Experiment and Simulation of plasma window

Kun Zhu, Sheng Huang, Wang shaoze, Yuarong, Zhiyu Guo

Physics school of Peking university

Institute of Heavy Ion Physics

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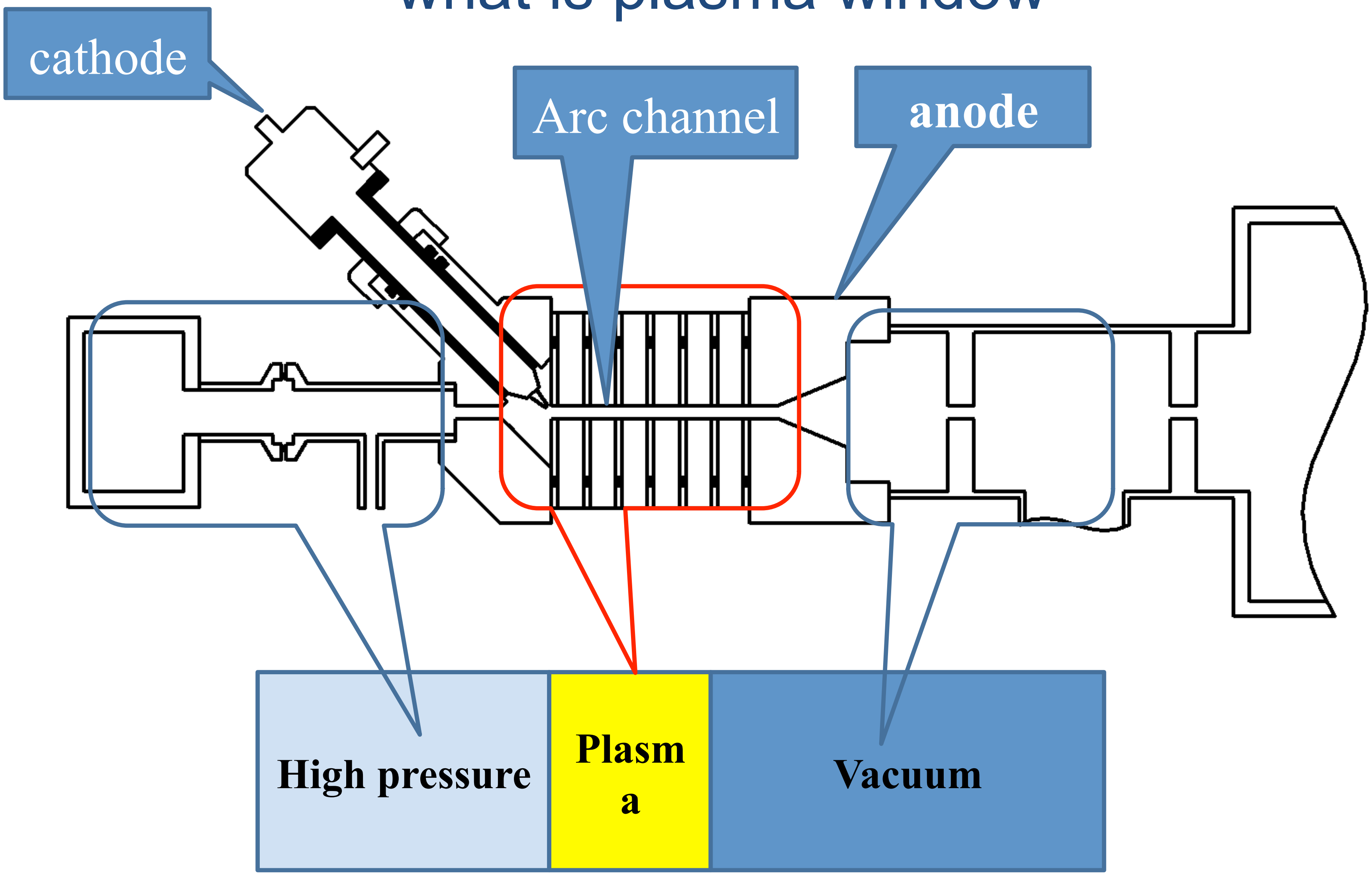
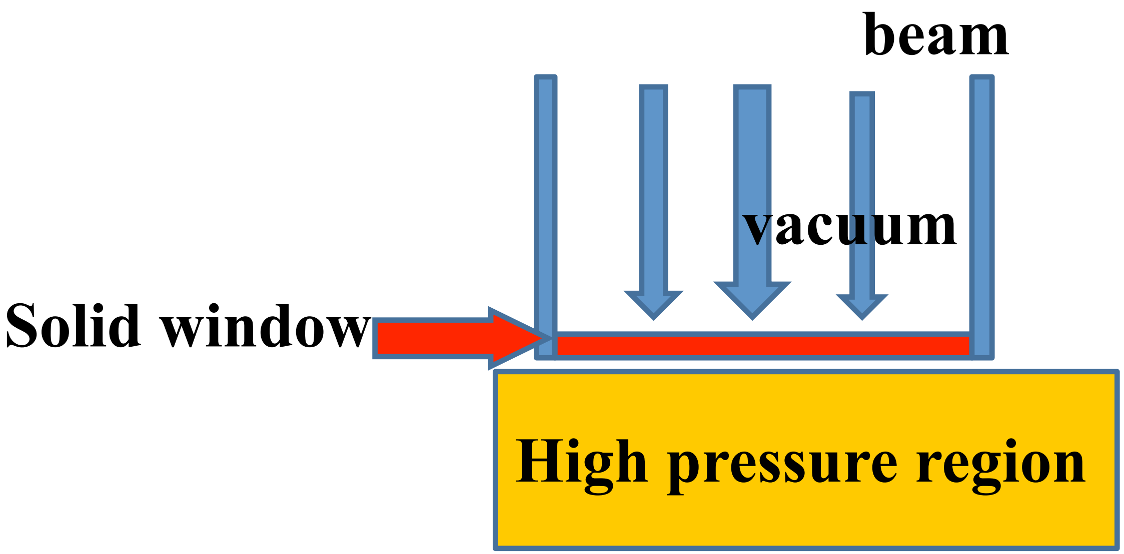
outline

- Introduction
- Plasma window test bench
- Simulation of plasma window
- conclusion

what is plasma window



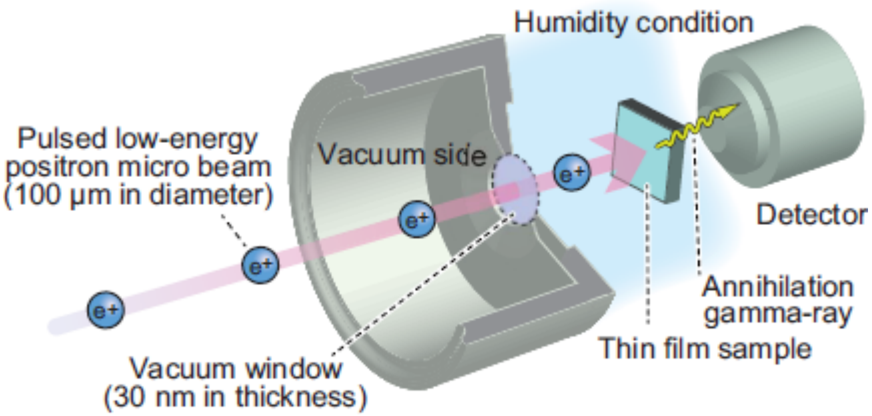
Traditional solid window



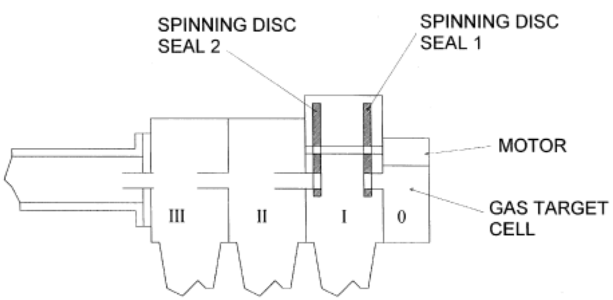
Beryllium window

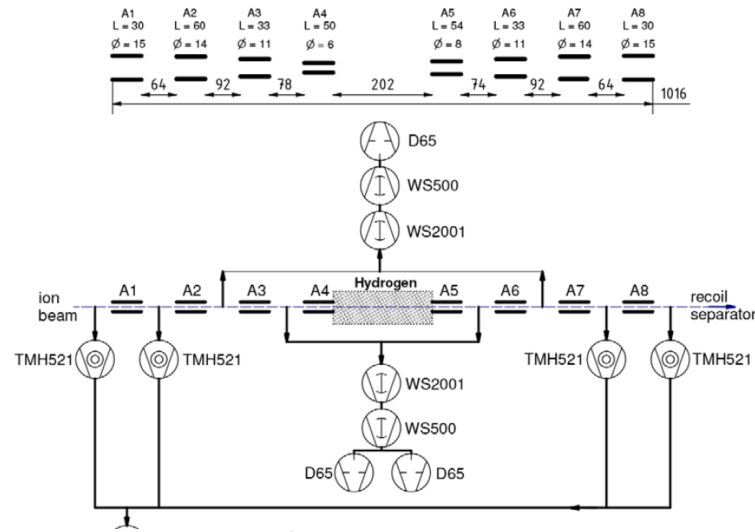
Disadvantage:

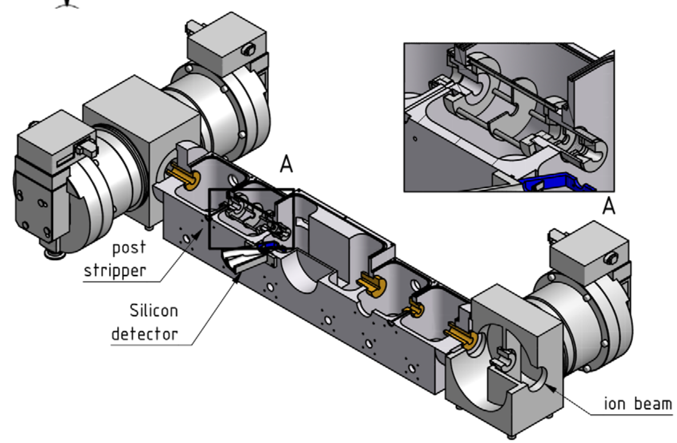
- Thermal damage
- Radiation damage
- Increase energy loss and energy spread



Windowless target







Windowless deuterium gas target

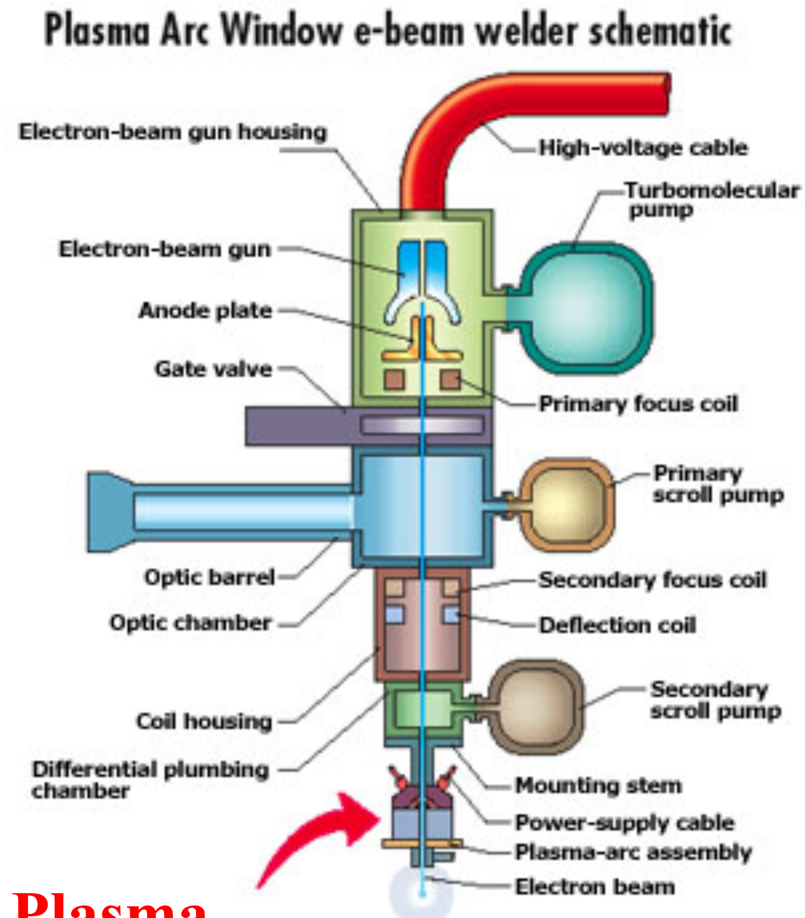
Expensive differential pump system
Complicated vacuum and mechanical system

windowless hydrogen gas target for ^{7}Be(p,γ) reaction measurement

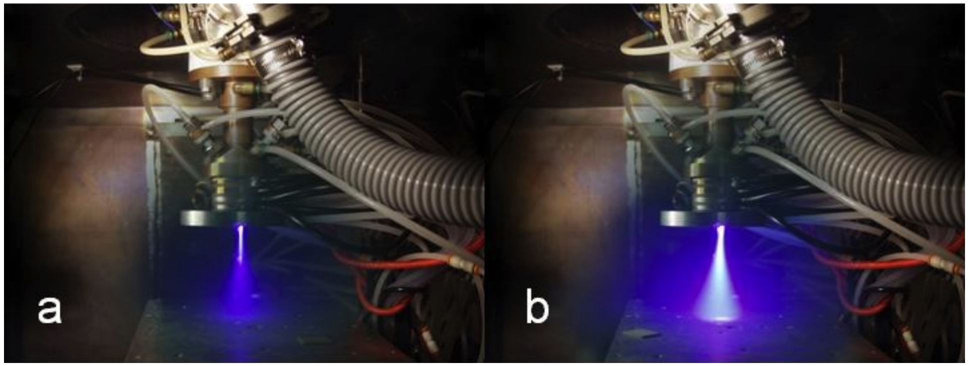
Why plasma window

- needn’t worry about thermal problem.
- No radiation damage
- Very thin equivalent thickness(~nm)
- Effectively improve the performance of differential pump system

Non-vacuum electron beam welding



Plasma window



9mA 25mA

Electron beam current after exiting plasma window ,

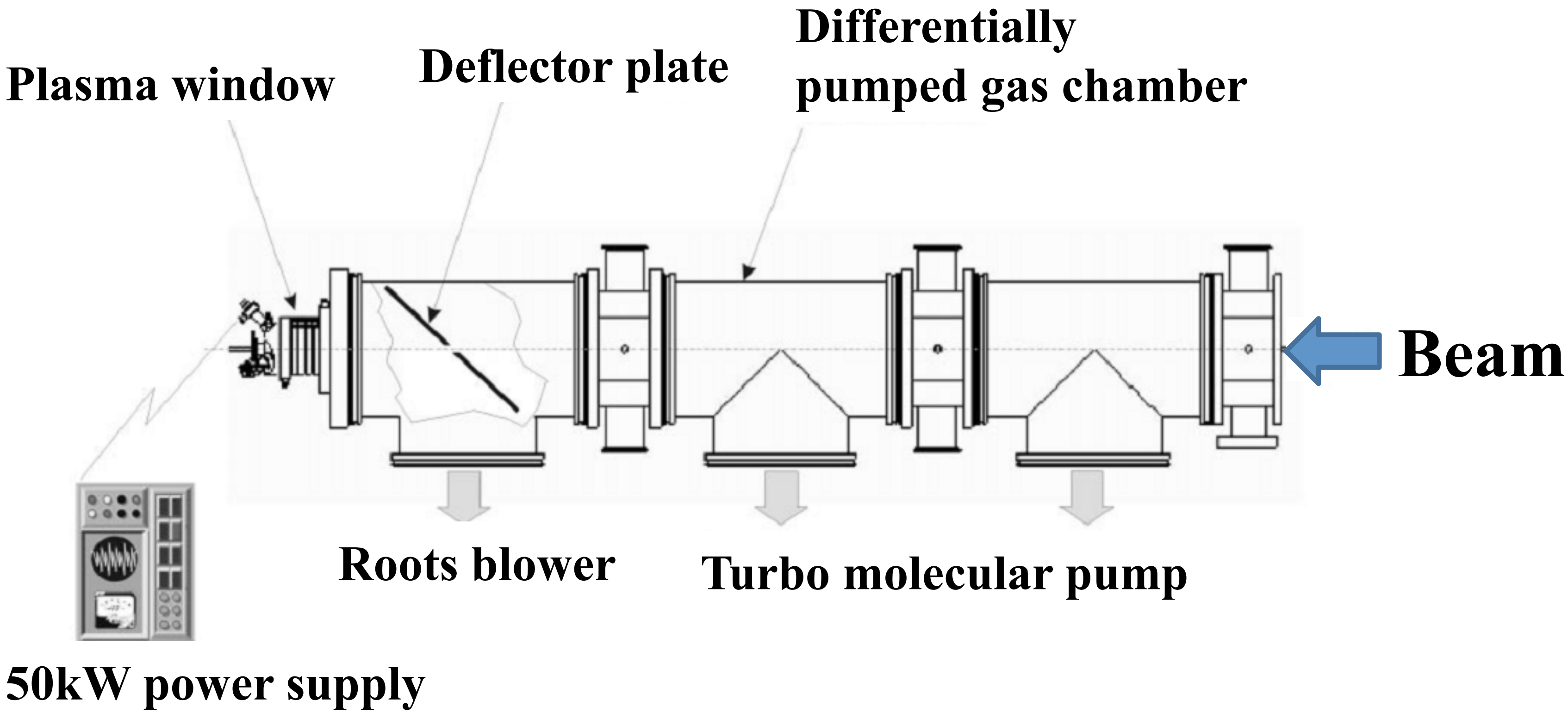
Pure helium gas

Aperture: 2.36mm

Current: 45A

Air boring and non-vacuum electron beam welding with a plasma window, Ady hershcovitch, Physics of plasma, 12(2005)

Deuterium gas target using plasma window



operating gas pressure is 0.5 bar for argon

Diameter of plasma window: 5mm

Performance of a plasma window for a high pressured differentially Pumped deuterium gas target for mono-energetic fast neutron Production-Preliminary results, A.De Beer, A. hershcovitch, et. al..NIMB, 170(2000), 259-265

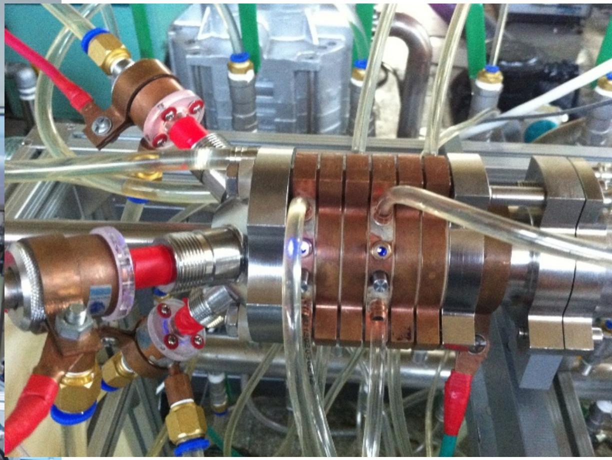
High ion current beam need larger plasma window

- Small diameter Plasma window(2-5mm) is successfully used for electron beam welding and gas target.
- If larger diameter plasma window is possible, It has some potential use for high current ion beam.

Plasma window test bench

Vacuum gauge

Plasma window



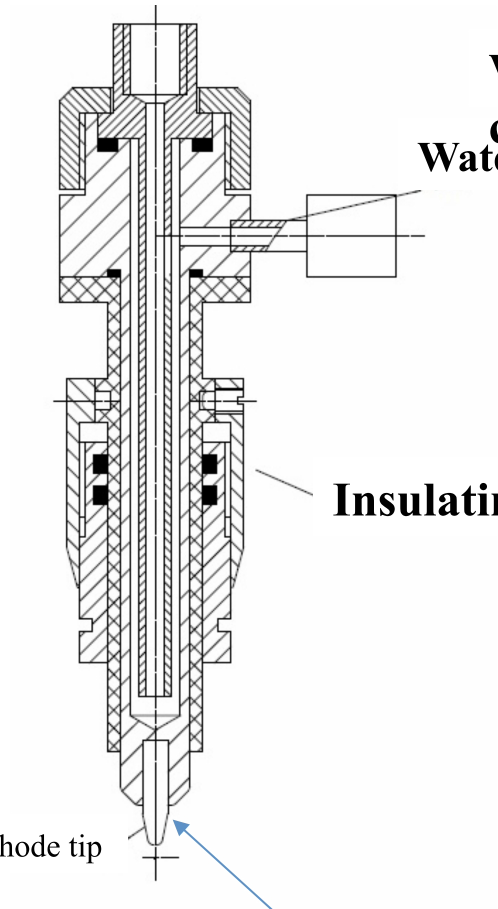
Two stage pump

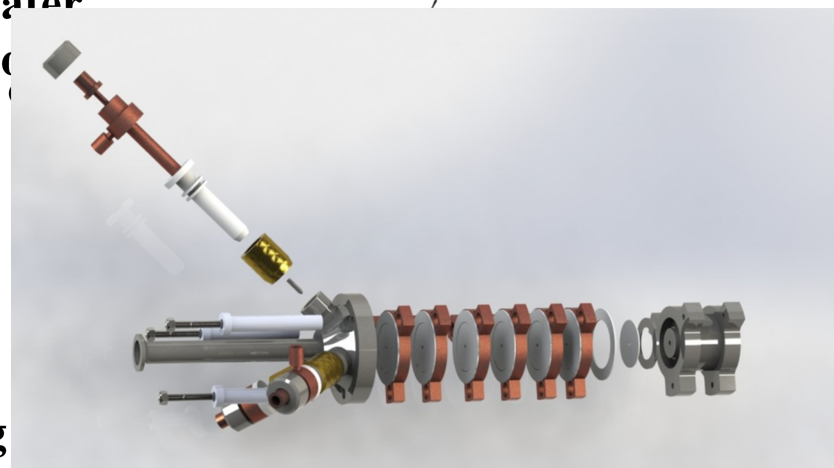
Arc power supply

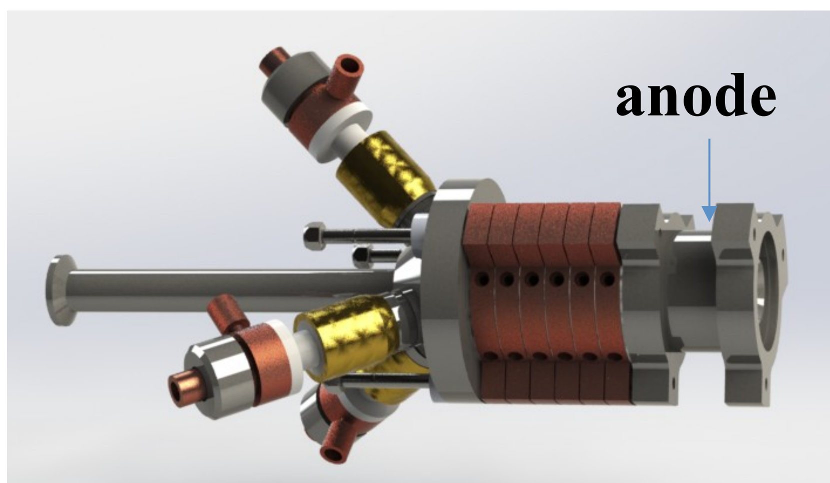
Plasma window

Spectrum diagnostic

Pressure measurement





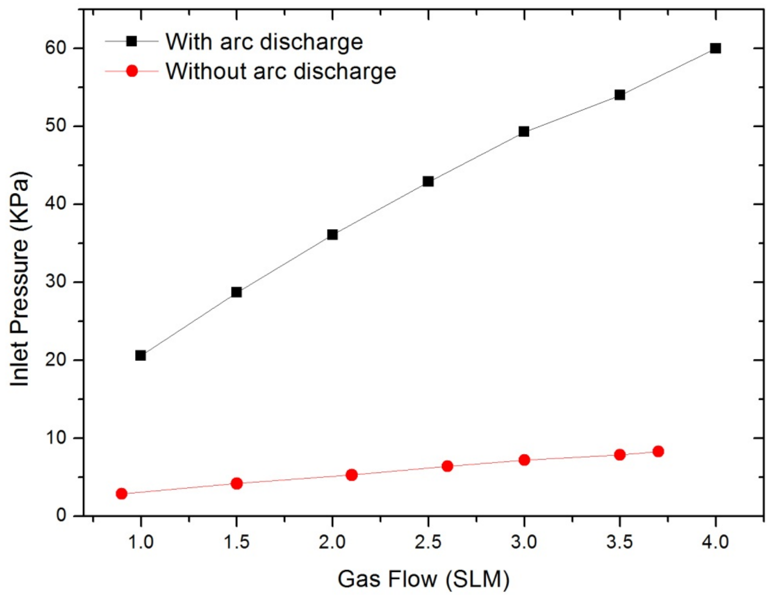


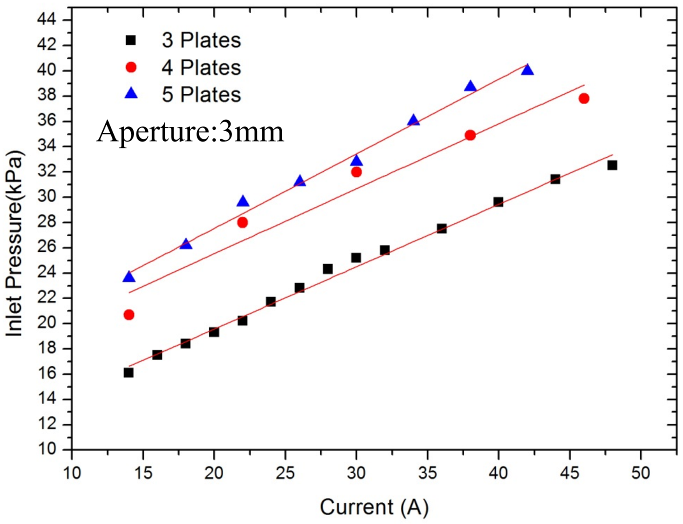
Three aperture:
3mm,6mm,10mm

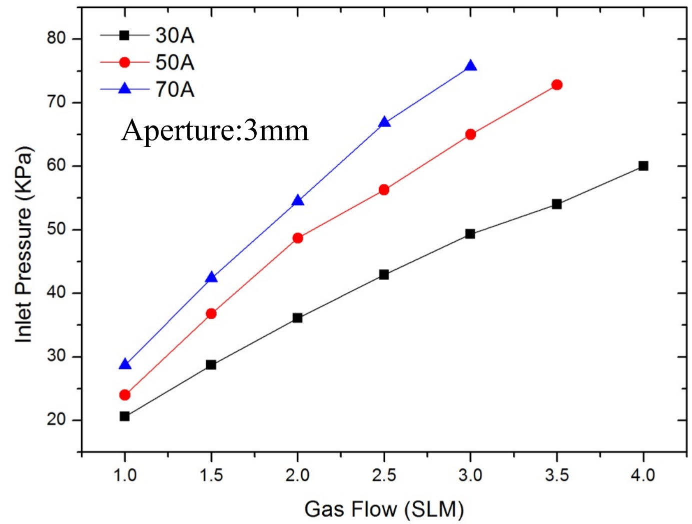
Plasma window sealing effect

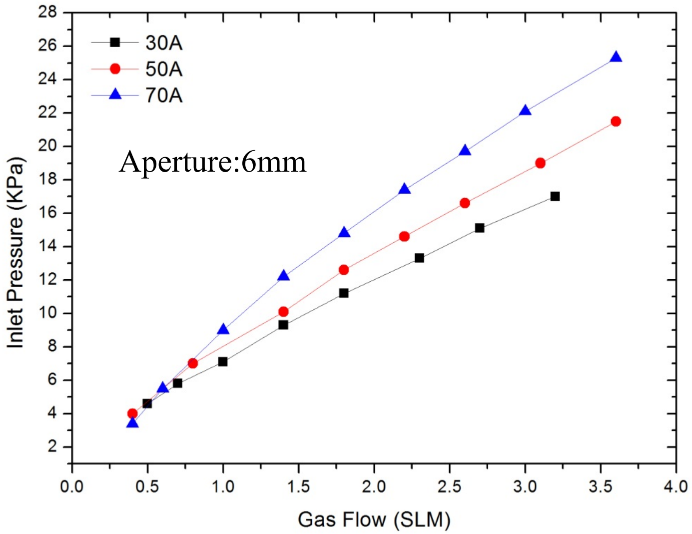
	Inlet pressure(kPa)	Outlet pressurek(Pa)	Gas flow(SLM)
discharge	**33.3**	**70**	**1.1**
No discharge	**12.7**	**220**	**12.3**

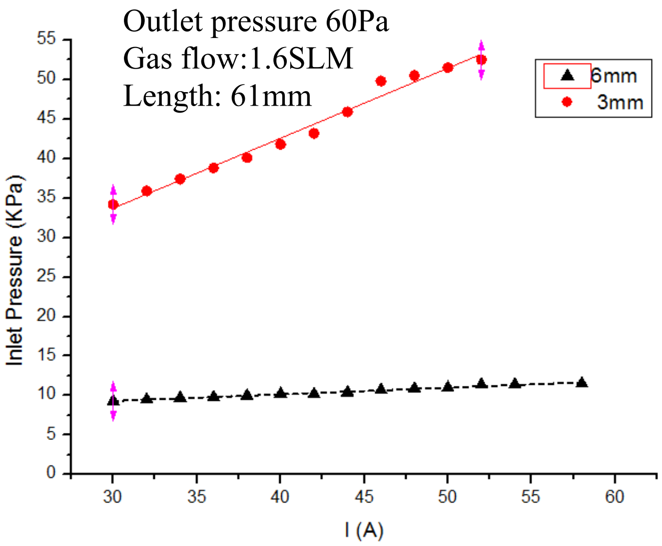
Operating current is 40A
operating voltage is 58V
this prove the plasma
window 's sealing effect !



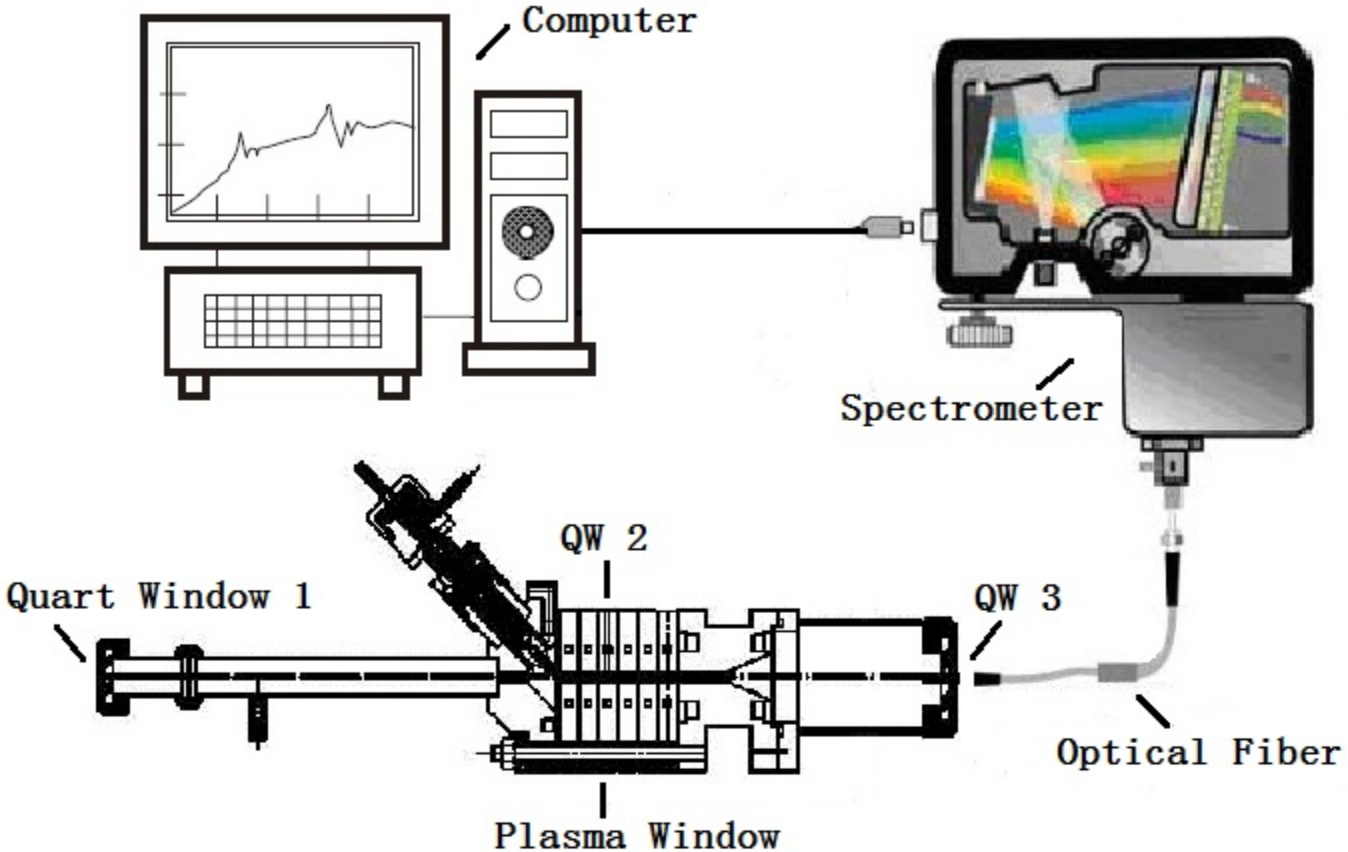

3 Plates
4 Plates
5 Plates
Aperture:3mm
Inlet Pressure(kPa)
Current (A)


30A
50A
70A
Aperture:3mm
Inlet Pressure (KPa)
Gas Flow (SLM)


30A
50A
70A
Aperture:6mm
Inlet Pressure (KPa)
Gas Flow (SLM)

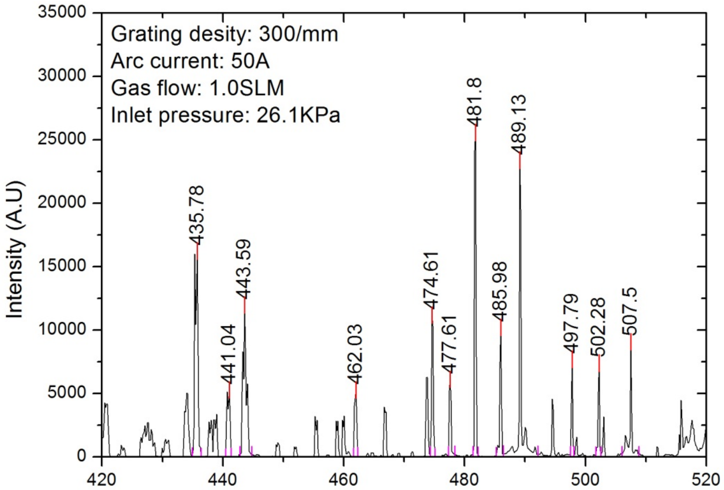

Outlet pressure 60Pa
Gas flow:1.6SLM
Length: 61mm
6mm
3mm
Inlet Pressure (KPa)
I (A)

Measurement with spectrometer

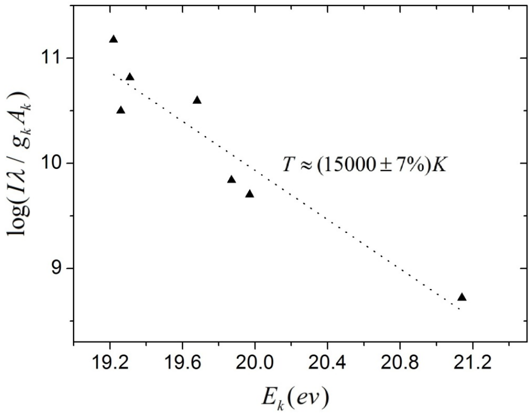


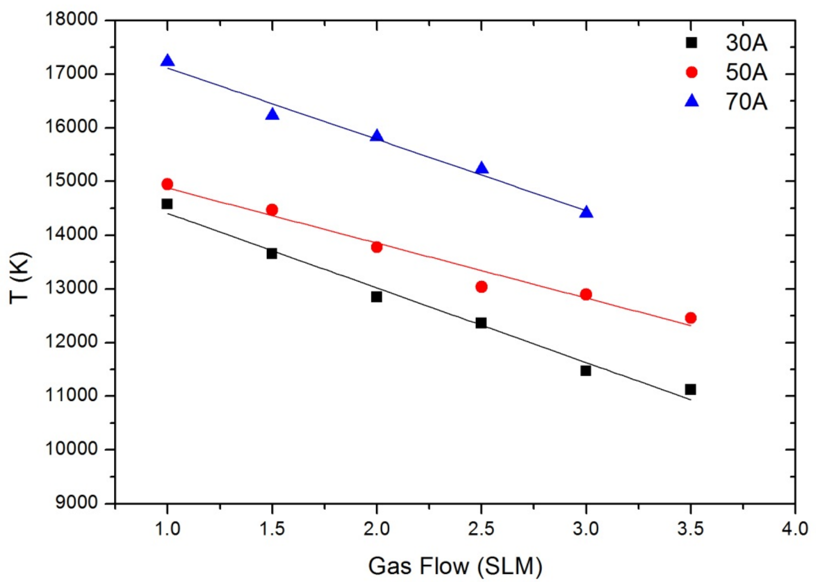
Schematic diagram of spectroscopy set up

Temperature of plasma



$$\ln\left(\frac{I_{ji}\lambda_{ji}}{A_{ji}g_{ji}}\right) = -\frac{E_j}{kT_e} + \ln\left(\frac{\Omega V F_c}{4\pi}\frac{hcN}{Z(T_e)}\right)$$





- Experiment show that the plasma window can work. But the sealing ability decreased quickly when plasma window's aperture increase. It may consume much more energy

Simulation of plasma window

- Use magneto-hydrodynamic model
- Ansys fluent
- Basic assumptions
- plasma is steady, continuous, axisymmetric and optically thin
- Plasma is in LTE state
- Swirling velocity is neglected

Input

Configuration
- Geometry, Grid generation
- Boundary conditions

- Discretization
- Hydrodynamic governing equations
- Equation solver

Material
- Radiation coefficients
- Gas transport coefficients

Output

Govering equation

Mass conservation equation $$\frac{\partial}{\partial z}(\rho v_z)+\frac{\partial}{r\partial r}(\mathrm{r}\rho v_r)=0$$

Momentum conservation equation

$$\frac{\partial}{\partial z}(\rho v_z v_z)+\frac{1}{r}\frac{\partial}{\partial r}(\mathrm{r}\rho v_z v_r)=-\frac{\partial P}{\partial z}+2\frac{\partial}{\partial z}(\mu\frac{\partial v_z}{\partial z})+\frac{1}{r}\frac{\partial}{\partial r}[\mathrm{r}\mu(\frac{\partial v_r}{\partial z}+\frac{\partial v_z}{\partial r})]+\mathrm{j}_r B_\theta$$

$$\frac{\partial}{\partial z}(\rho v_z v_r)+\frac{1}{r}\frac{\partial}{\partial r}(\mathrm{r}\rho v_r v_r)=-\frac{\partial P}{\partial r}+\frac{2}{r}\frac{\partial}{\partial z}(\mathrm{r}\mu\frac{\partial v_r}{\partial r})+\frac{\partial}{\partial r}[\mu(\frac{\partial v_z}{\partial r}+\frac{\partial v_r}{\partial z})]-2\mu\frac{v_r}{r^2}-\mathrm{j}_z B_\theta$$

Energy conservation equation

$$\frac{\partial}{\partial z}(\rho v_z C_p T)+\frac{1}{r}\frac{\partial}{\partial r}(\mathrm{r}\rho v_r C_p T)=\frac{\partial}{\partial z}(k\frac{\partial T}{\partial z})+\frac{1}{r}\frac{\partial}{\partial r}(\mathrm{r}k\frac{\partial T}{\partial r})+\frac{j_r{}^2+j_z{}^2}{\sigma}-q_r+\frac{5}{2\mathrm{e}}k_{\mathrm{B}}(\mathrm{j}_z\frac{\partial T}{\partial z}+j_r\frac{\partial T}{\partial r})+\mathrm{B}_\theta(\mathrm{j}_r v_z-j_z v_r)$$

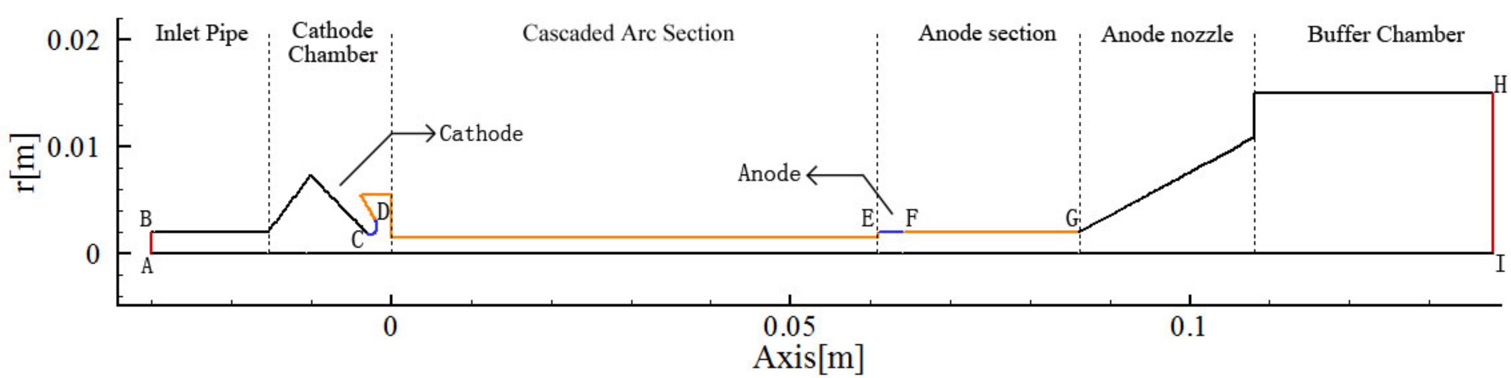
$$\partial/\partial z\,(\sigma\partial\phi/\partial z)+\partial/r\partial r\,(r\sigma\partial\phi/\partial r)=0$$

$$-(\frac{\partial}{\partial z}\frac{\partial A_z}{\partial z})+\frac{1}{r}\frac{\partial}{\partial r}\frac{\partial A_z}{\partial r})=\mu_0 j_z$$

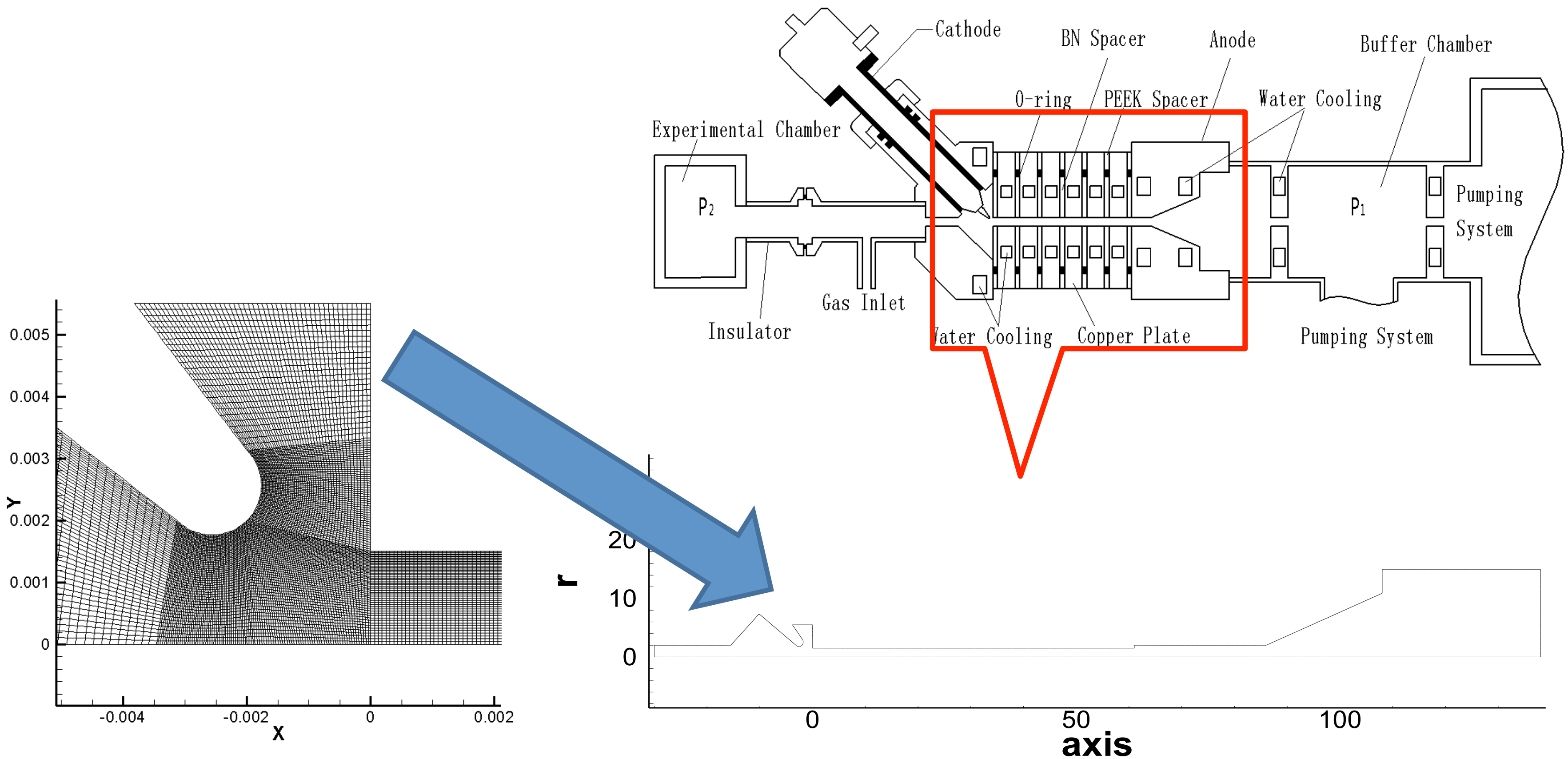
$$-(\frac{\partial}{\partial z}\frac{\partial A_r}{\partial z})+\frac{1}{r}\frac{\partial}{\partial r}\frac{\partial A_r}{\partial r})=\mu_0 j_r$$

Boundary condition

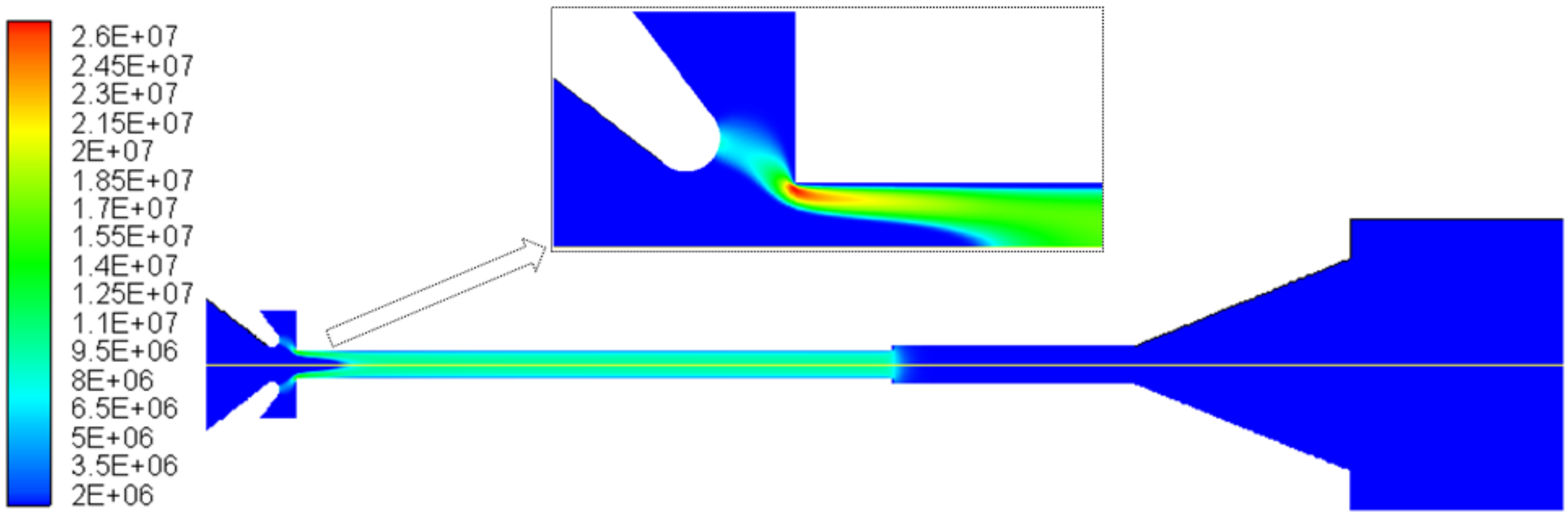
	P	$\vec{u}$	T	ϕ	$\vec{A}$
AB: Inlet	$P = 52.5KPa$	/	$T = 300$	$\partial\phi / \partial n = 0$	$A_i = 0$
HI: Outlet	$P = 60$	/	$\partial T / \partial n = 0$	$\partial\phi / \partial n = 0$	$\partial A_i / \partial n = 0$
AI: Axis	$\partial P / \partial n = 0$	$\partial u_i / \partial n = 0$	$\partial T / \partial n = 0$	$\partial\phi / \partial n = 0$	$\partial A_i / \partial n = 0$
CD: Cathode	$\partial P / \partial n = 0$	0	$-k\partial T / \partial n = h_w(T - 400)$	$\phi = -140$	$\partial A_i / \partial n = 0$
EF: Anode	$\partial P / \partial n = 0$	0	$-k\partial T / \partial n = h_w(T - 400)$	$\phi = 0$	$\partial A_i / \partial n = 0$
DE&FG: Wall	$\partial P / \partial n = 0$	0	$T = 400$	$\partial\phi / \partial n = 0$	$\partial A_i / \partial n = 0$
BC&GH: Wall	$\partial P / \partial n = 0$	0	$T = 300$	$\partial\phi / \partial n = 0$	$\partial A_i / \partial n = 0$



Simulation domain



Current Distribution

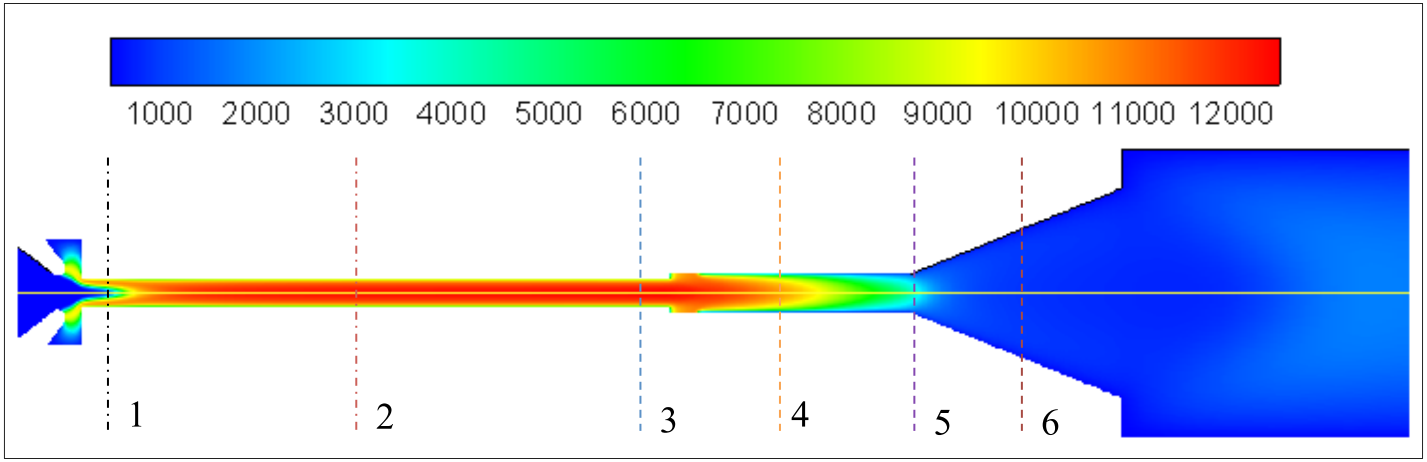


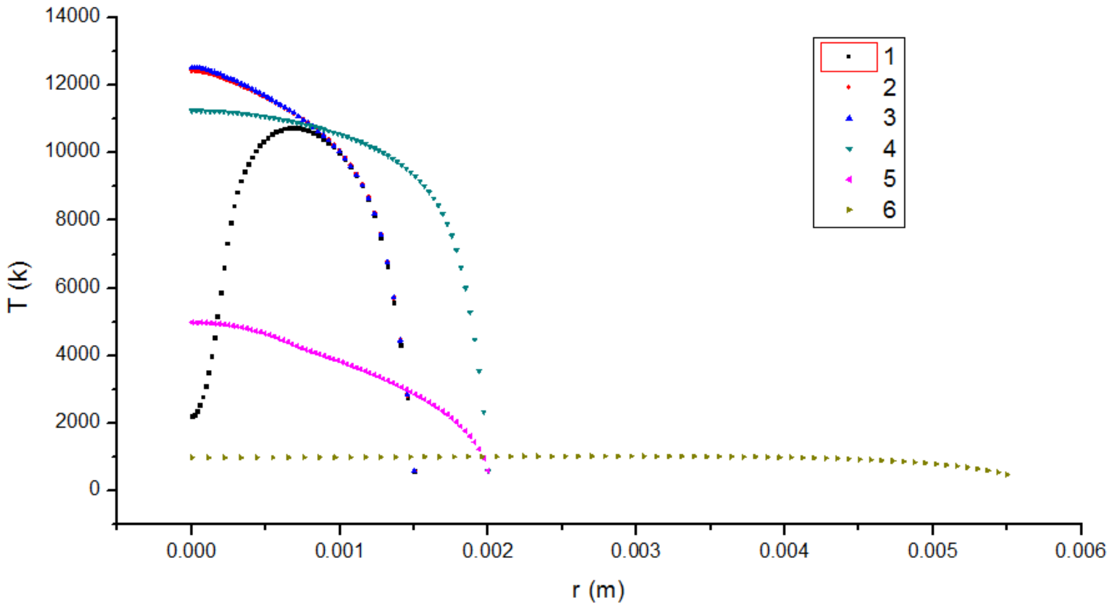
Sheng huang, Kun Zhu, et al, Numerical Simulation Study on Fluid Dynamics of Plasma Window Using Argon, Physics of plasmas, 2013

— Peking University Neutron Imaging Facility —

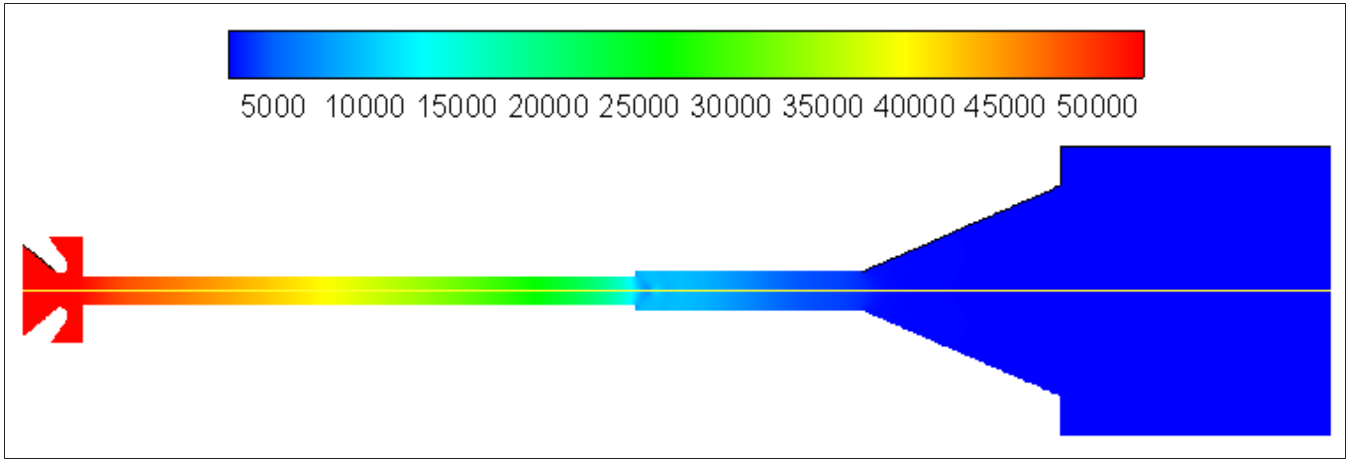
PEKING UNIVERSITY

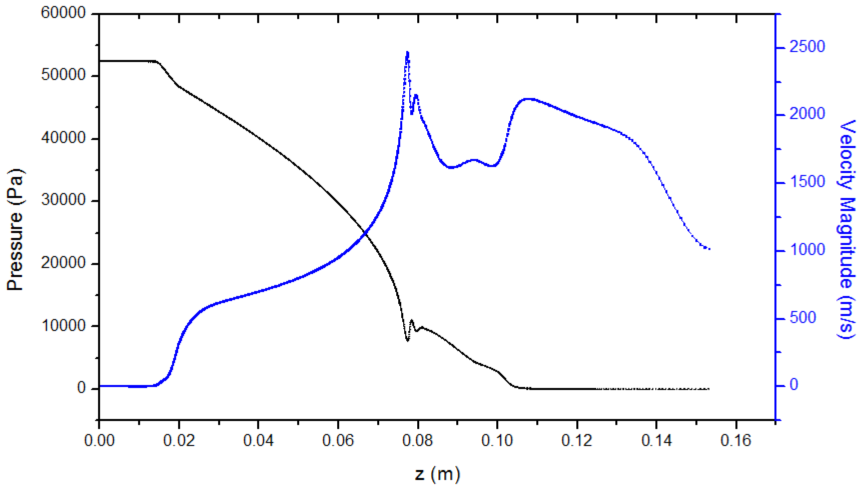
Temperature Distribution





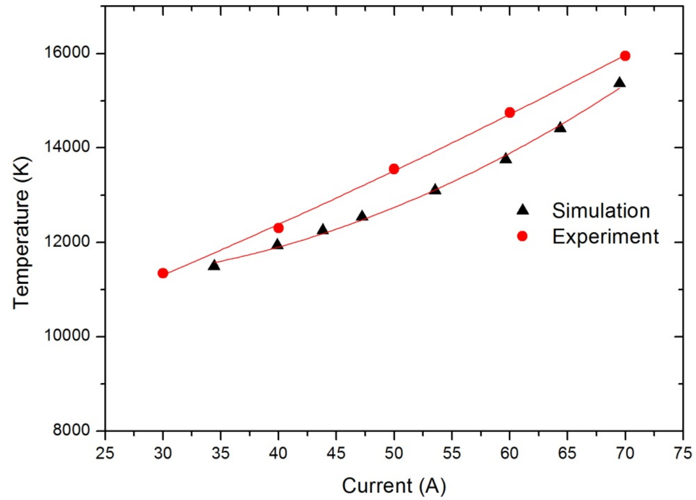
Pressure Distribution

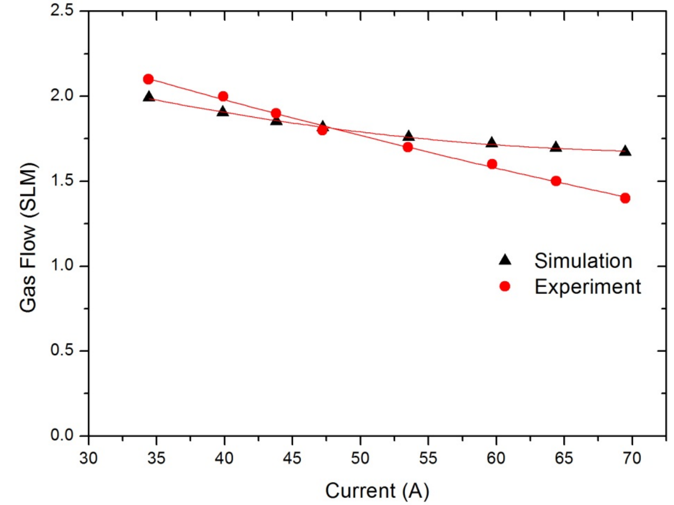


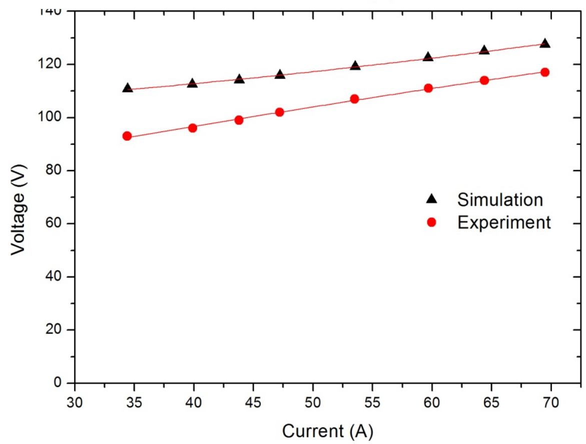


Pressure and velocity distribution along axis

Comparison of Experiment and Simulation results





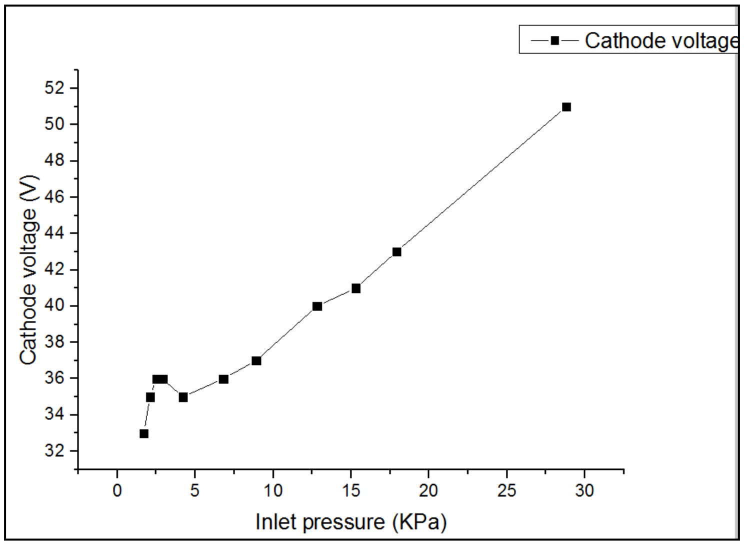


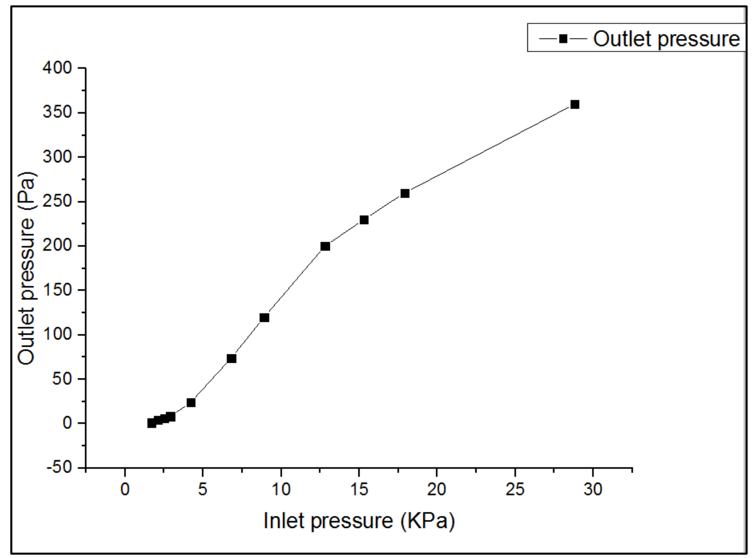
Inlet pressure: 51kPa
Aperture : 3mm
Length: 51mm

Sheng huang, Kun Zhu, et al, **Quantitative characterization of arc discharge as vacuum interface,** Physics of plasmas, 2014

How to increase the aperture?

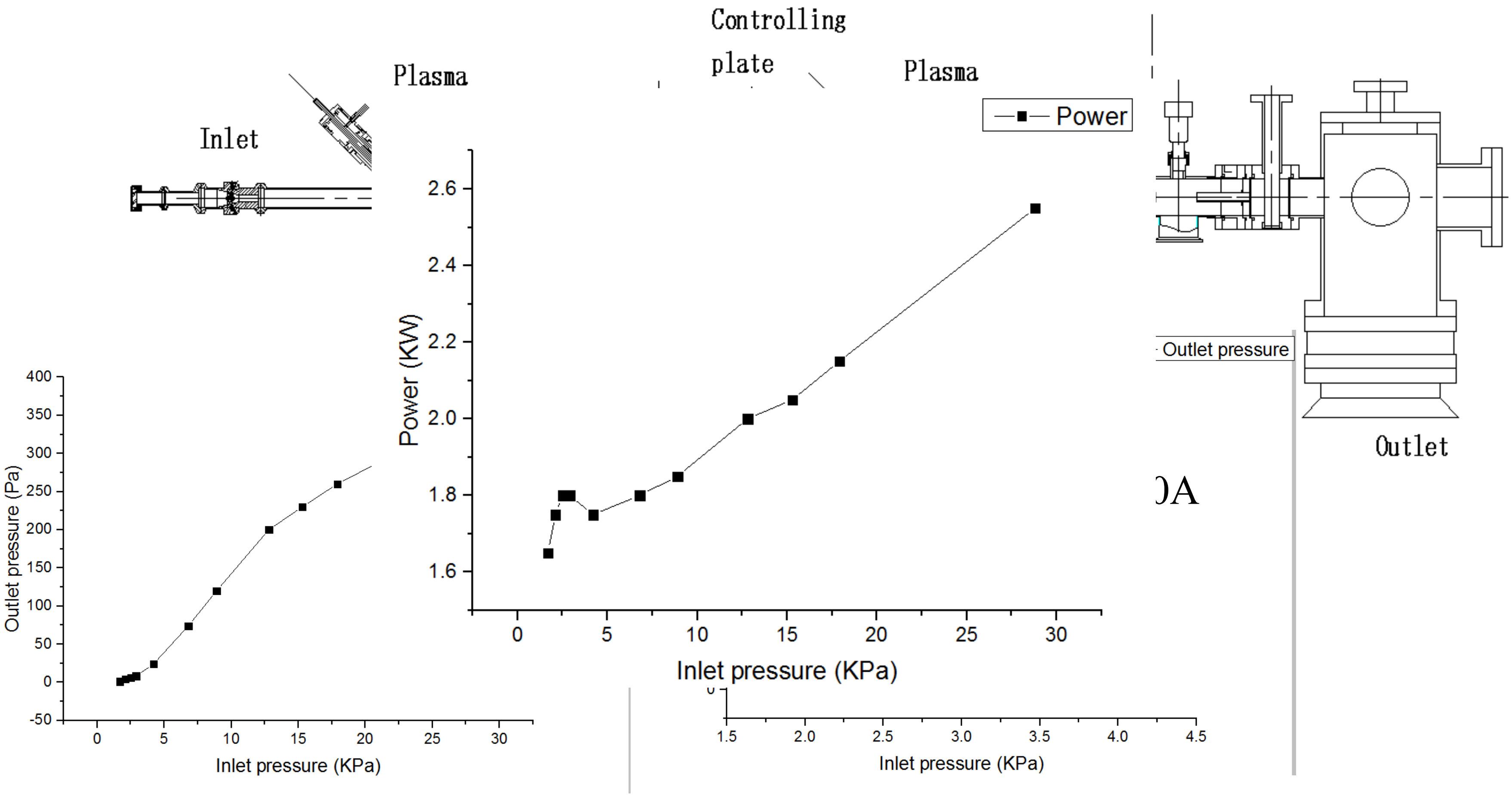
- Power is proportional to r^2, 10 times of 3mm plasma window





Aperture： 10mm
Fixed Current： 50A

Two stage construction



Conclusion

- A test bench of plasma window is built. Small aperture plasma window experiment is done.
- A simulation model is set up, the simulation result is agree with experiment result. It can be used for evaluating the performance of larger aperture plasma window
- Large aperture will need very high power, So we design a new structure of two stage plasma windows with 10mm aperture, experiments have been done and the feasibility is proven

Future

- Do plasma window experiments with deuterium gas
- Improve the structure of plasma window
- Use the simulation method to optimized the property of large diameter plasma window
- Build two stage plasma window with large diameter if possible

Thank you for your attention!