulation model

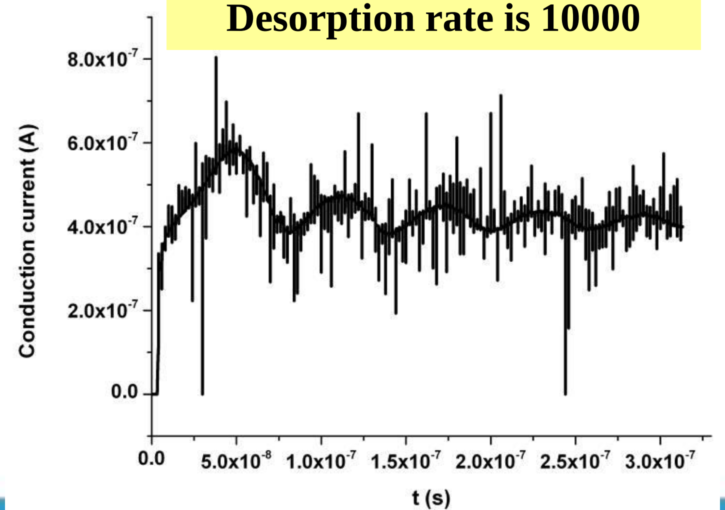
- The present simulations could adopt the same grid and time step which are demanded in PIC simulation, namely, grid equal to 0.2μm and time step equal to 10^{-15} s.
- If the conduction current in gaps abruptly increase more than 100 times, it is considered as breakdown in the gaps. And if the conduction current has no increase for a long time, the simulation is interrupted factitiously.

3.1 Conduction current for different desorption rate

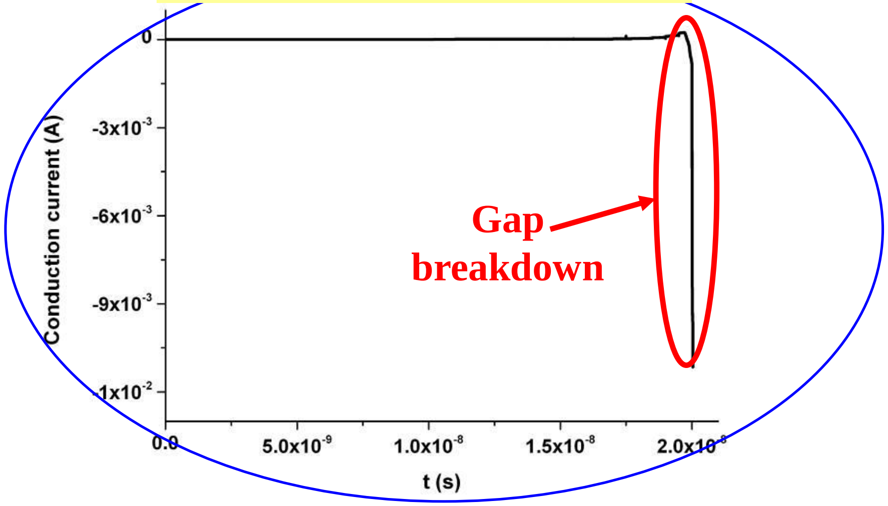
Desorption rate is 1000



Desorption rate is 10000



Desorption rate is 100000

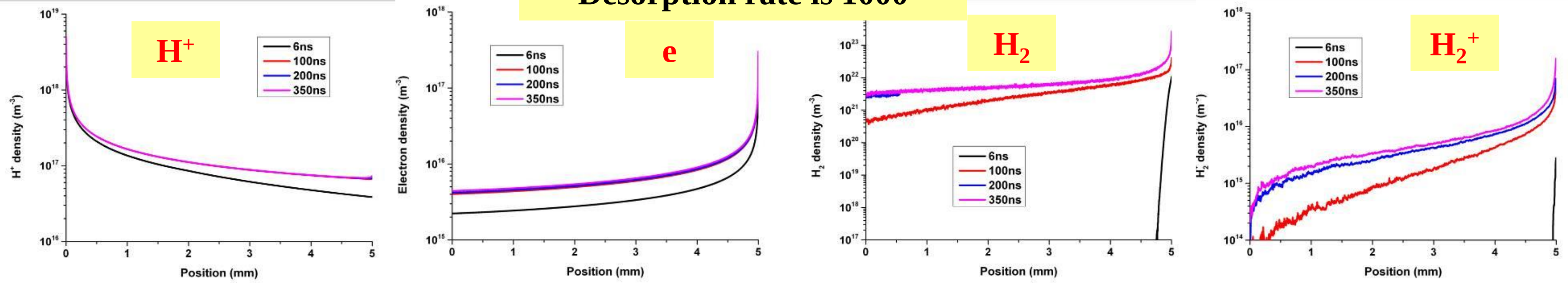


- Gap breakdown induced until desorption rate equal to 100000.
- Gap breakdown occurs at about 20ns.
- Namely, a certain time is necessary to induce breakdown.

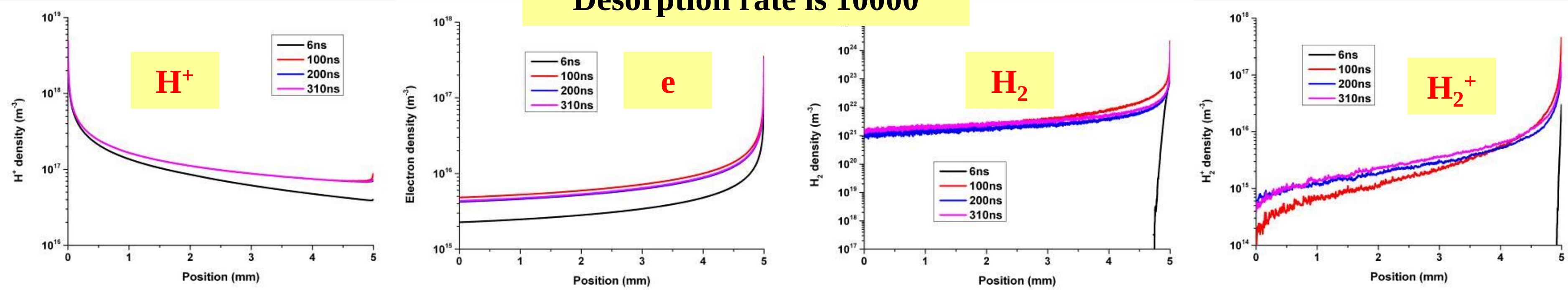
Simulation results and analysis

3.2 Particles density distribution evolution (for breakdown not occurs)

Desorption rate is 1000



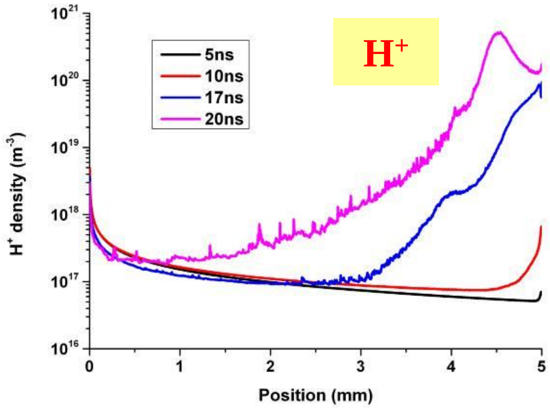
Desorption rate is 10000

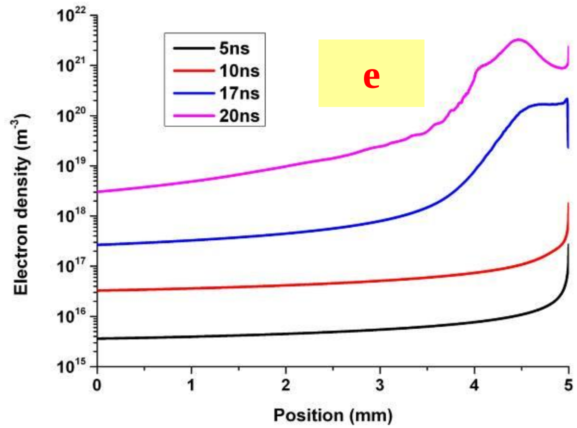


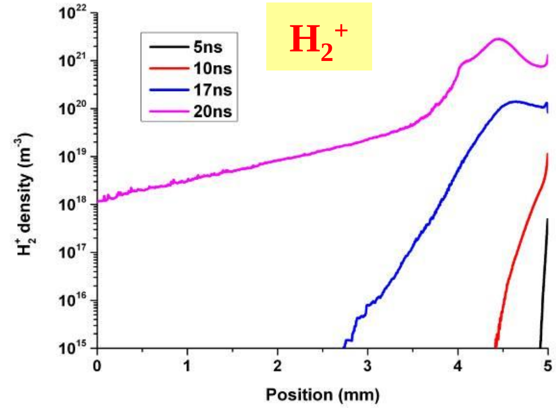
■ H_2 uninterrupted generated by bombardment of H^+, but it could not induce breakdown until the gas fulfill the gap；

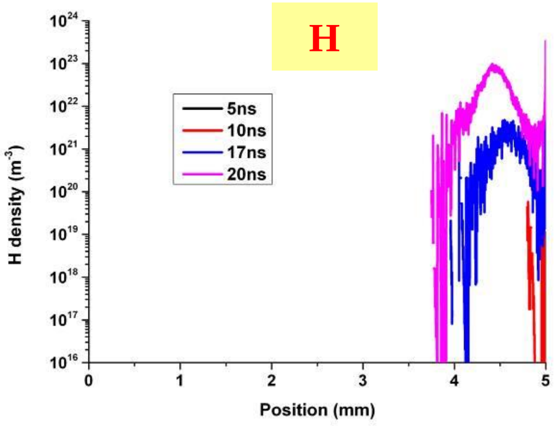
■ With the desorption rate increase， H_2^+ density a few increase， but electron density hardly increase。

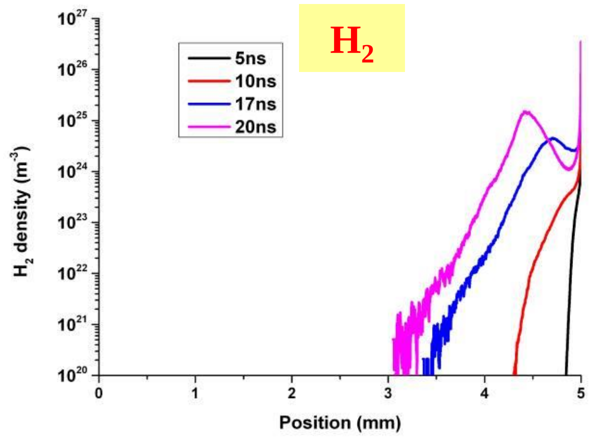
3.3 Particles density distribution evolution (for breakdown occurs)







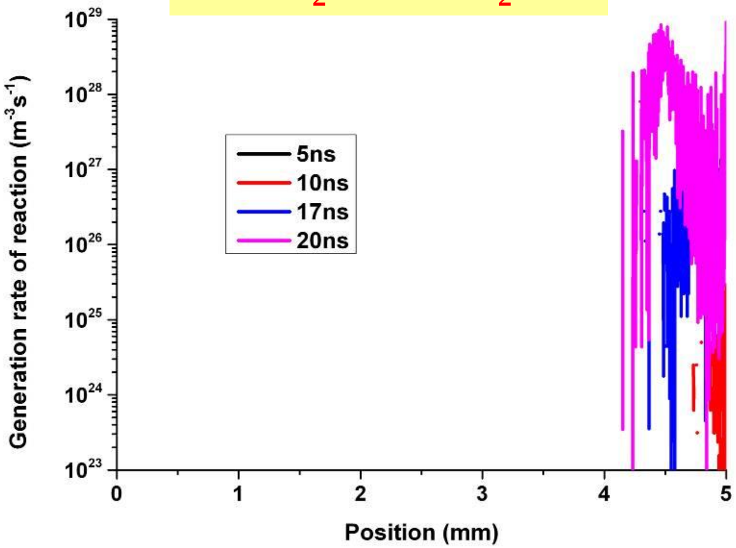




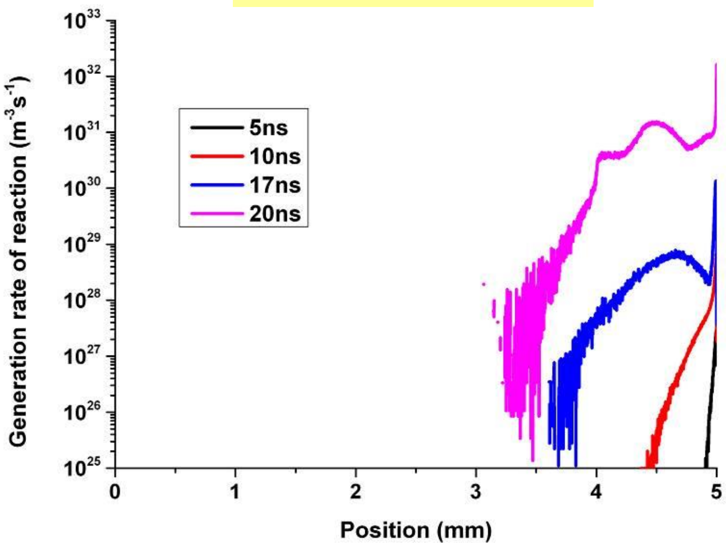
- When breakdown occurs, H_2 not fulfill the gap, but the density reach $10^{25}m^{-3}$ near the electrode
- When breakdown occurs, H^+ density obviously increase, it is related to abundant H appears.
- Electrons avalanche in local high density gas near electrode is the main reason to induce gap breakdown.

3.4 Generation rate of different reactions

$H^+ + H_2 \rightarrow H^+ + H_2^+ + e$



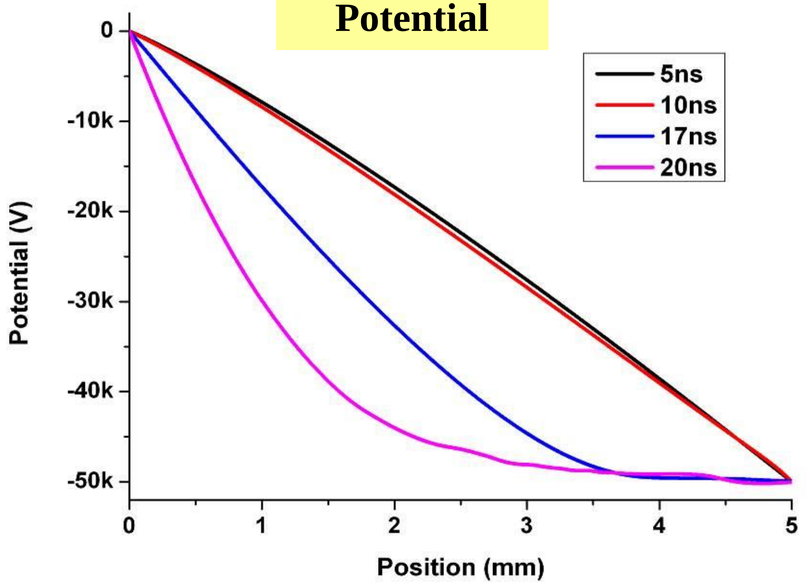
$e + H_2 \rightarrow H_2^+ + e + e$



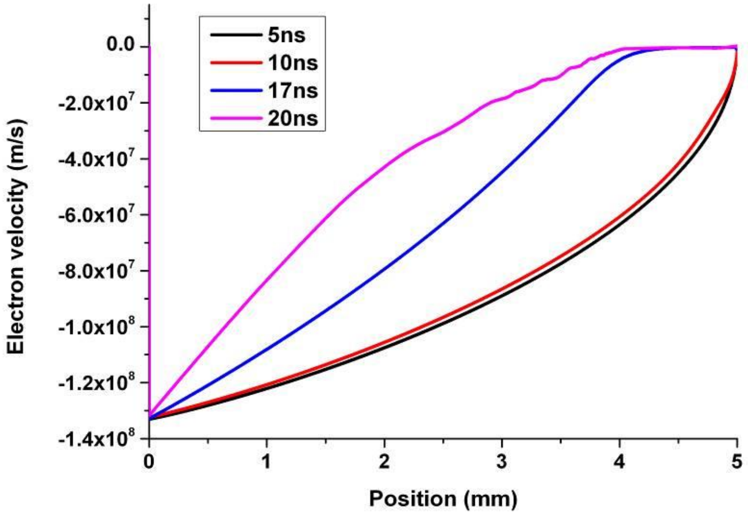
- It is evident that electrons ionization H_2 is much more than H^+ ionization H_2 to produce electrons.
- The "initial" electrons to ionization H_2 actually are the secondary electrons generated by H^+ bombarding electrode.

3.5 Potential distribution and electron velocity distribution

Potential



Electron velocity



- The appearance of high density electrons and ions lead to the form of plasma sheath near the high voltage electrode.
- Electrons velocity decrease evidently while plasma sheath forms near the high voltage electrode. And it lead to electrons are more possible to interact with local high density H_2 which desorption form the high voltage electrode.

Conclusion

- The critical value of local desorption gas density to induced breakdown is $10^{25}m^{-3}$ obtained by simulations.
- Secondary electrons generation at the high voltage electrode by the bombardment of protons and electrons ionization desorption gas near the high voltage electrode are the key factors to induce breakdown.
- The form of sheath near the high voltage electrode is available to electrons avalanche.

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Thanks for your attention!