Plasma window experiment and simulation

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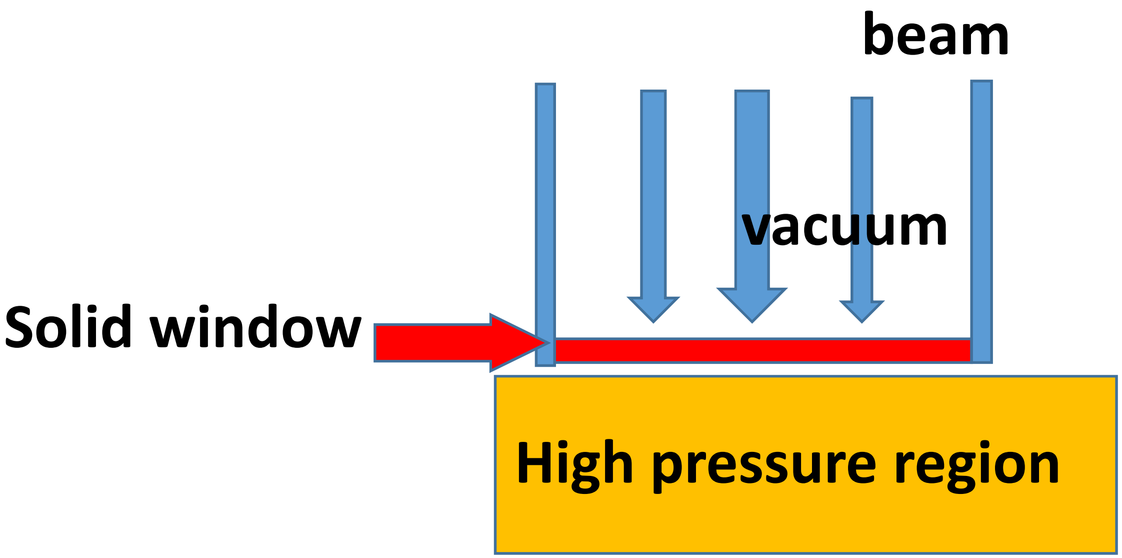
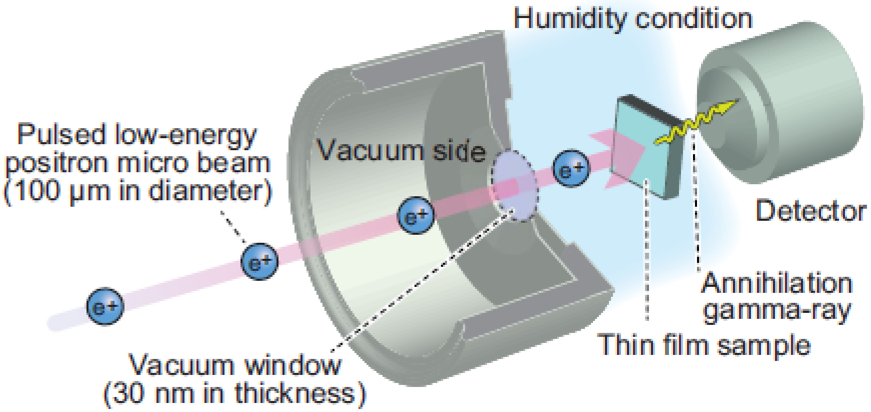
Outline

- **Introduction**
- **Plasma window test bench**
- **Simulation of plasma window**
- **Conclusion**

Traditional solid window



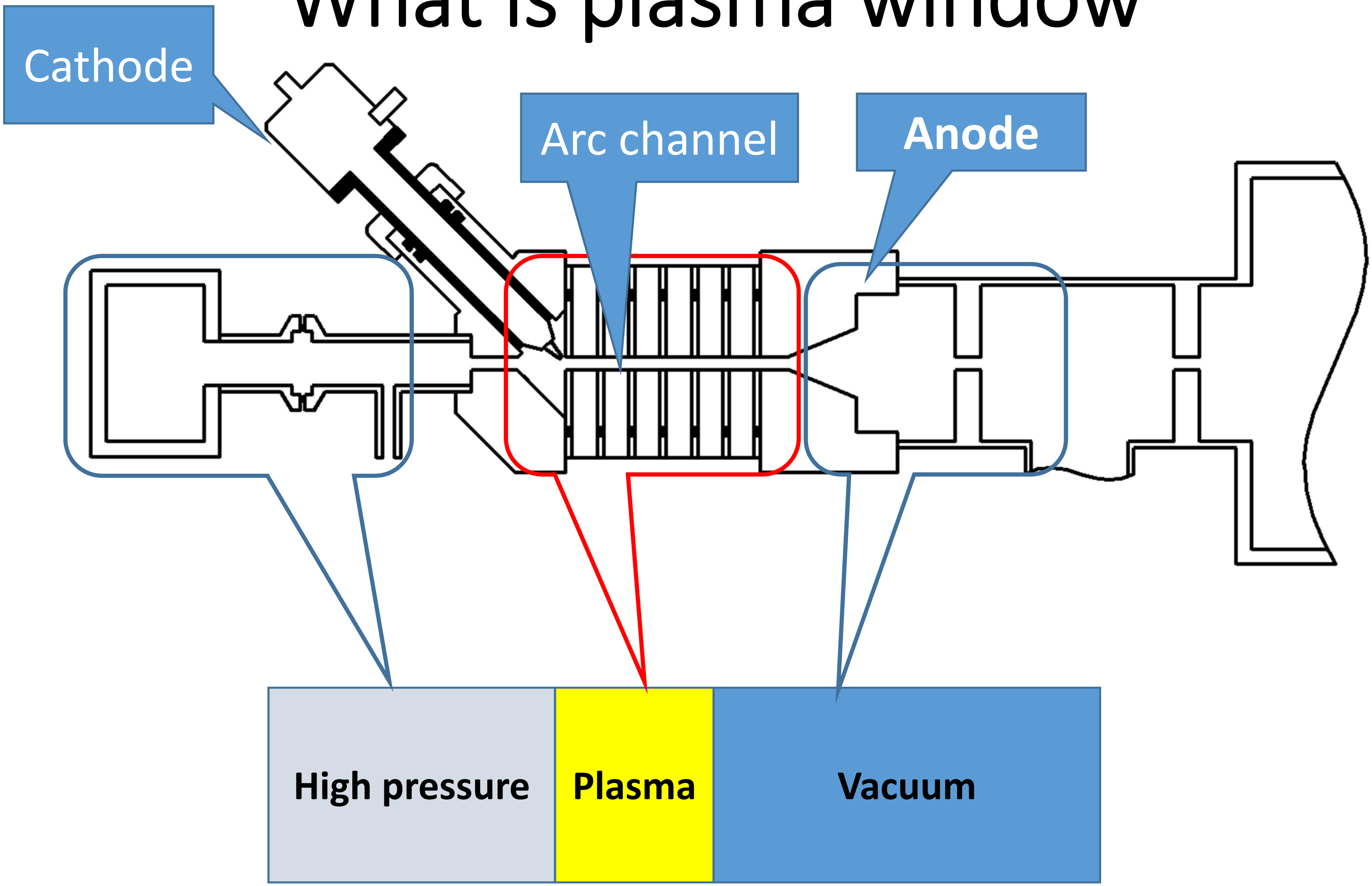
Beryllium window



Disadvantage:

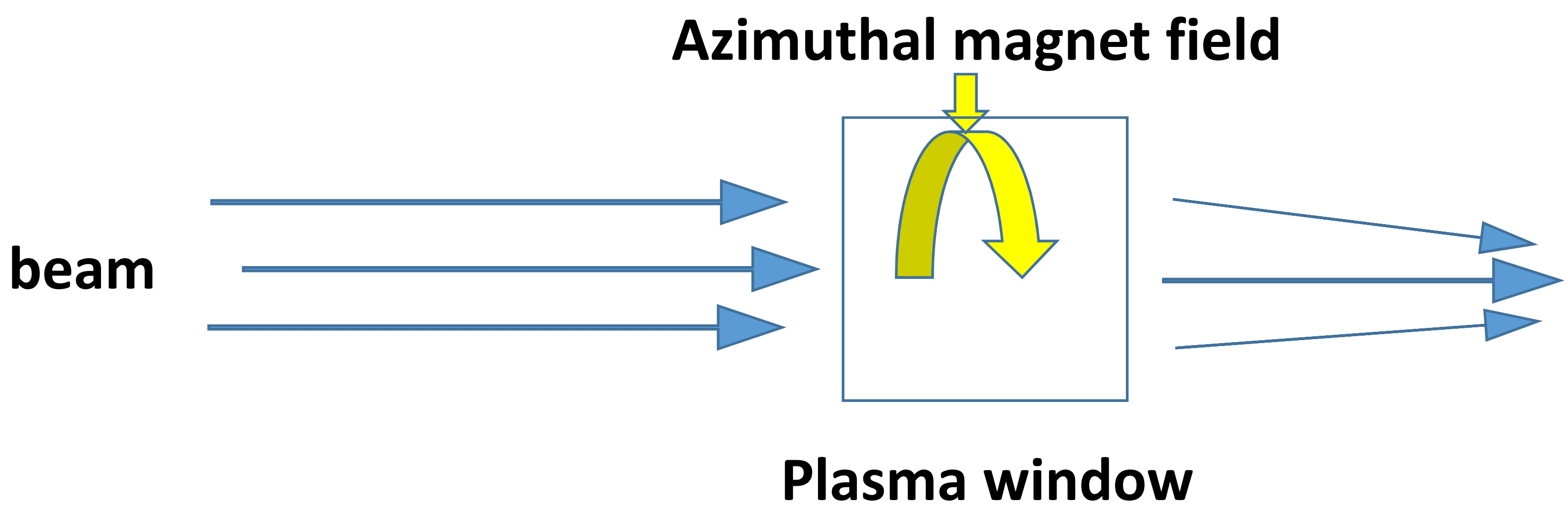
- Thermal damage
- Radiation damage
- Increase energy loss and energy spread

What is plasma window

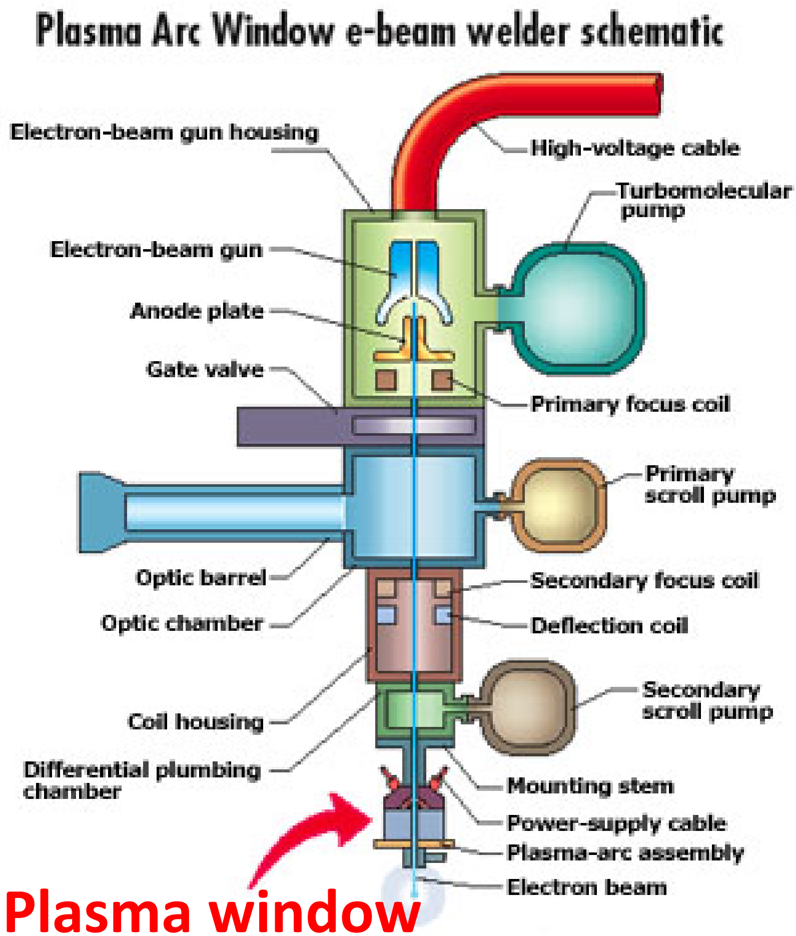


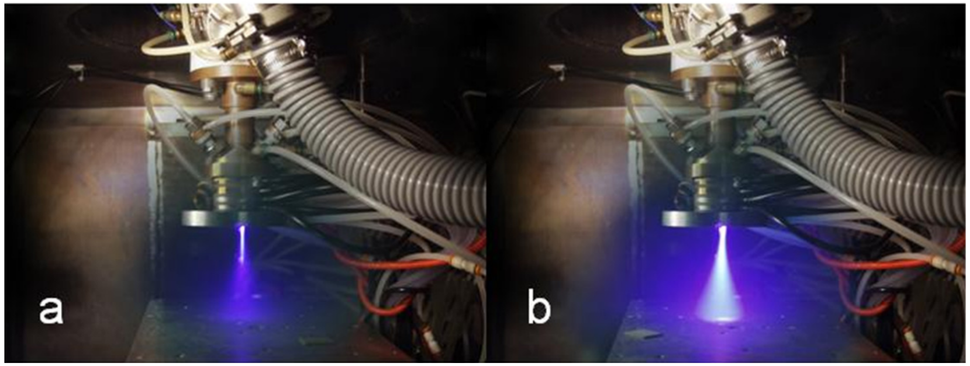
Why plasma window

- Needn’t worry about thermal problem.
- No radiation damage
- Very thin equivalent thickness(~nm)
- Focusing beam



Non-vacuum electron beam welding





9mA 25mA

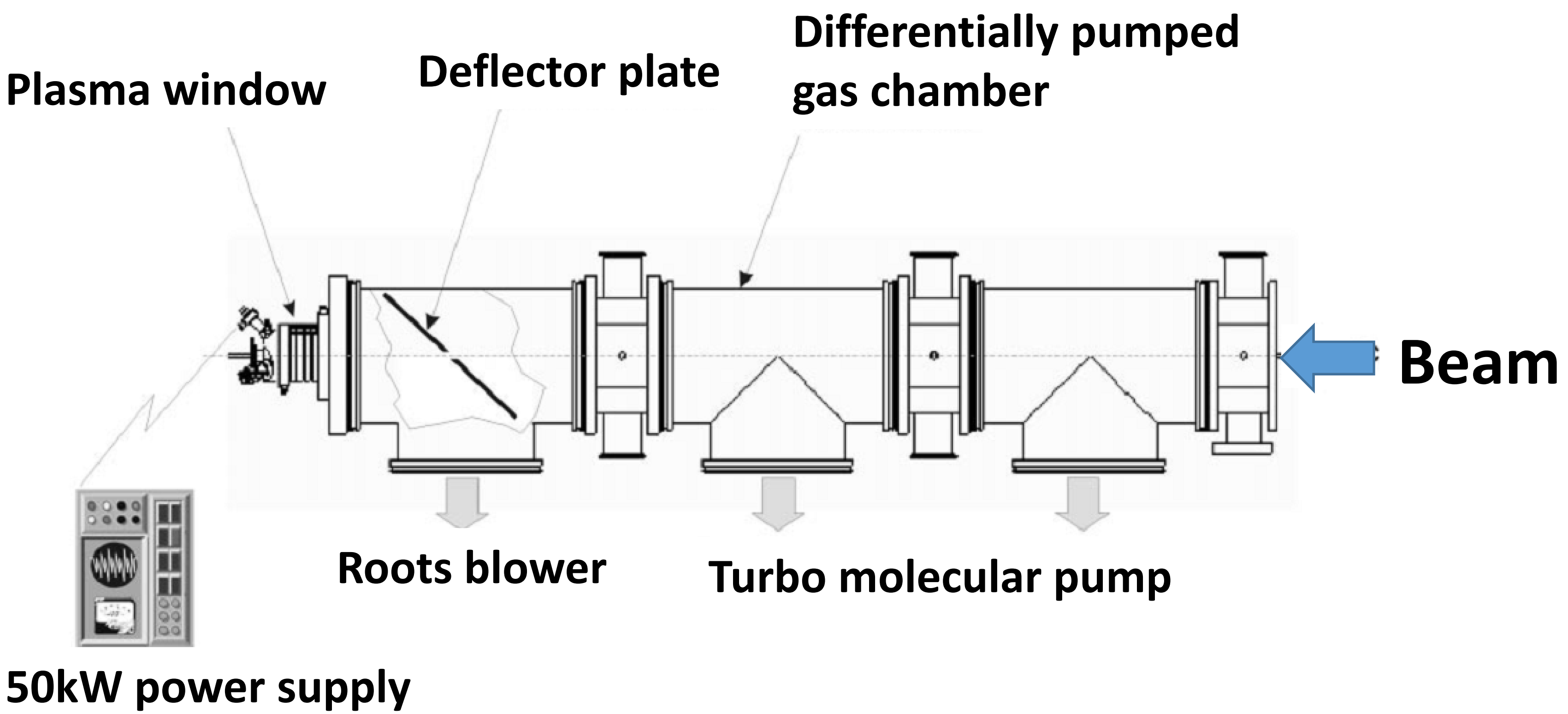
Electron beam current after exiting plasma window , Pure helium gas

Aperture: 2.36mm

Current: 45A

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

Gas target using plasma window



operating gas pressure is 0.5 bar for argon

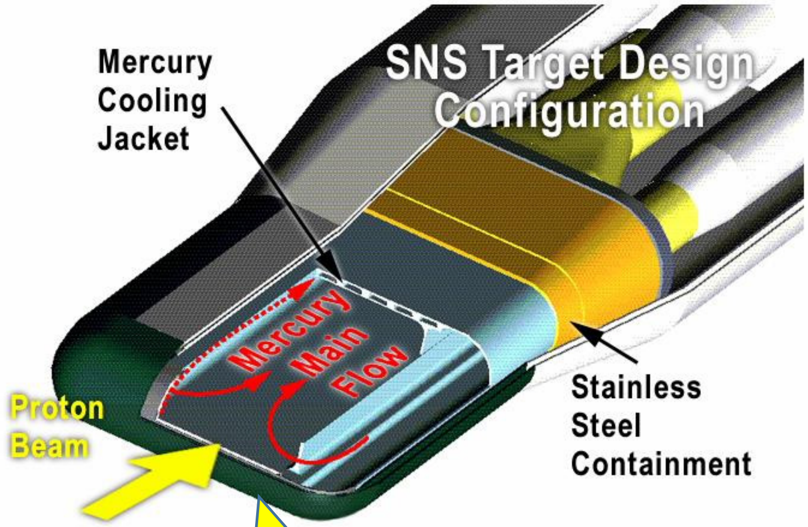
Diameter of plasma window: 5mm

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 current beam need larger plasma window

- **Small diameter Plasma window(2-5mm) is successfully used for electron beam welding and gas target.**
- **If large diameter(>3cm) plasma window is possible, It has very important application for SNS and ADS**.

Plasma window used for SNS



1.5mm beam window

- **damaged after 3000mw-hours**
- **DPA damage and thermal problem of Beam window effect the lifetime of target**
- **The lifetime of target is shorten if the beam power increase**
- **Could we replace the beam window by plasma window?**

Produce a larger aperture plasma window fit for SNS , the plasma window with 2 inch diameter require about 40kw power source

Plasma window for SNS target, Deepak Raparia& Ady hershcovitch, BNL

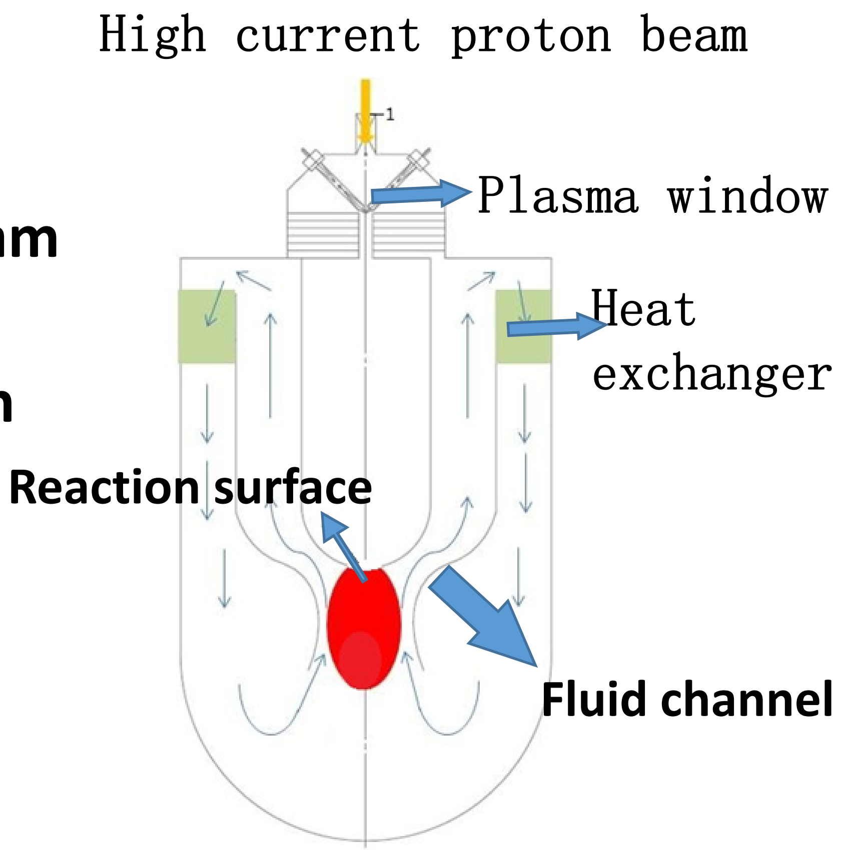
Plasma window used for ADS

- Two kinds of Pb-Bi liquid target
- target with window → low beam power
- windowless target → high beam power

difficulties:

1. control free surface of liquid metal

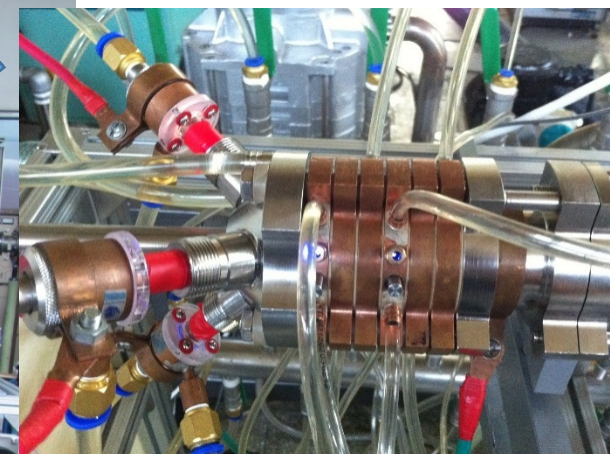
2. Keep vacuum of beam pipe.



Plasma window test bench

Vacuum gauge

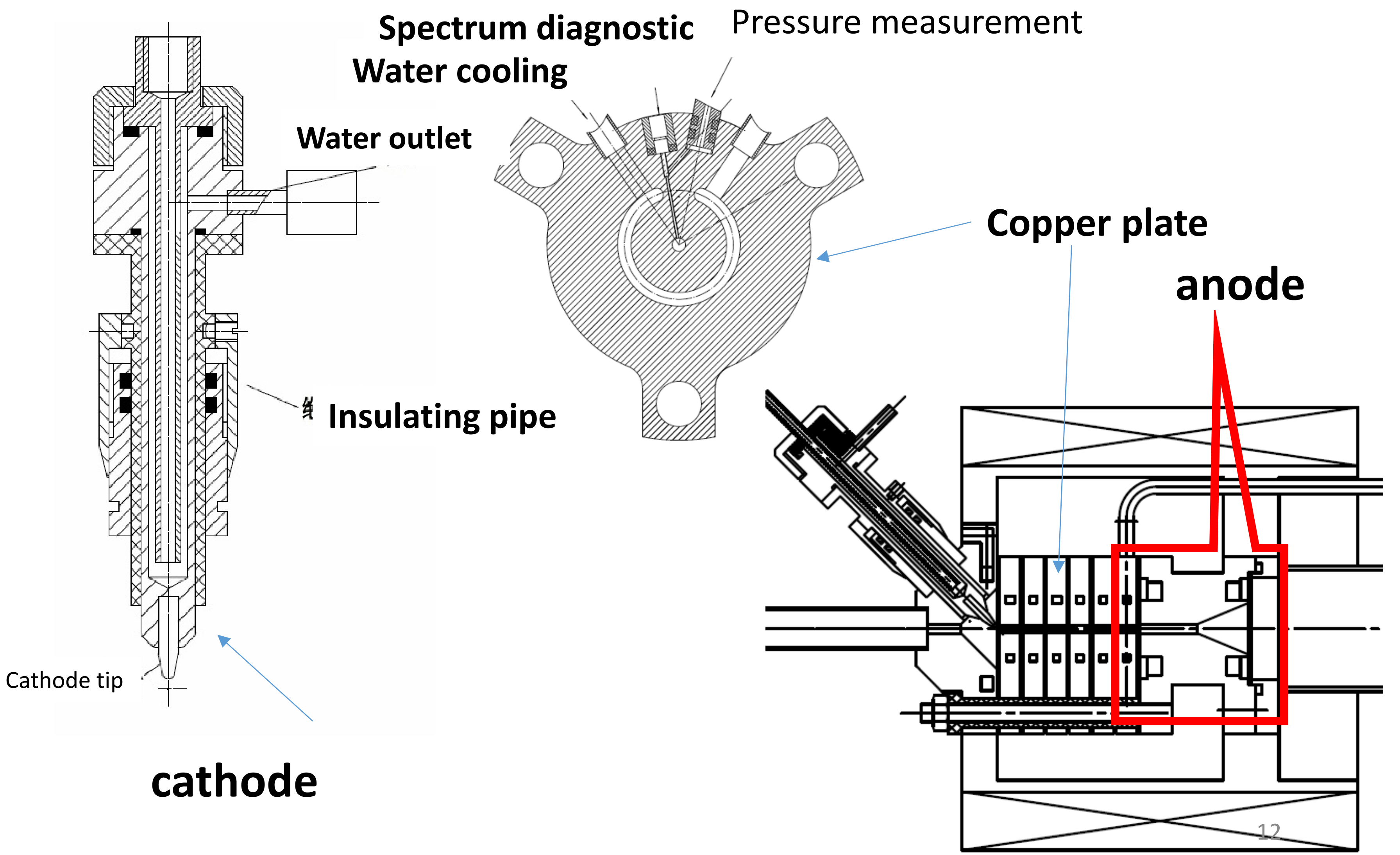
Plasma window



Two stage pump

Arc power supply

Plasma window

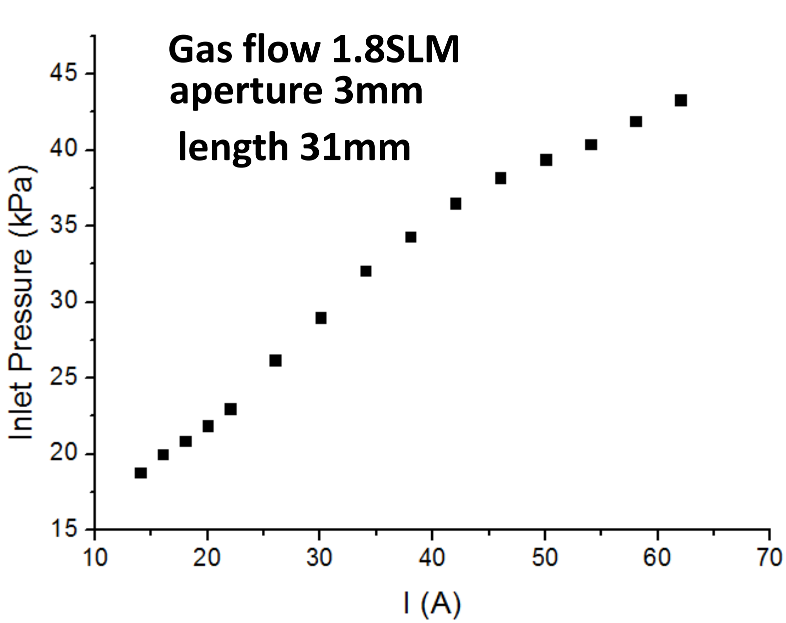


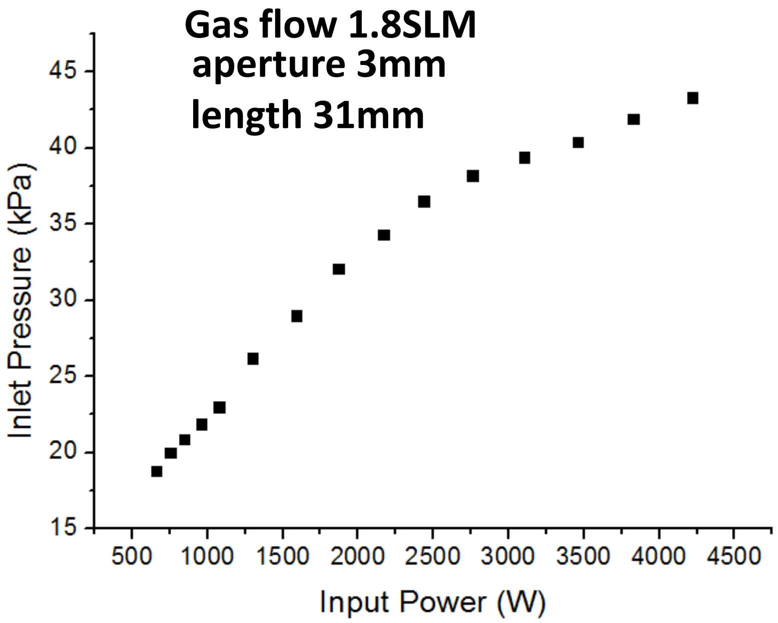
Plasma window sealing effect

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

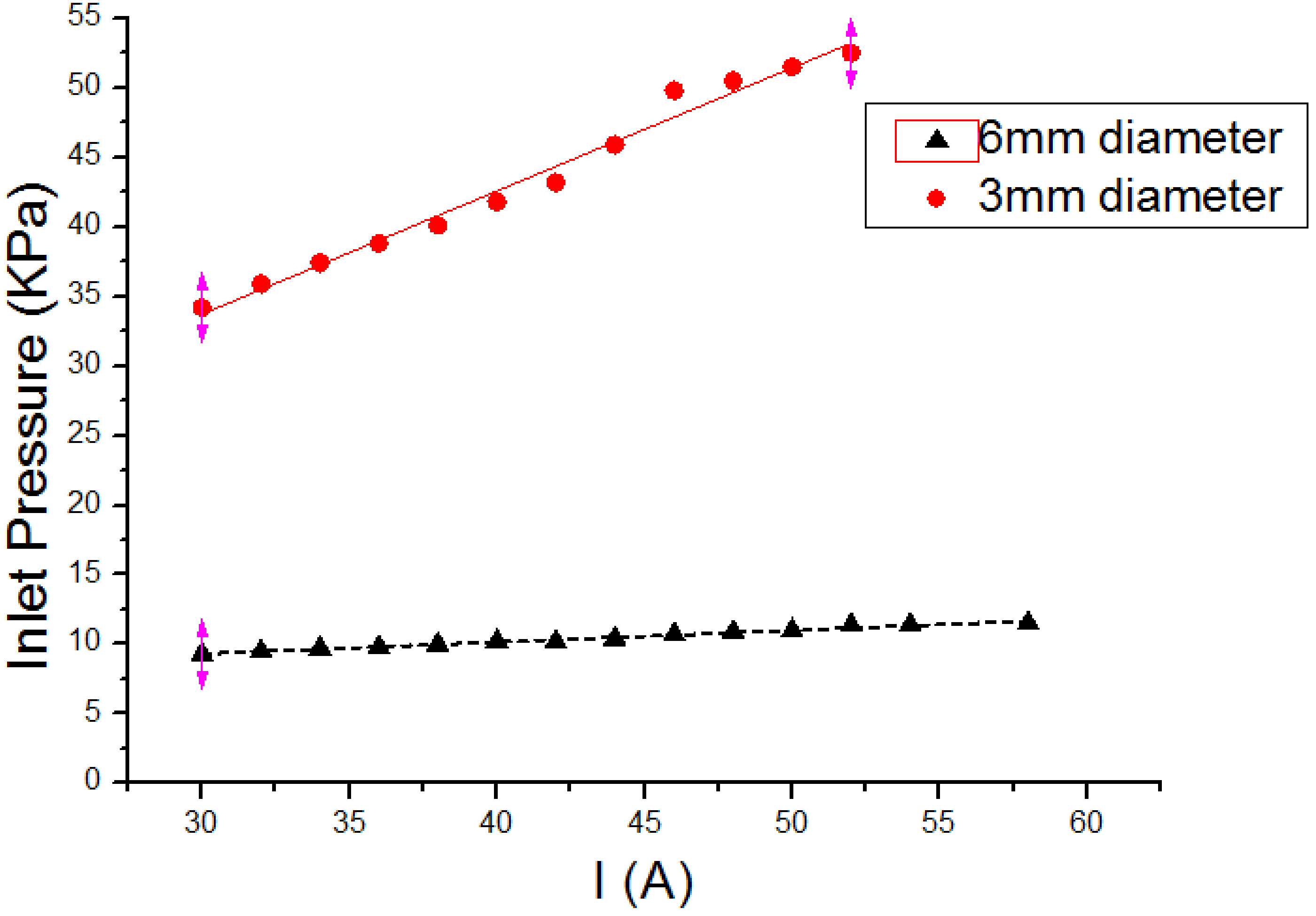
Operating current is 40A,
Operating voltage is 58V

Experiment result prove the plasma window ‘s sealing effect





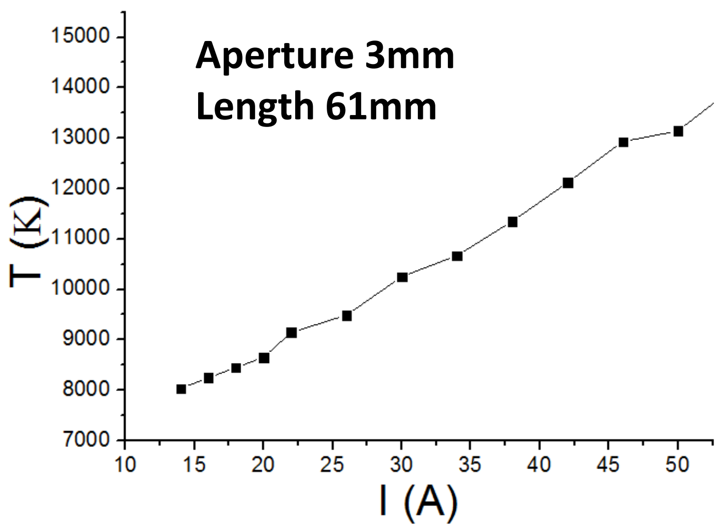
Plasma window's sealing property is not a simple linear relation with operating current and power



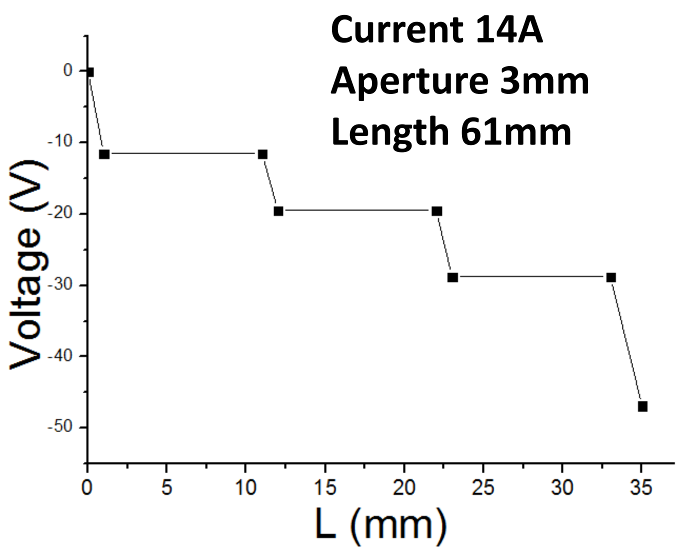
Inlet Pressure (KPa)
55
50
45
40
35
30
25
20
15
10
5
0
30
35
40
45
50
55
60
I (A)
6mm diameter
3mm diameter

Plasma temperature measurement

- **Conductivity correspond to plasma temperature.**



Temperature change with operating current

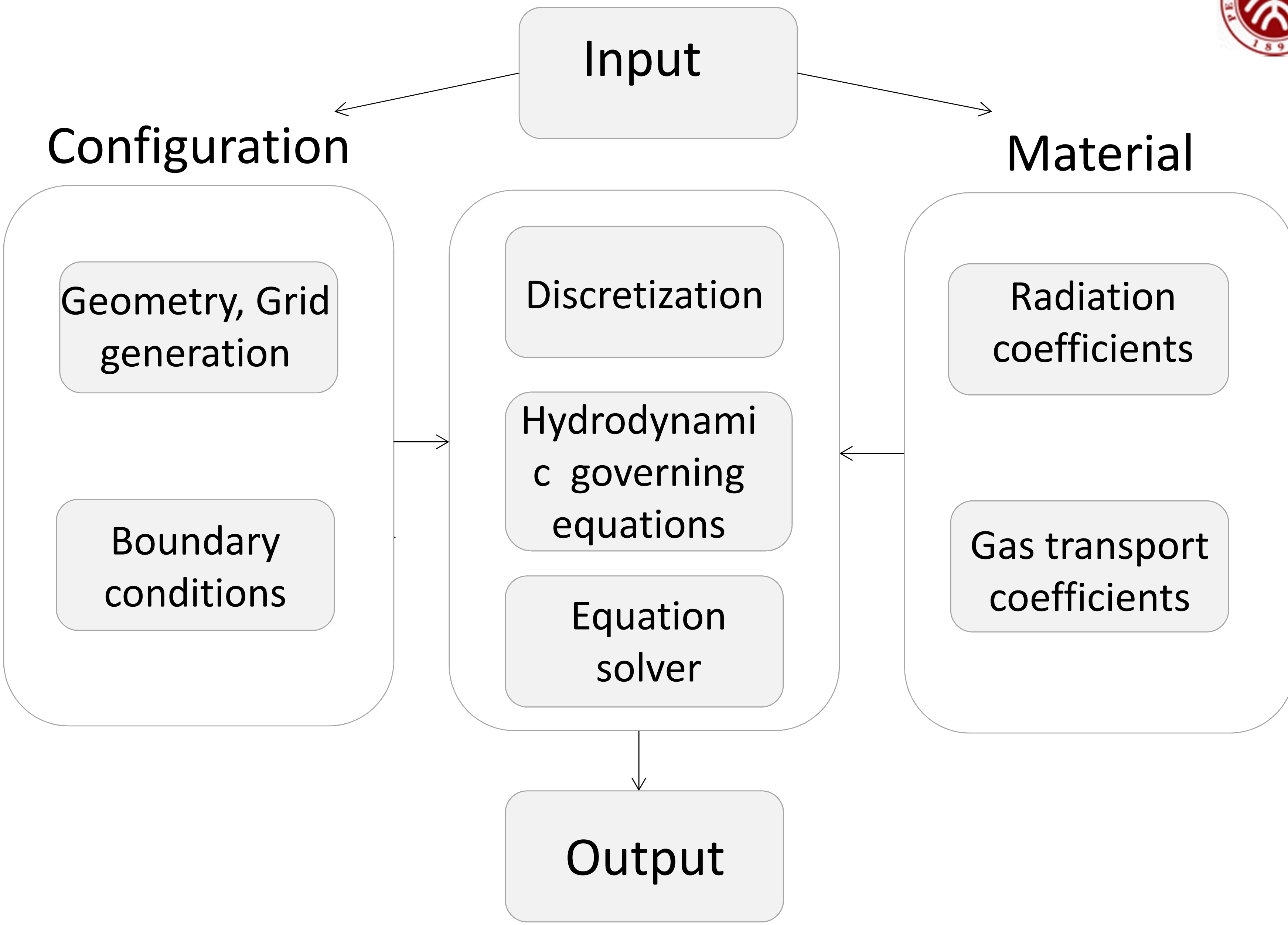


Voltage distribution along plasma window

- 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
Material
Geometry, Grid generation
Boundary conditions
Discretization
Hydrodynamic governing equations
Equation solver
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

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

$$\frac{\partial}{\partial z}(\sigma\frac{\partial \phi}{\partial z})+\frac{\partial}{r\partial r}(r\sigma\frac{\partial \phi}{\partial r})=0$$

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

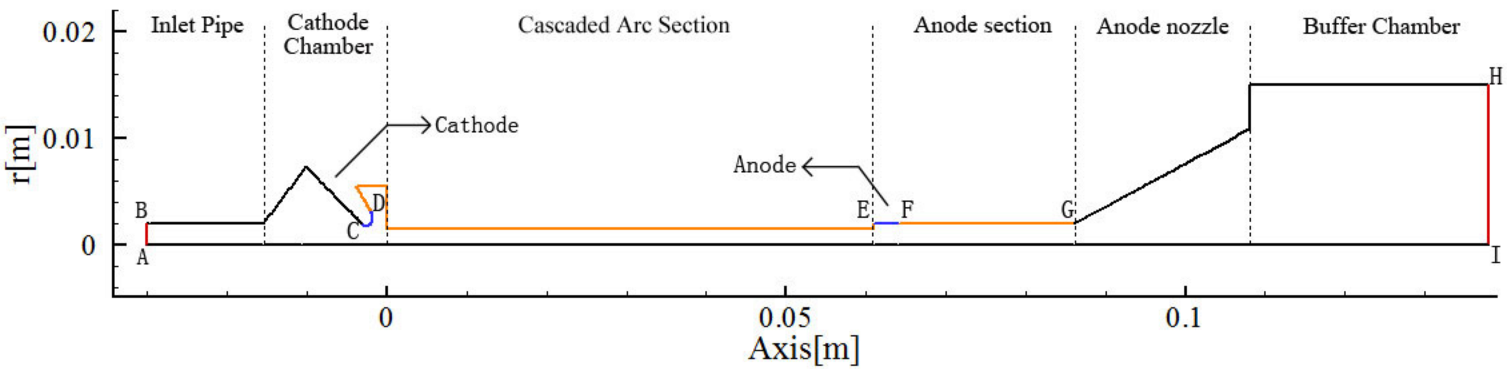
$$-(\frac{\partial}{\partial z}\frac{\partial A_r}{\partial z})+\frac{1}{r}\frac{\partial}{\partial r}\frac{\partial A_r}{\partial r})=\mu_0 j_r$$

μ,k and σ are function of T and P

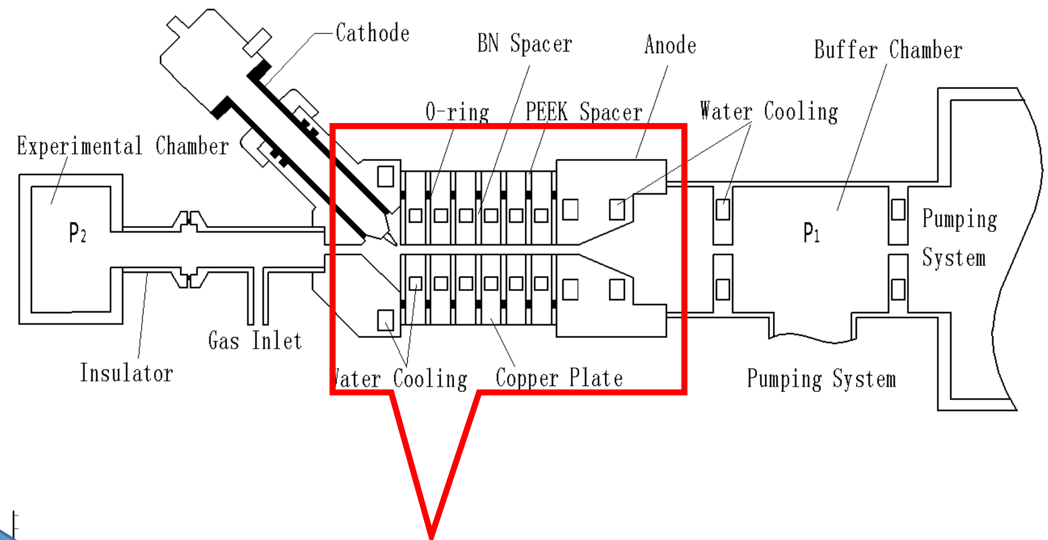
Nonlinear equation set

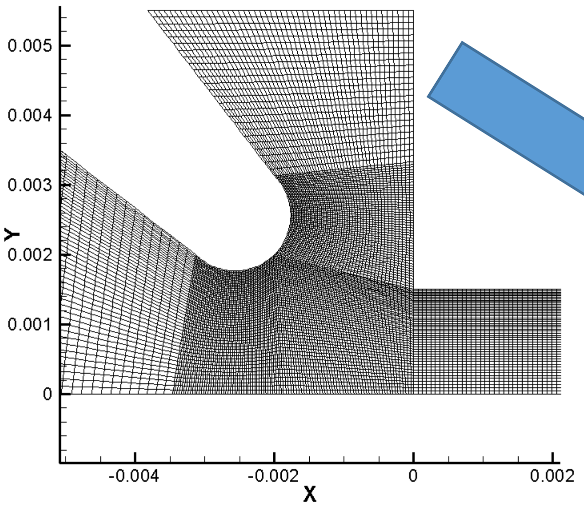
Boundary conditions

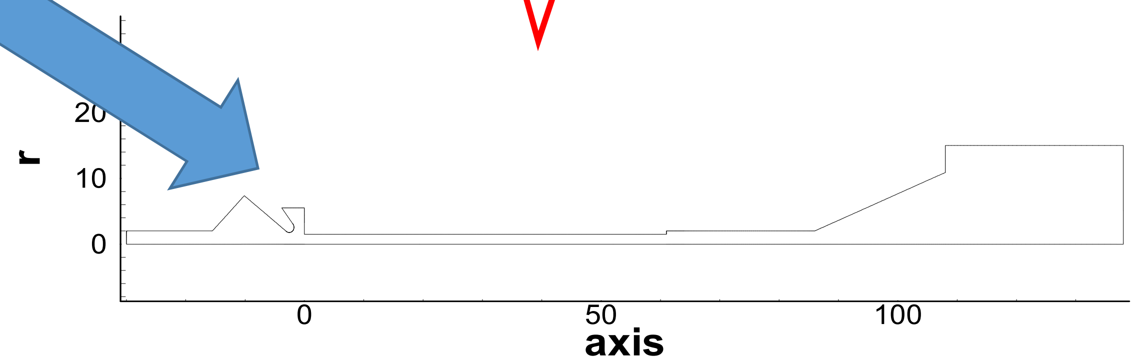
	P	$\vec{u}$	T	ϕ	$\vec{A}$
AB: Inlet	$P = 52.5KPa$	/	$T = 300$	$\partial\phi / \partial n = 0$	$A_i = 0$
HI: Outlet	$P = 60$	/	$\partial T / \partial n = 0$	$\partial\phi / \partial n = 0$	$\partial A_i / \partial n = 0$
AI: Axis	$\partial P / \partial n = 0$	$\partial u_i / \partial n = 0$	$\partial T / \partial n = 0$	$\partial\phi / \partial n = 0$	$\partial A_i / \partial n = 0$
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	$T = 300$	$\partial\phi / \partial n = 0$	$\partial A_i / \partial n = 0$



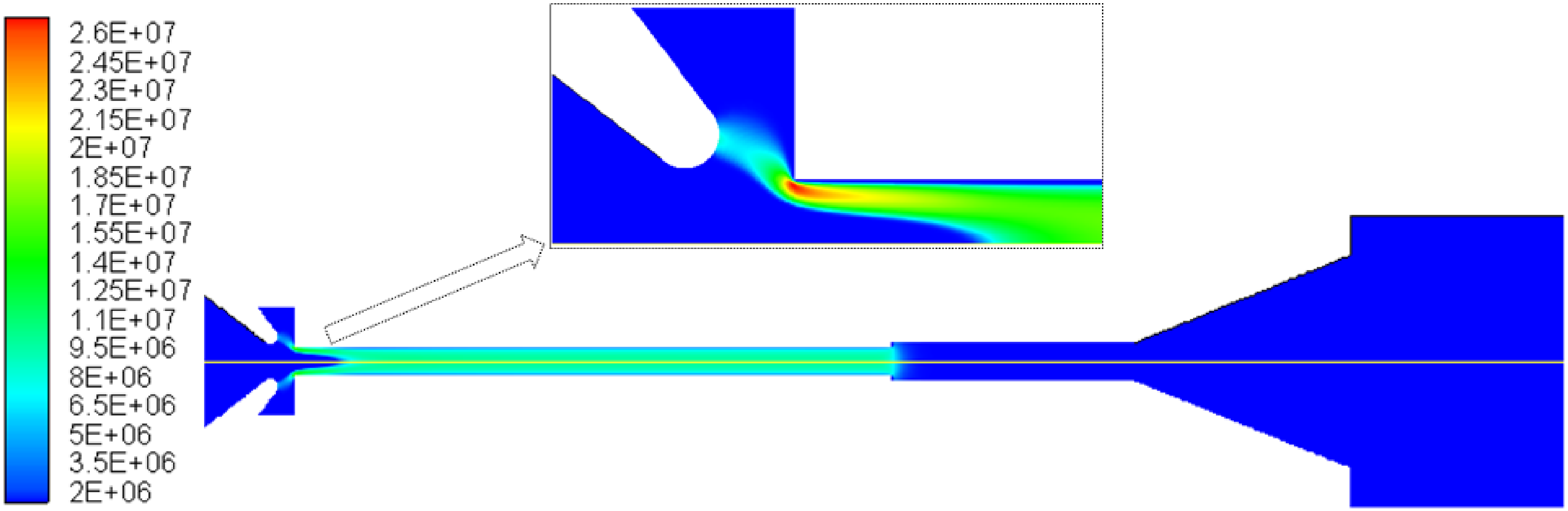
Simulation domain



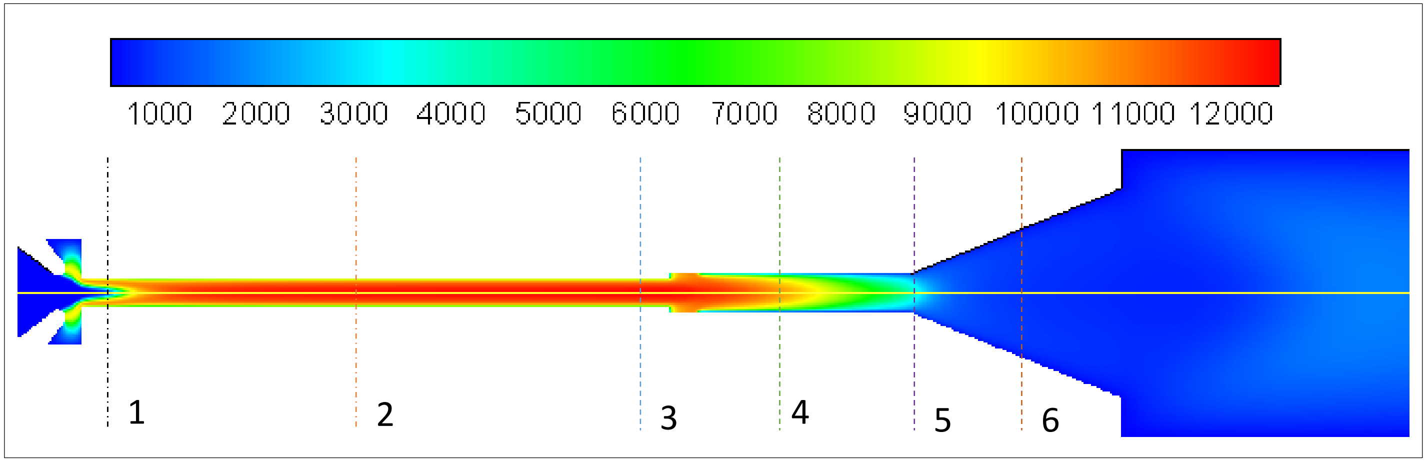


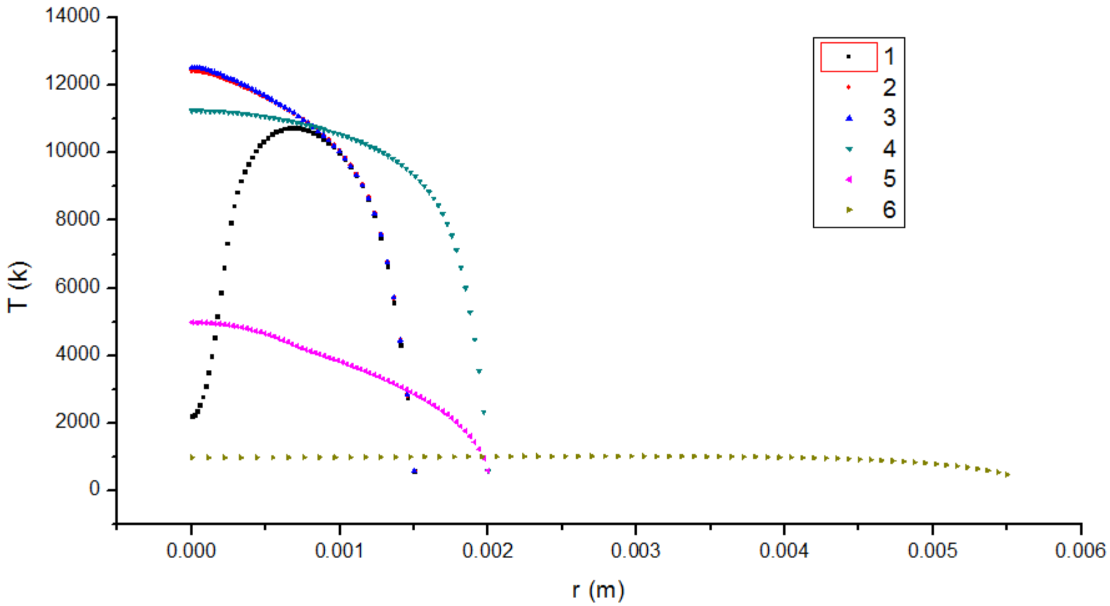


Current Distribution

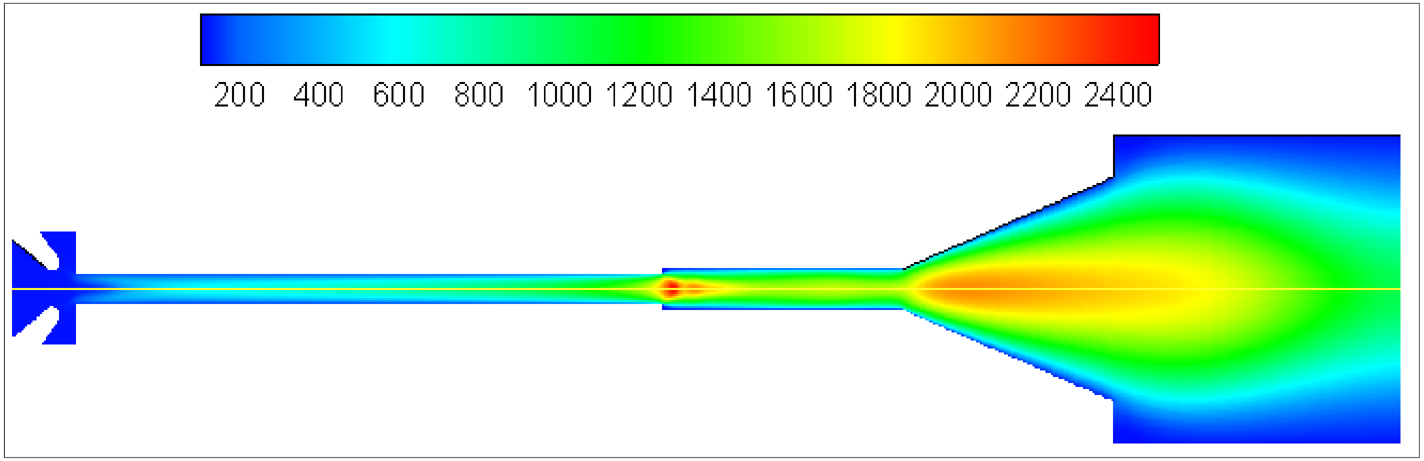


Temperature Distribution

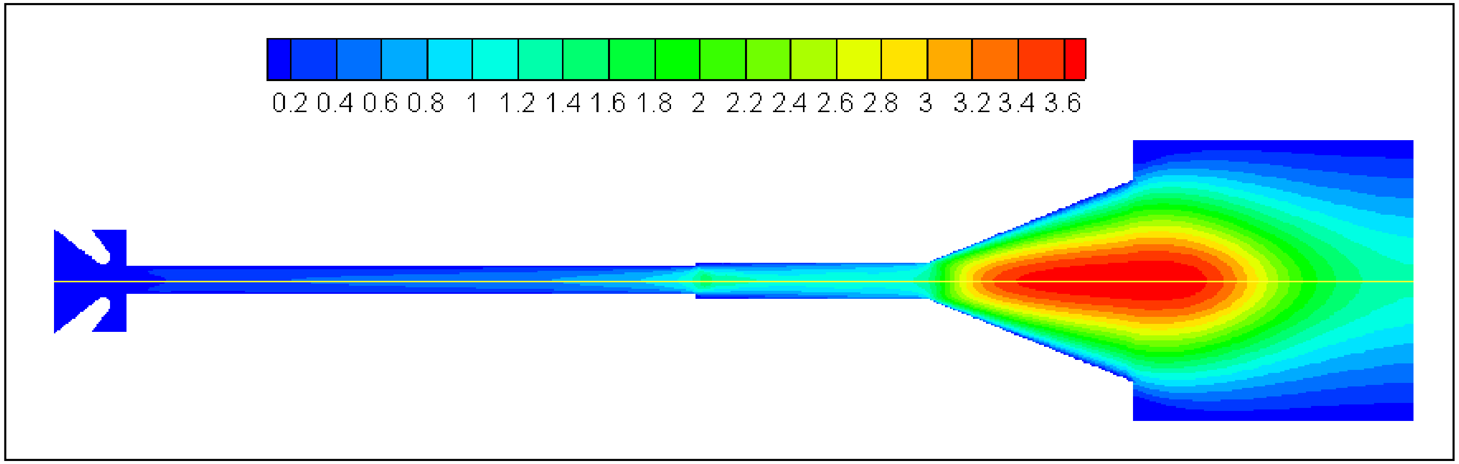




Velocity and Mach Number Distribution

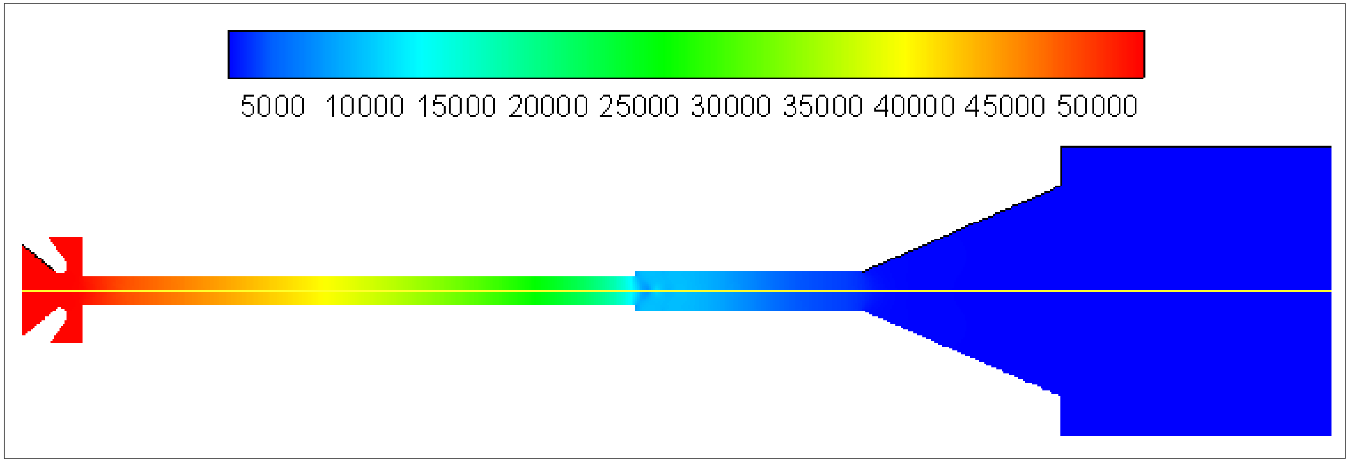


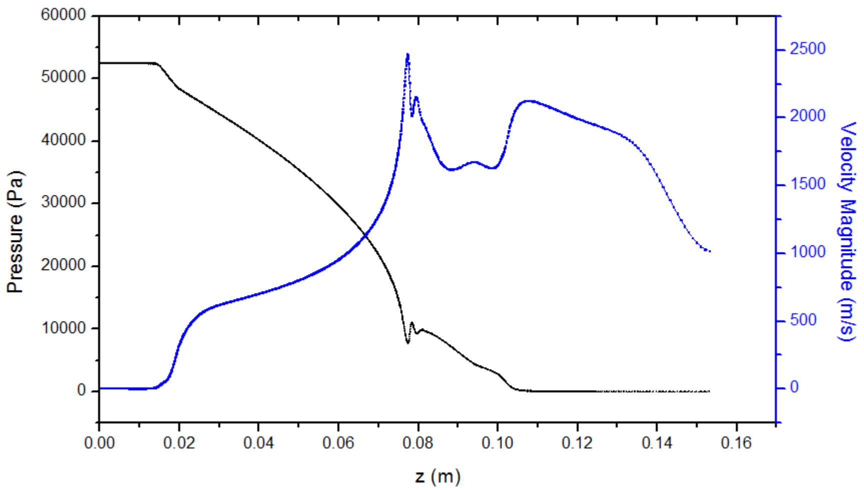
Velocity distribution



Mach number distribution

Pressure Distribution





Pressure and velocity distribution along axis

Comparison of Experiment and Simulation results

<table>
<tr><th></th><th>Inlet Pressure</th><th>Outlet Pressure</th><th>I</th><th>ϕ</th><th>Gas Flow</th></tr>
<tr><td>Experiment</td><td>52.5KPa</td><td>60Pa</td><td>47A</td><td>115V</td><td>4.87E-5kg/s</td></tr>
<tr><td>Computed</td><td rowspan="2">Fixed</td><td rowspan="2">Fixed</td><td rowspan="2">Fixed</td><td>140V</td><td>5.12E-5kg/s</td></tr>
<tr><td>Error</td><td>17.8%</td><td>4.8%</td></tr>
</table>

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 studying the performance of larger aperture plasma window

Acknowledgement

- Thanks for Ady Hershcovitch’s(BNL) help on plasma window test bench.

Thank you for your attention!