SMASHI & MeLA ECR Ion Sources at NFRI:

One† for Highly-charged Ions
and the Other‡ for High Current Metal Ions

The 22nd International Workshop on ECRIS

H. J. YOU, S. O. Jang, W. I. Choo

31, August, 2016

National Fusion Research Institute

Contents

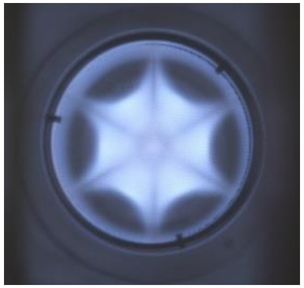
1) †SMASHI for Medium Current Highly-charged Ions

2) ‡MeLA for High Current Singly-charged Gas/Metal Ions

†SMASHI=Superconducting Multi-Application Ion Source for Highly-charged Ions

‡MeLA=Magnet-embedded Lisitano Antenna

†



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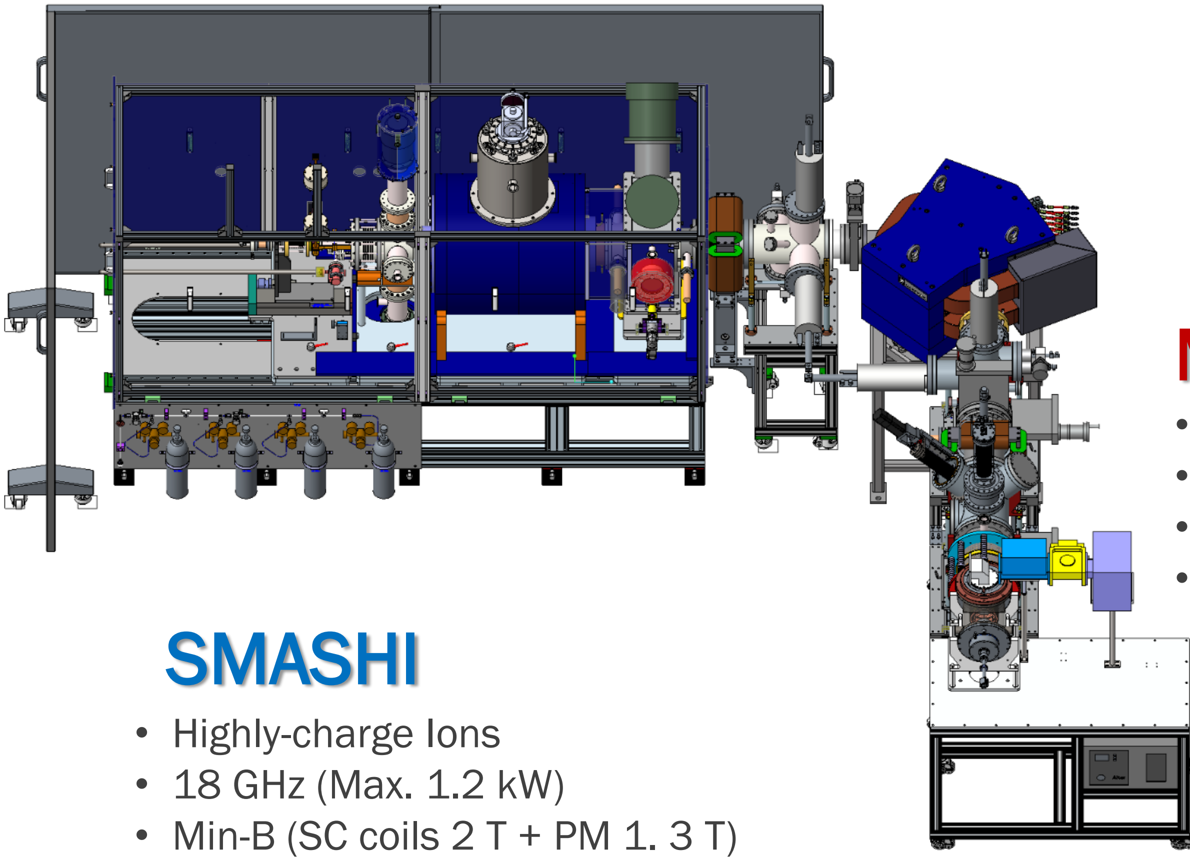
Layout of NFRI ECR Ion Source Facility



MeLA

- High current metal ions
- 2.45 GHz (Max. 3 kW)
- PM (~ 0.2 T)
- MeLA size (Φ120 mm)

SMASHI

- Highly-charge Ions
- 18 GHz (Max. 1.2 kW)
- Min-B (SC coils 2 T + PM 1. 3 T)
- Plasma chamber (Φ82 mm)

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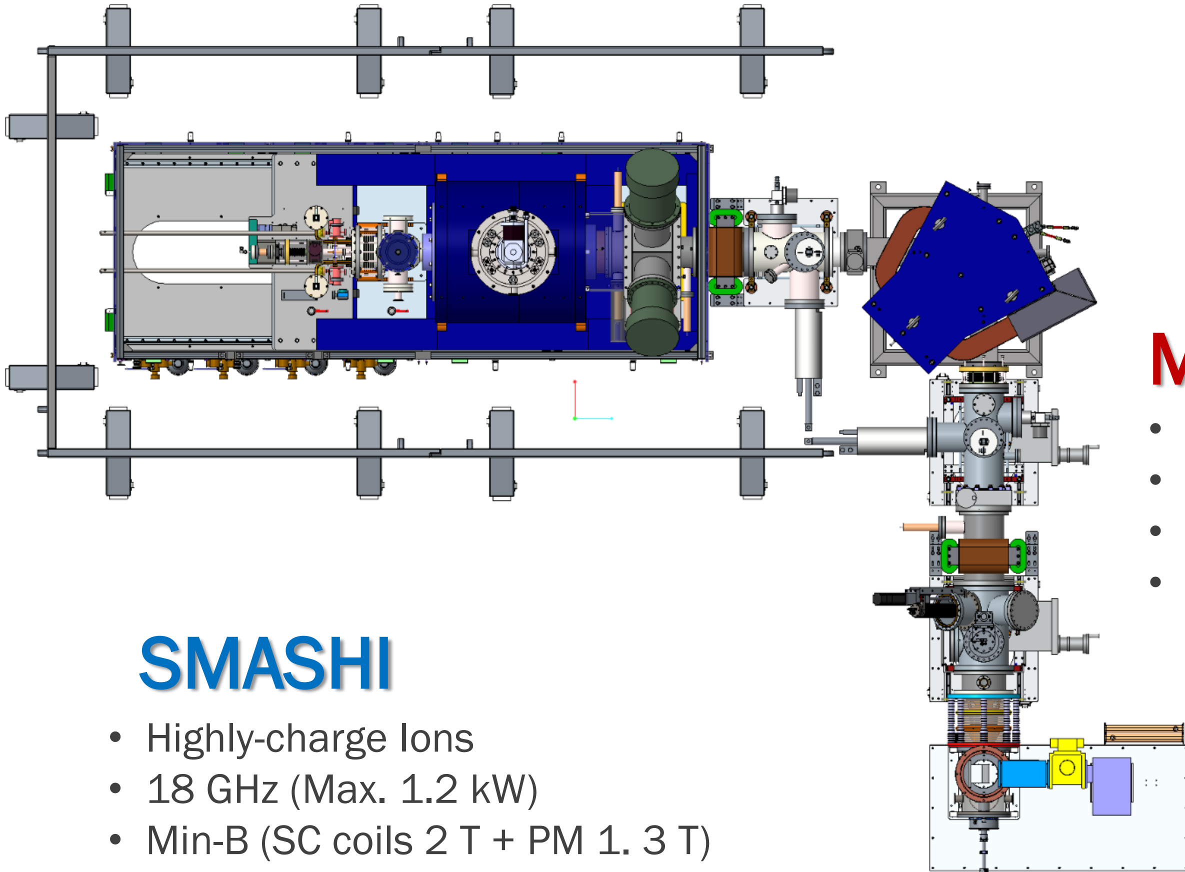

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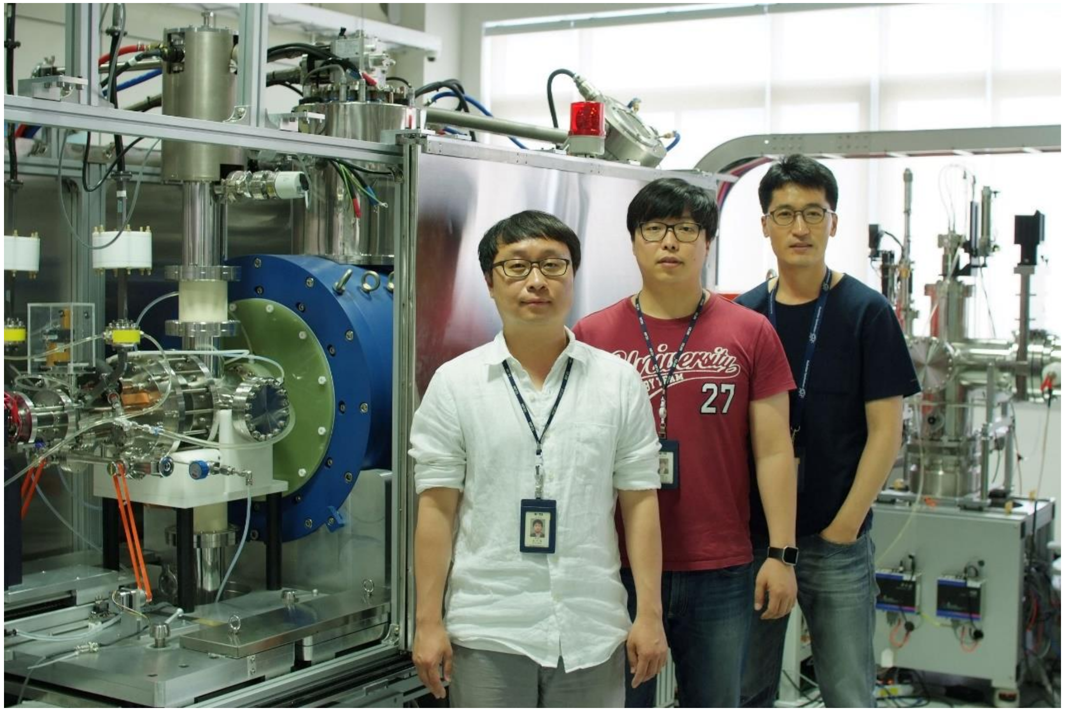
Microwave Plasma/Ion Source TEAM

» We are three (small team), but still young



SMASHI

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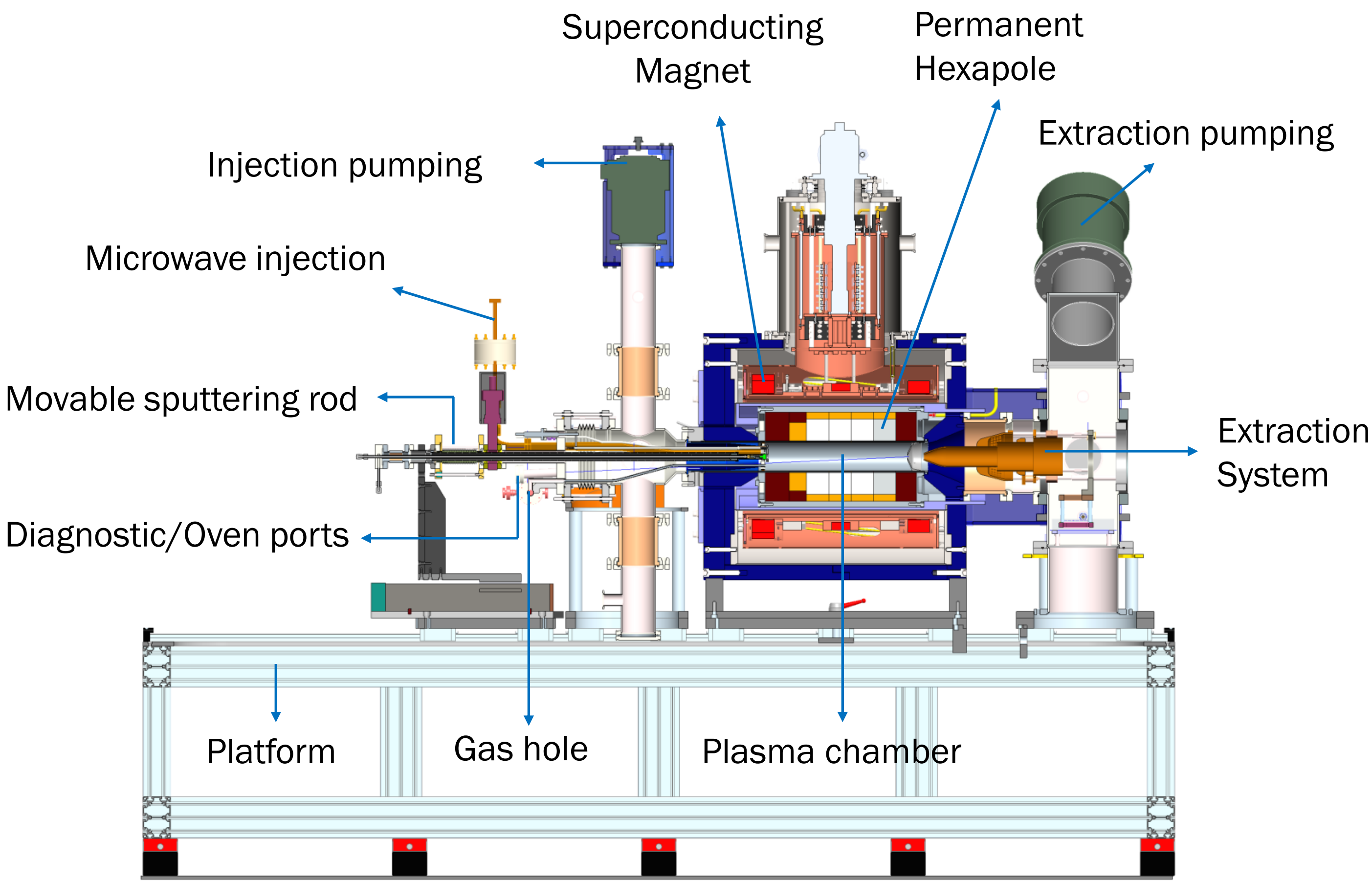
» SMASHI (Superconducting Multi-Application Source of Highly-charged Ions)



Design Features of SMASHI

Design Features of SMASHI

» **2.1 T ($B_{inj,max}$), 1.5 T ($B_{ext,max}$), 0.4-0.6 T (B_{min})**

→ "Liquid He-free" high field magnet and its flexible tuning

→ Very low power consumption (200 →15 kW)

» **1.28 T** of high radial field (permanent magnet hexapole)

» Two frequency heating (**18, 18±Δ GHz**)

2 set of TWT (Max. power=650 W) can give 1250 W

» Capability to generate at the same time **diverse ion elements from gas to metal**

» High power-capable **Al plasma chamber** (Ø82×460 mm=2.2 liter)

» **Movable extraction-einzel lens system** (15-30 kV) for low beam emittances

» **Two diagnostic ports** for diagnosing the extraction region of plasma

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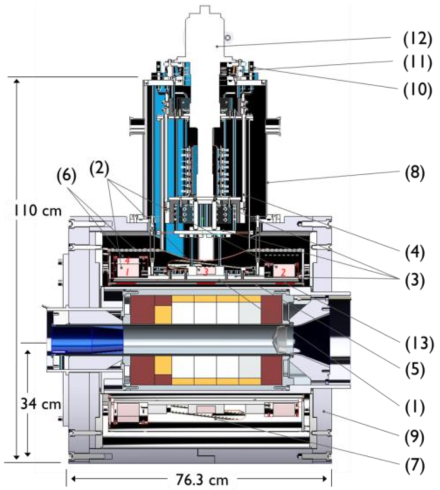

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Main parameters of magnetic field

f (GHz)	18, 18±Δ	(Two frequency)
$B_{inj,\,max}$ (T)	2.1	B_{inj}/B_{ecr} = 3.4 – 4.4
$B_{ext,\,max}$ (T)	1.5	B_{ext}/B_{rad} = 1.2
B_{ecr} (T)	0.65	
B_{rad} (T)	1.28	B_{rad}/B_{ecr} ~2.0
B_{last} (T)	1.3	B_{last}/B_{ecr} = 2.0
B_{min} (T)	0.4-0.55	B_{min}/B_{rad} = 0.3 – 0.4

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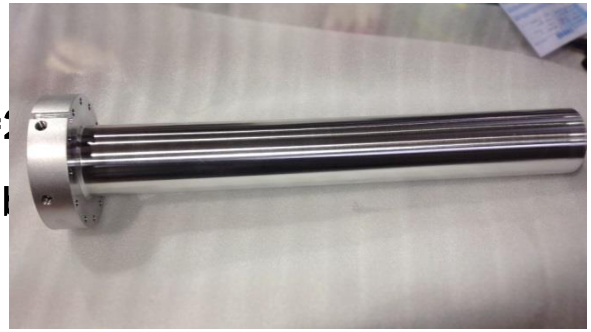

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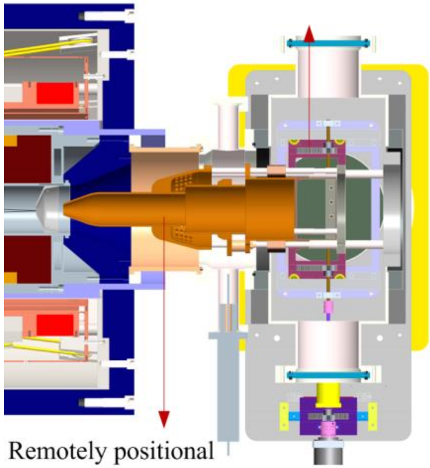

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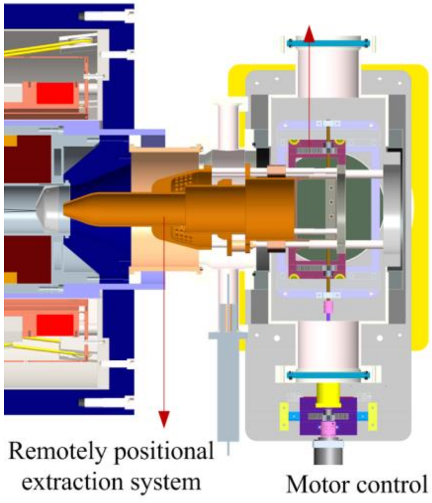

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Purposes of 18 GHz SMASHI at NFRI (1)

» **Development of Advanced high-performance ECR ion source**

1) Studies on ECRIS Plasma

2) Development of compact high-performance ECR ion sources
   for material(surface) interaction and/or compact heavy ion therapy

» **Highly-charged Ion Matter Interaction by using well-defined ion beams**

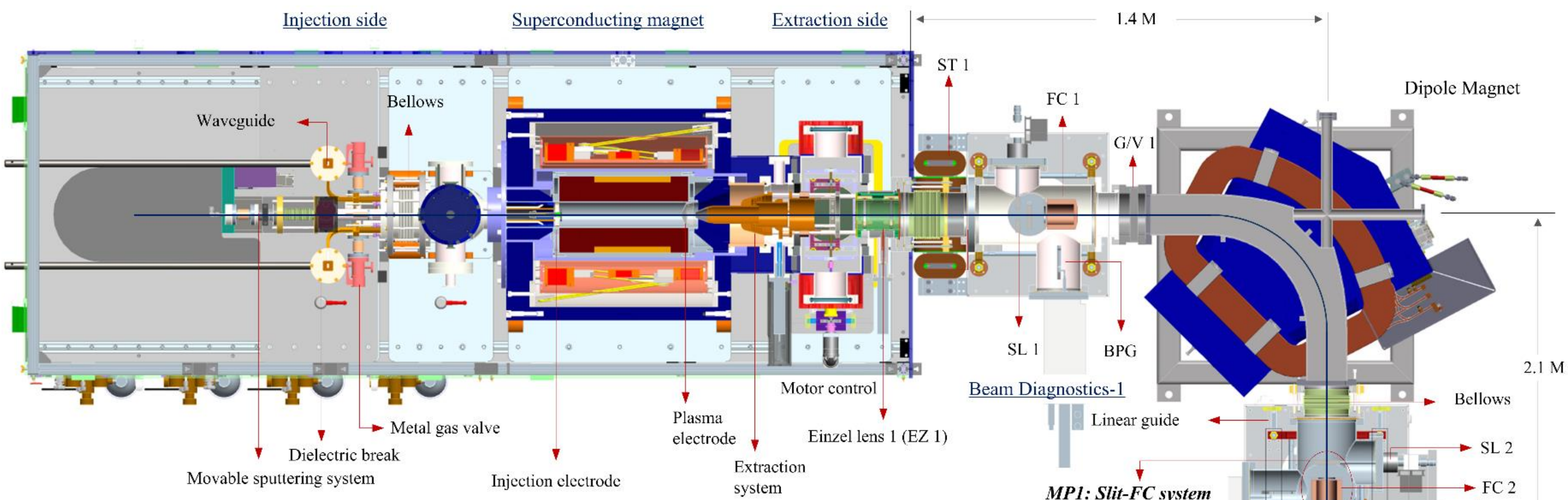
1) Investigation of various highly-charged ion-surface interaction

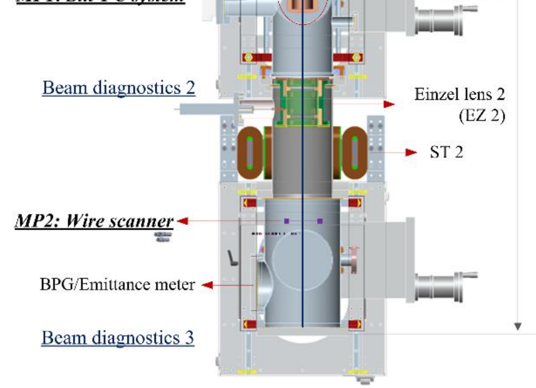
2) Ion beam studies & development of new fusion reactor material (C, Be, W…)

3) Highly-charged ion induced products (X-rays, highly-excited neutrals)

Setup of SMASHI & LEBT

» **SMASHI(SC Multi-Application Source of Highly-charged Ions) & its LEBT**





EZ=EinZel lens
ST=STeering magnet
SL=SLit
BPG = Beam Profile Grid
FC = Faraday Cup
G/V = Gate Valve

Dipole Magnet:
Bending radius=400 mm
Resolution = 150
Pole gap = 60 mm
Double focusing (nominal focal length=0.8 m)

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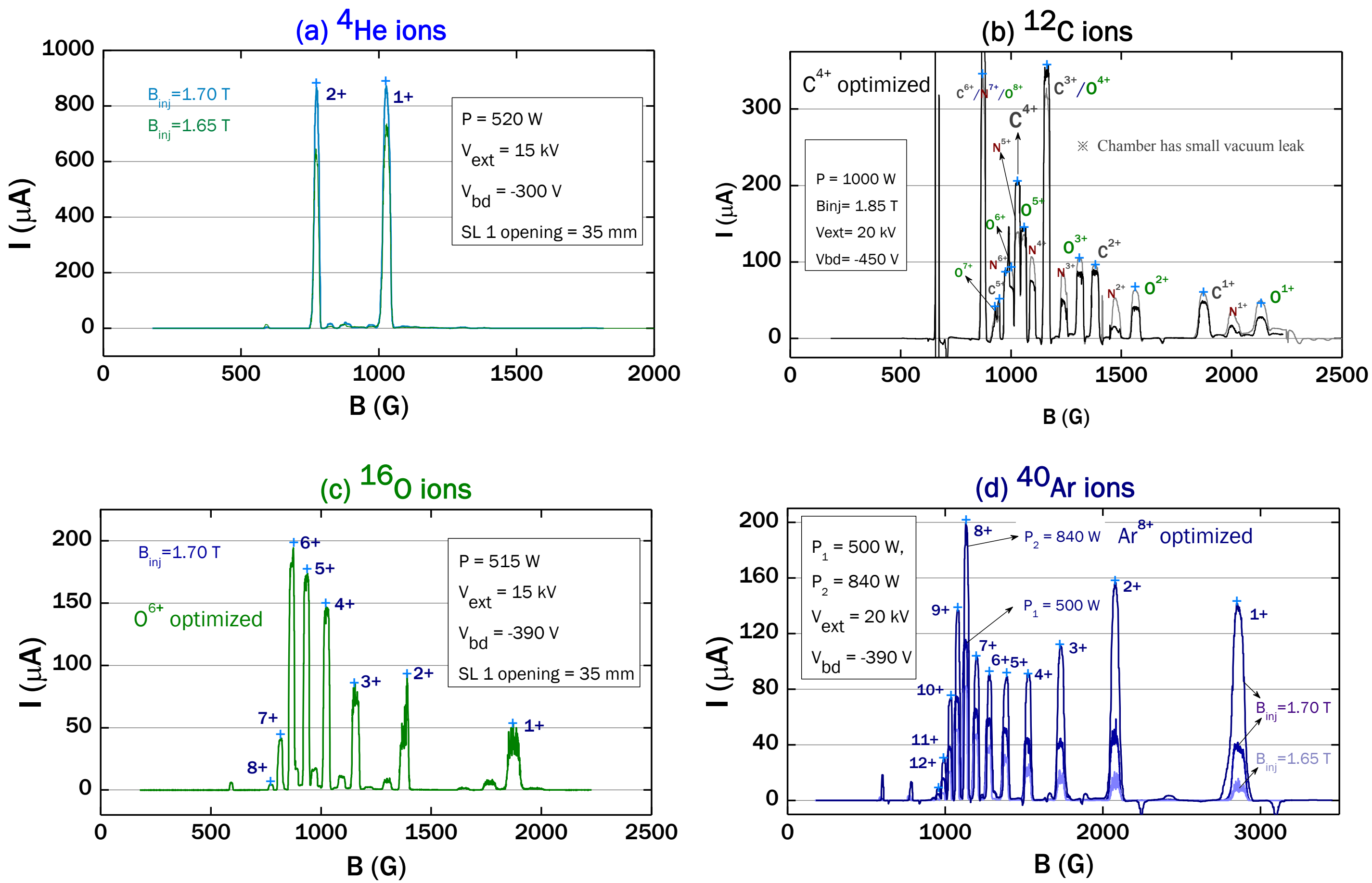
Beam charge spectra from SMASHI

» Preliminary beam charge spectra of He/C/O/Ar beams



Initial Beam Results

» Preliminary results of beam charge spectra from SMASHI (B_{inj}=1.7 T, Max. power=600/900 W)

Charge	^{4}He	^{12}C		^{32}O	^{40}Ar		^{132}Xe	
	500 W	500 W†	1 kW†	500 W	500 W	840 W	500 W	900 W
1+	910	200	47					
2+	**900***	210	85					
3+		-	-					
4+		**100***	206*					
5+		25	49	184				
6+			-	**202***				
7+				43	70	105		
8+				4.3	**120***	**200***		
9+					78	138		
10+					41	75		
11+					18	31		
12+					5	9.4		
13+					1.2	2		
19+							2.7	25
20+							**2.5***	**23***
21+							2.3	22

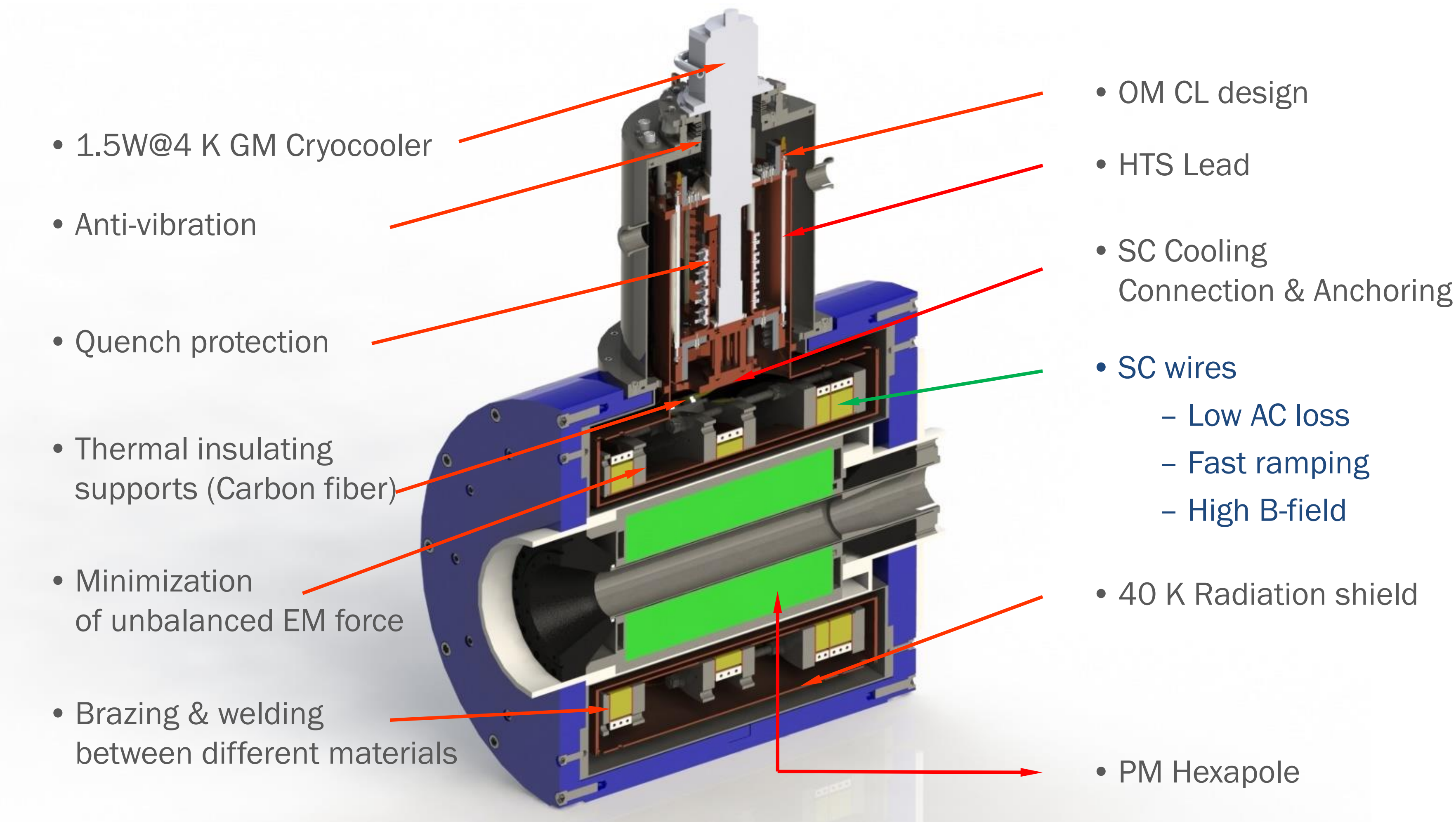
* optimized charge, † under small vacuum leak

Operation conditions

- Max. TWT Power = 600 W[1] + 300 W[2]
  Input power was limited to ~900 W due to high X-ray dose rate(>0.5 μSv/h) at operator position
- B_{inj}=1.7 T (80 %), B_{ext}=1.3 T, B_{min}=0.5 T
- Extraction voltage ≤ 20 kV, ∅8 mm aperture
- Biased disk voltage = -(200~600) V
- Stainless steel plasma chamber & No gas mixing
- † Carbon beam was obtained under small vacuum leak (plasma chamber)

See the poster WEPP16 for more information

Newly developed Liquid He-free SC Magnet (SM 2)



Liquid He-free SC Magnet for high field 18 GHz ECRIS

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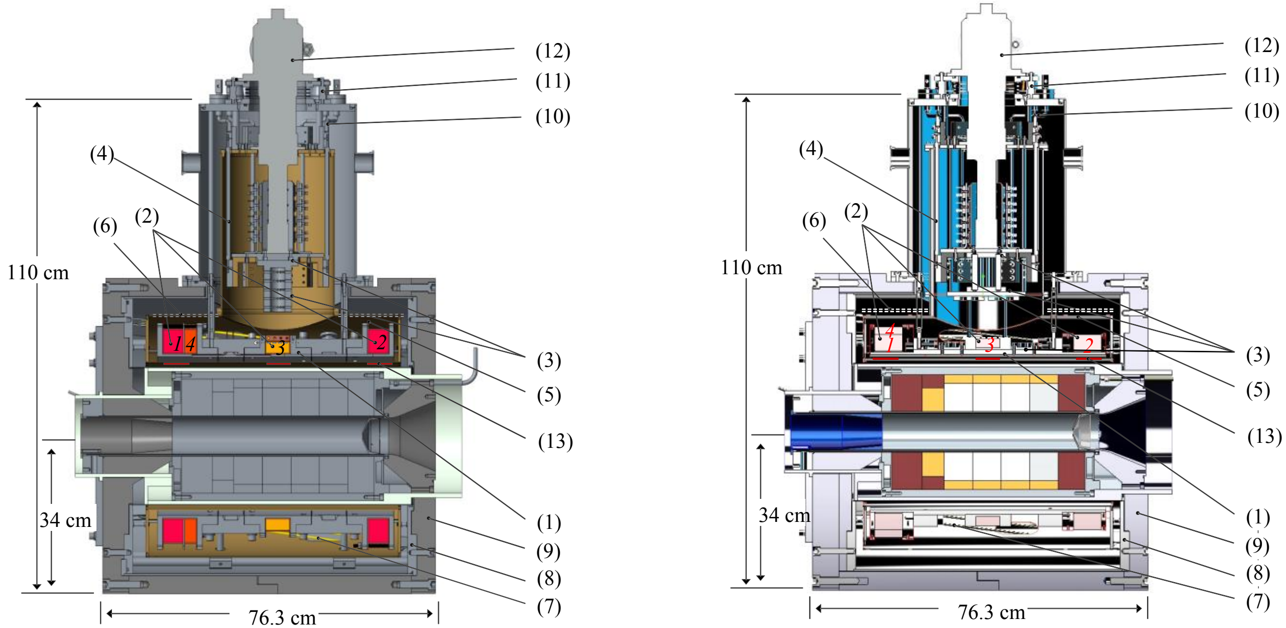
SM 2 is for Fast Coil Excitation & Tuning

<SM II: NEW> **<SM I: Previous>**



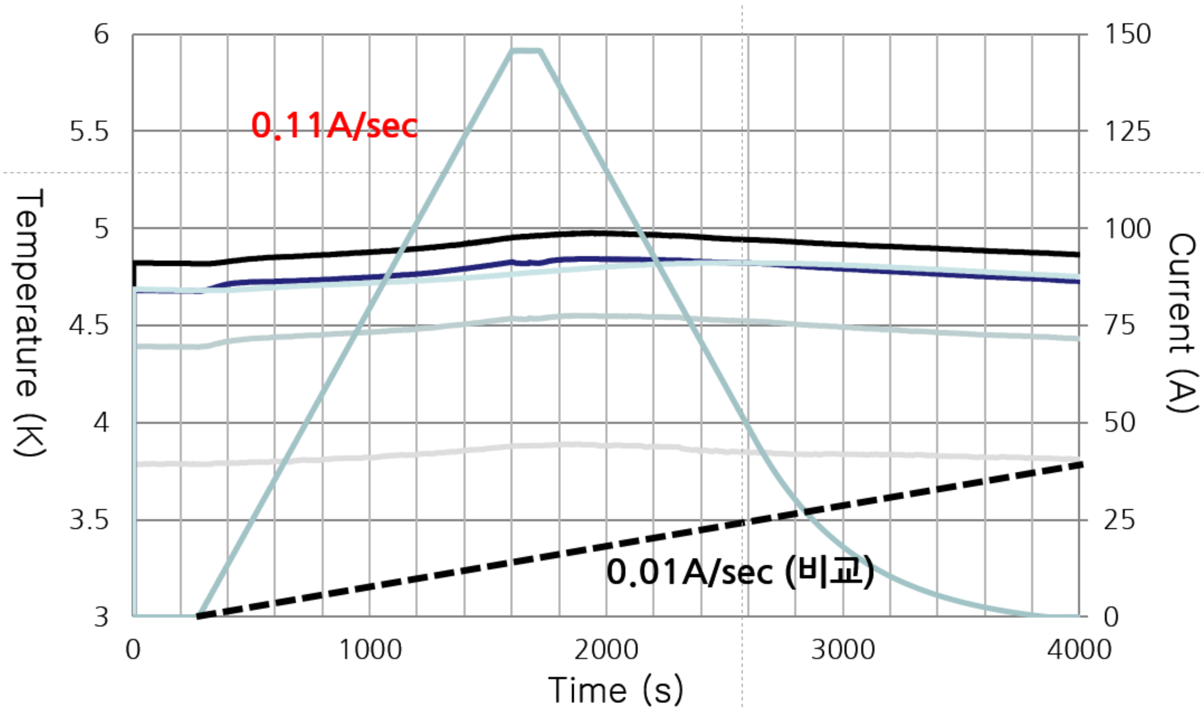
(a) (b)

(a) A newly-upgraded SC magnet capable of fast-ramping & higher magnetic field compared with the previous SC magnet: (1) S.S. Bobbin (previous: OFHC bobbin), (2) SC coil, (3) Thermal link, (4) HTS lead, (5) Radiation shield, (6) ML thermal shield, (7) Thermal insulating support, (8) Vacuum chamber, (9) Iron yoke, (10) Current lead, (11) Anti-vibrator, (12) 4 K Cryocooler, (13) Quench protection

How to get fast coil excitation

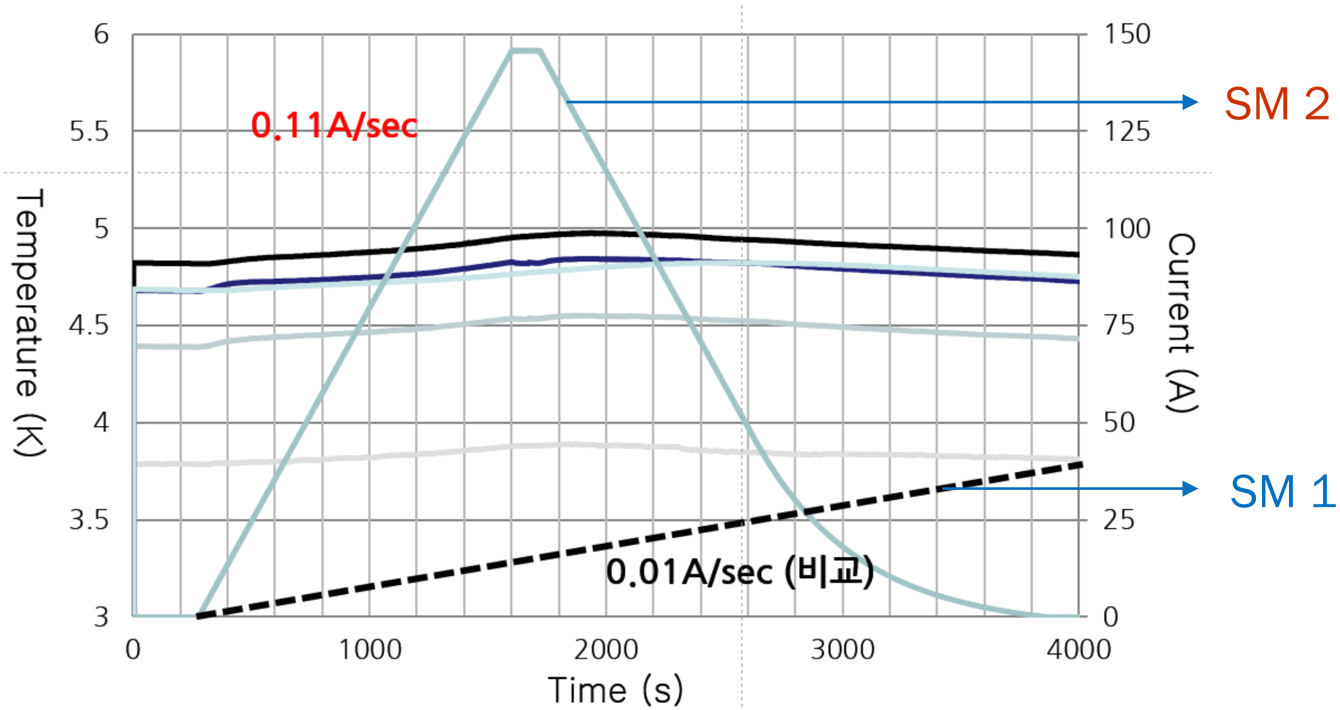
	New (SM II)		Previous (SM I)		Expected Enhancement
Coil bobbin					
Material	[1]SUS304		OFHC Copper		Eddy current loss ≃ 1/3000(220 J → 0.07 J)
Superconducting wire					
Superconductor	NbTi		NbTi		
Wire diameter	∅ 0.8 (mm)		1.2×0.75 (mm)		Hysteresis loss≃1/10 110 J → 11 J
Filament	▪ Diameter=10.4 (μm) ▪ [2]Number of filament=1740 ▪ Twist pitch=18 (mm)		▪ Diameter≃100 (μm) ▪ Number of filament= 54 ▪ Twist pitch=42 (mm)		
Matrix	Oxygen Free Copper		Oxygen Free Copper		Eddy current loss≃1/4 125 mJ → 31 mJ
Cu to SC ratio	[3]2.4		1.3		
Minimum RRR	100		70		
Min. Ic at 4.2 K	Ic at 5 T	420 (A)	Ic at 7 T	510 (A)	
	Ic at 6 T	330 (A)	Ic at 8 T	362 (A)	
	Ic at 7 T	250 (A)	Ic at 9 T	230 (A)	

Coil Excitation Results



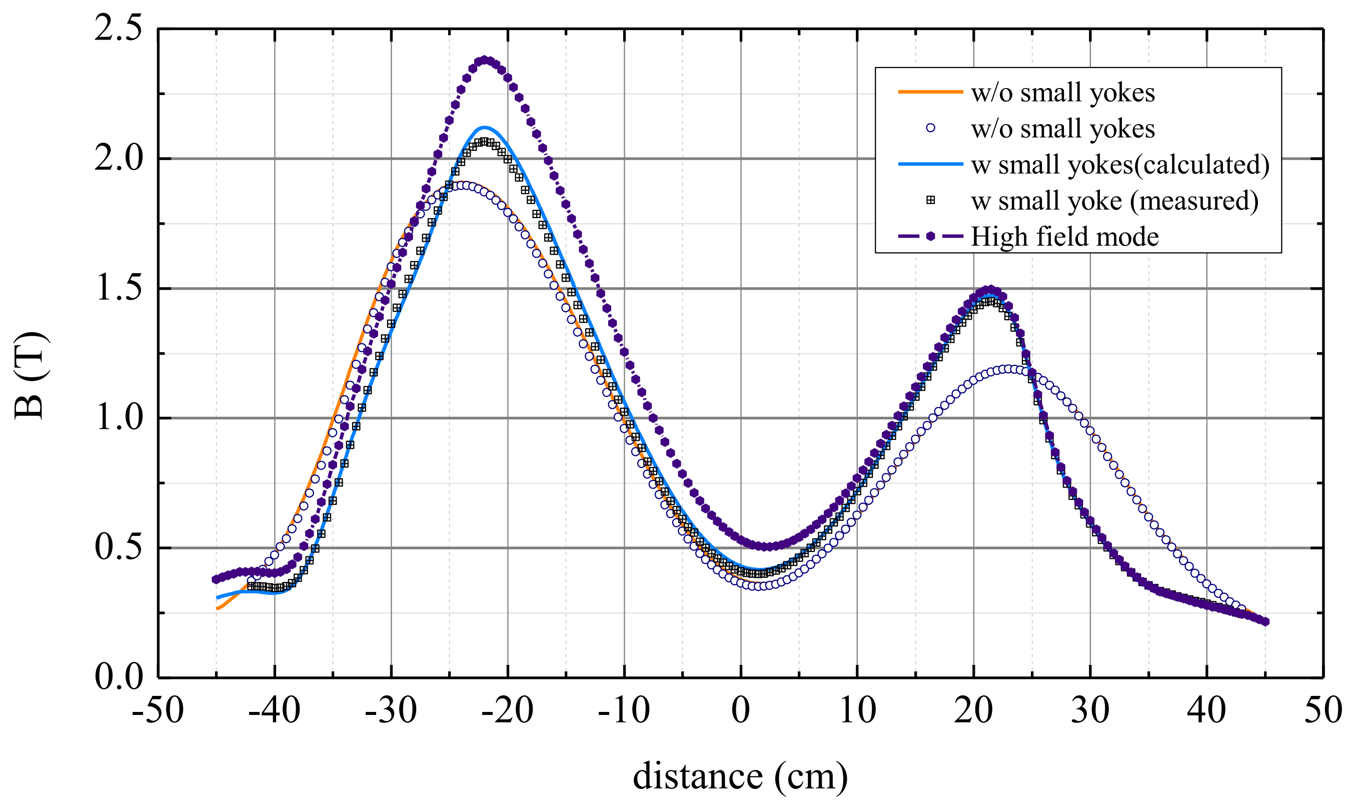
Test results of excitation/de-excitation speed (10 times higher)

Coil Excitation Results



Test results of excitation/de-excitation speed (10 times higher)

Magnetic field obtained

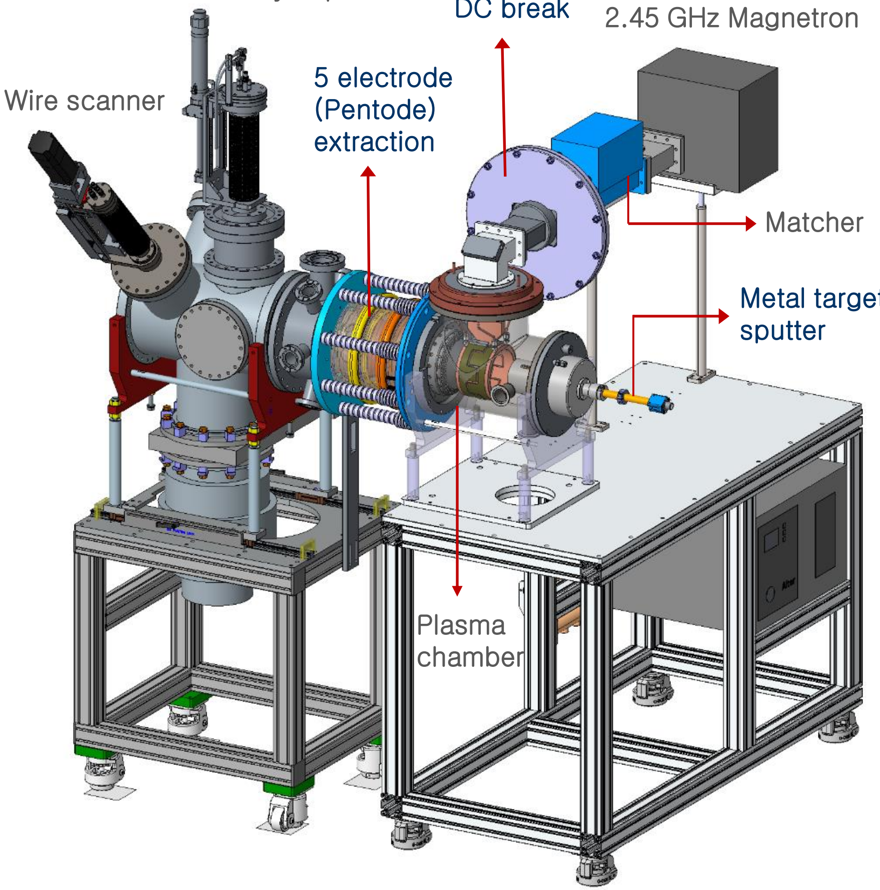


B-field profiles from the new fast ramping SC magnet II

MeLA ion source

MeLA ion source

» **MeLA** (Magnet-embedded Lisitano Antenna): High Current Metal Ion Source



High current metal ion source

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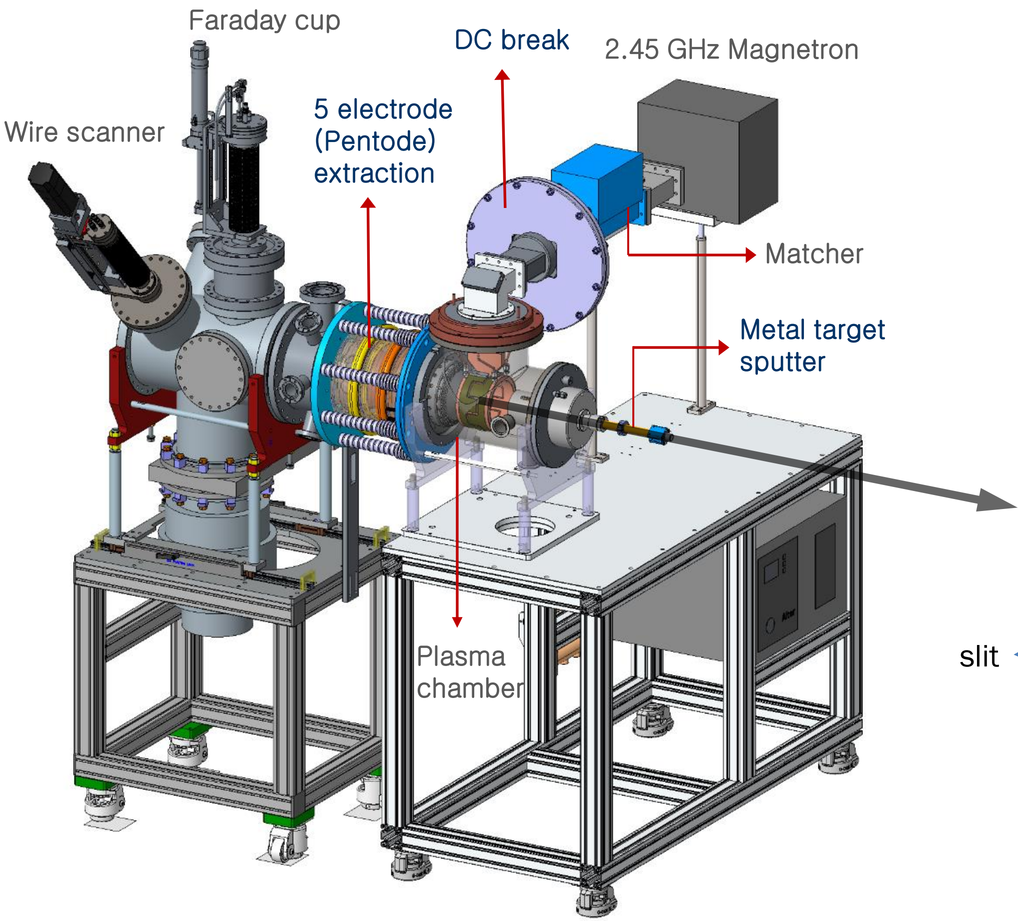
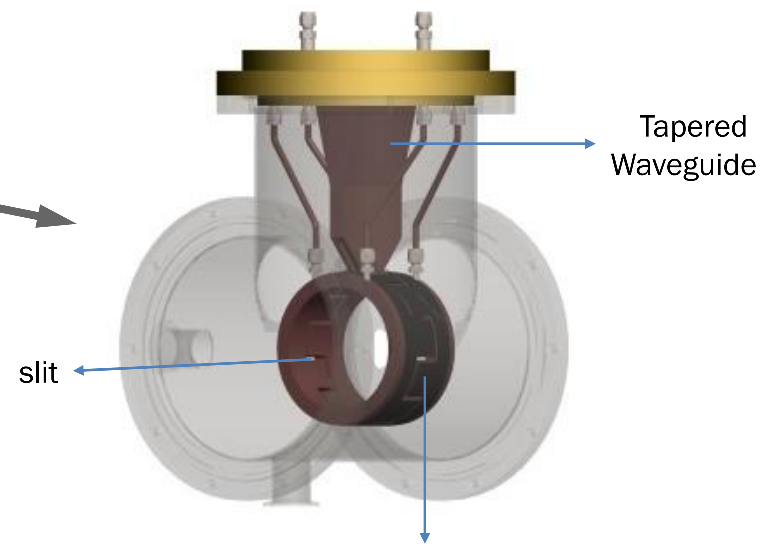


High current metal ion source

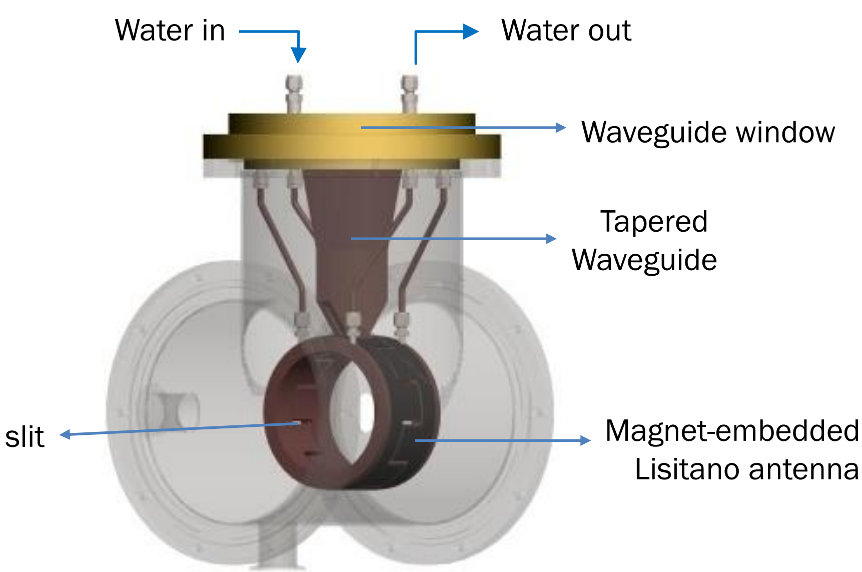
Magnet-embedded & WG directly-coupled
Lisitano Antenna

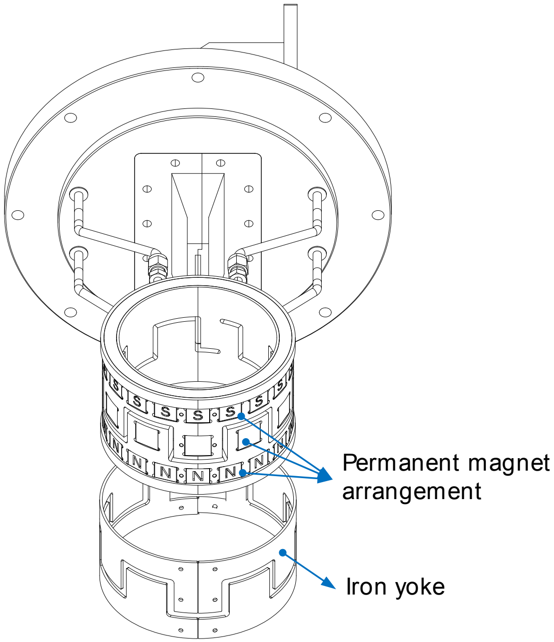


Magnet-embedded Lisitano antenna

Antenna

Magnet-embedded & WG directly-coupled Lisitano Antenna





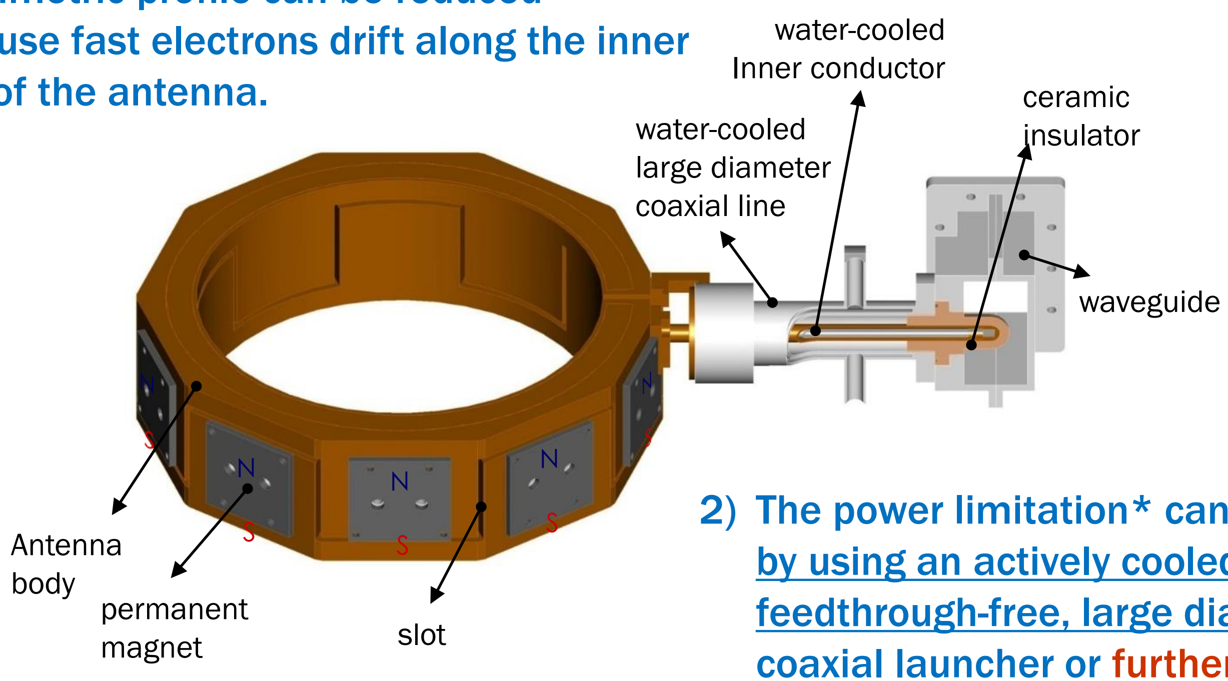
- Antenna diameter=Φ118 mm
- Number of slits= 11

- Number of magnets= 18 at Up/Down & 11 at Middle

Where is MeLA from? (1)

» MeLA was actually developed for a new plasma source by our team

1) By using the proper magnet arrangement, Asymmetric profile can be reduced because fast electrons drift along the inner wall of the antenna.



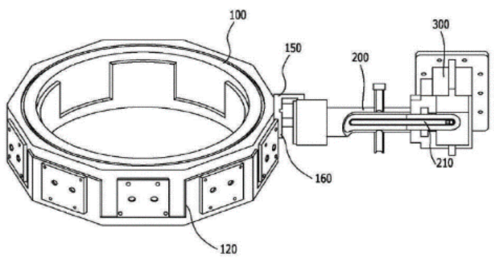
2) The power limitation* can be solved by using an actively cooled, feedthrough-free, large diameter coaxial launcher or further waveguide direct coupling.

* Conventional Lisitan antenna has a limitation of power launching capability (< 1 kW),

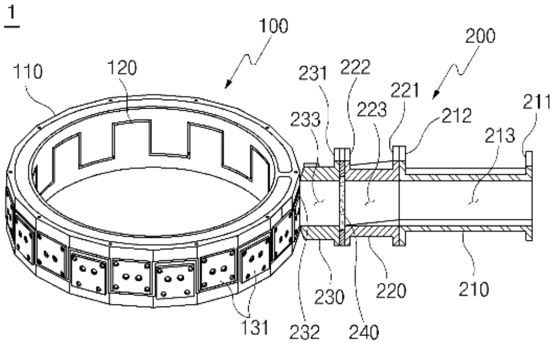
Where is MeLA from? (2)

» Two kind of Antenna excitations

(1) Coaxial excitation



(2) Waveguide excitation

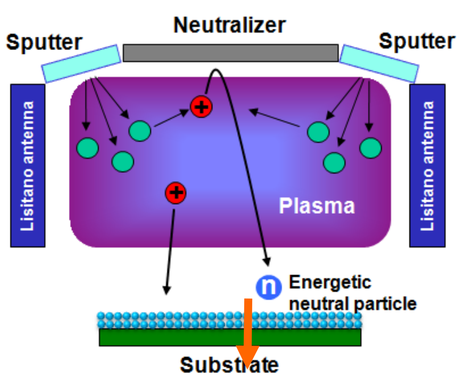


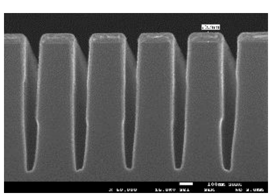
† H. J. You, Y. H. Jung, S. W. Jang, and B. J. Lee "*Permanent magnet embedded Lisitano-coil driven antenna for large-area uniform plasma generation*" Patent 10-2009-78248 31 August 2009.

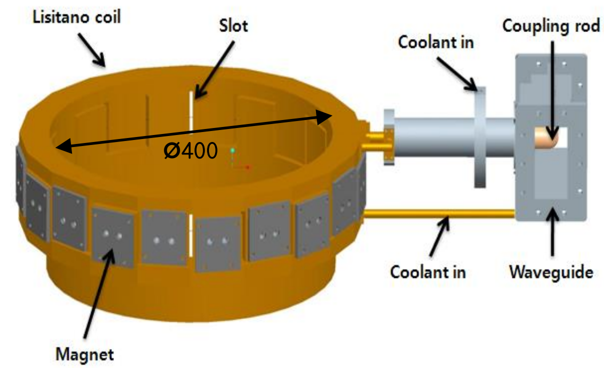
Where is MeLA from? (3)

» MeLA has been used for a plasma processing

ex) Copper barrier/seed Layer)








PECVD


Metal(Cu, Ta, Al) Deposition


Ion Implantation

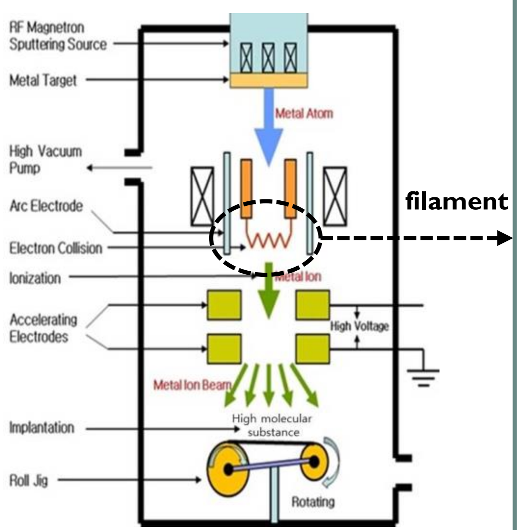

Ashing

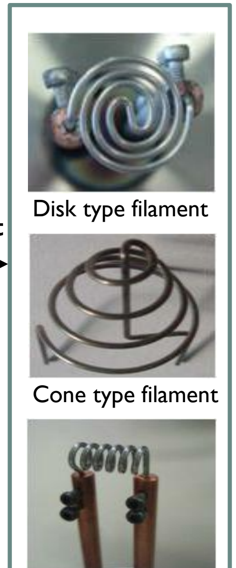

Etching

MeLA as a metal ion source

» MeLA's competitiveness as an metal ion source

Usual method: filament type(<10 μA)



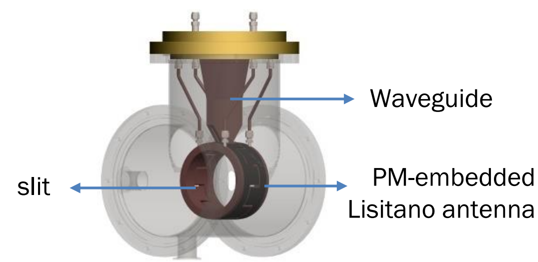

Disk type filament
Cone type filament
Spiral type filament

Demerits

- Short life (~100 hours)
- Difficulty to generate various metal ions
- Low plasma density (Beam intensity <10 μA)

New method: MeLA ion source(>1 mA)

Magnet-embedded & WG directly-coupled Lisitano Antenna

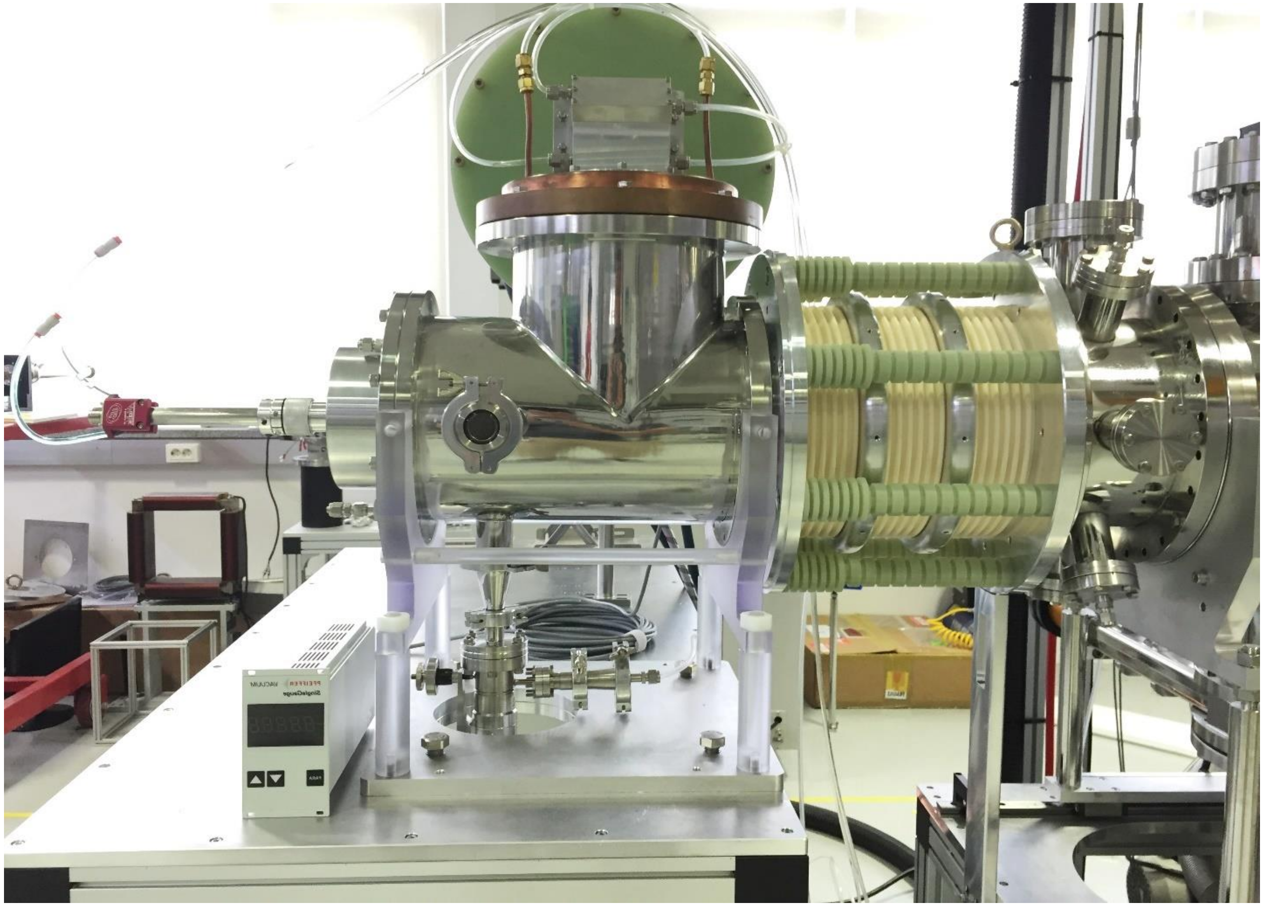


Advantages of MeLA ion source

- **Longer life & various metal ions**
  ∵ metal antenna better for metal ion beam
- **High density (10^{12} cm^{-3})→ 10 mA**
- **Low operating pressure < 1 mTorr**
- **Scalable (small to big size: 10 cm<1 M)**

MeLA ion source at NFRI

» **MeLA** for High Current Metal Ion Source



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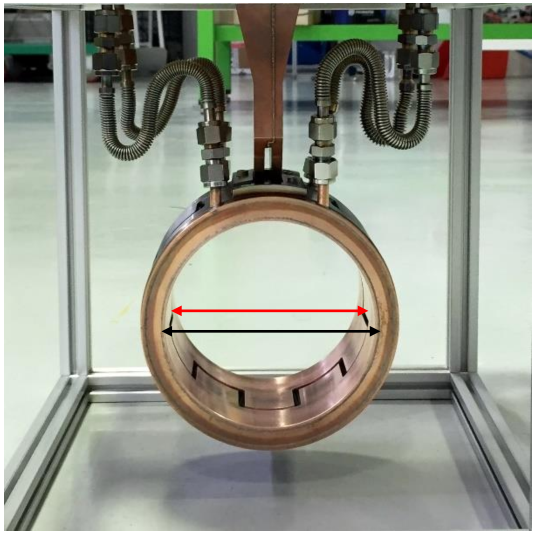
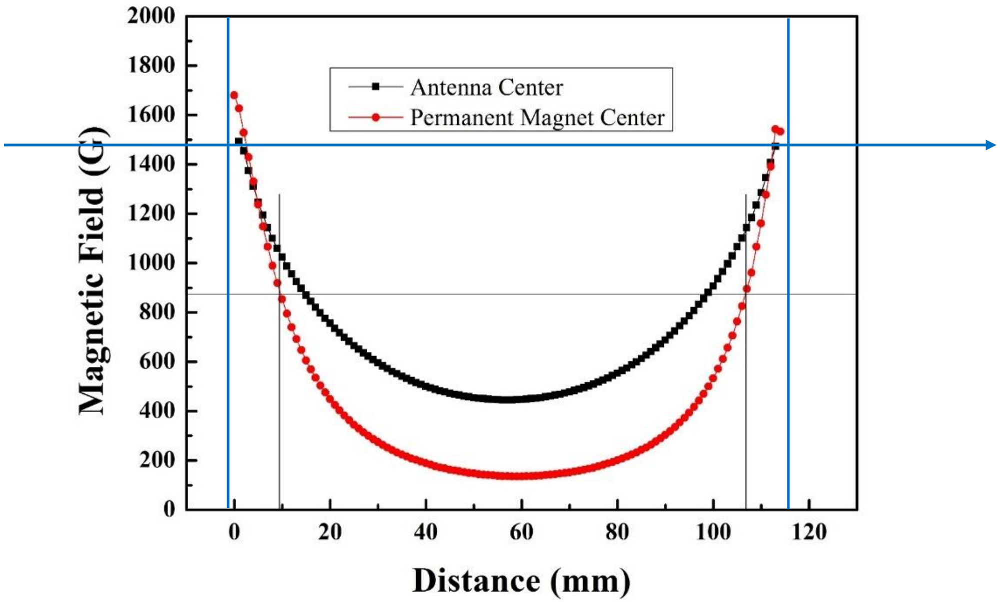
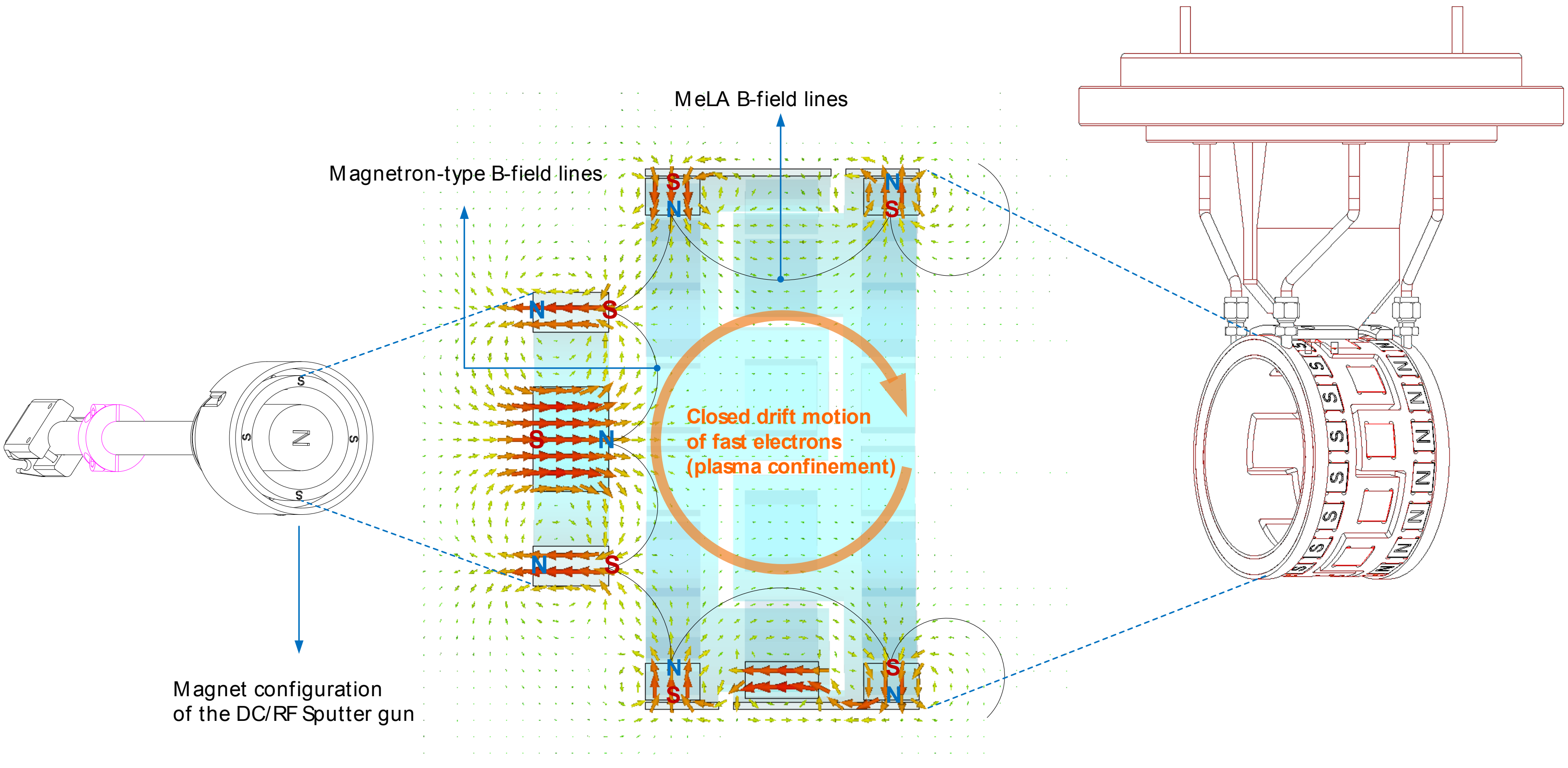
Magnetic field measurement





Combination of MeLA & Sputter B-field



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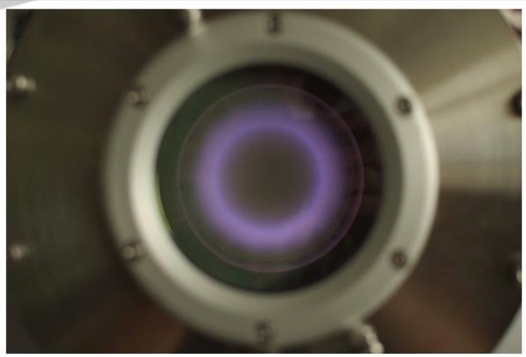
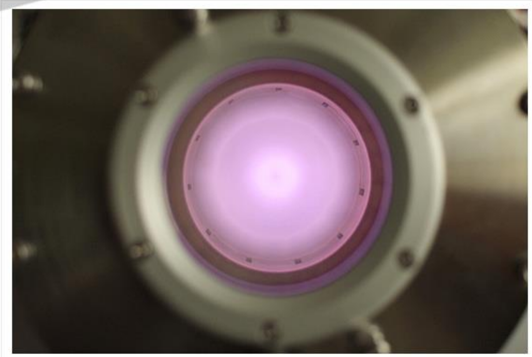
First Plasma We Get

First Plasma Generation

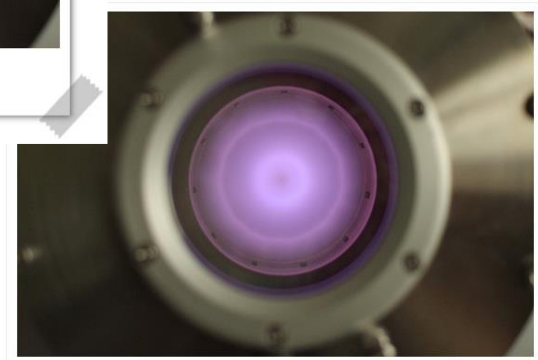
» Generated plasma for argon gas



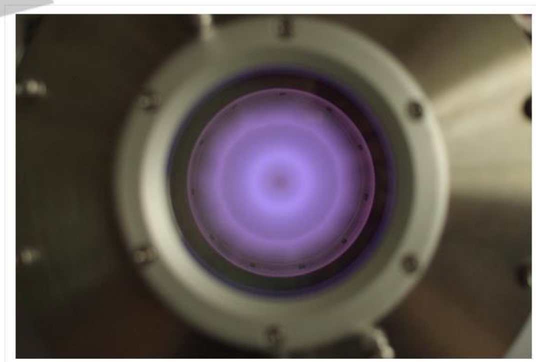
1 kW, 2×10^{-4} Torr



2 kW, 8×10^{-4} Torr



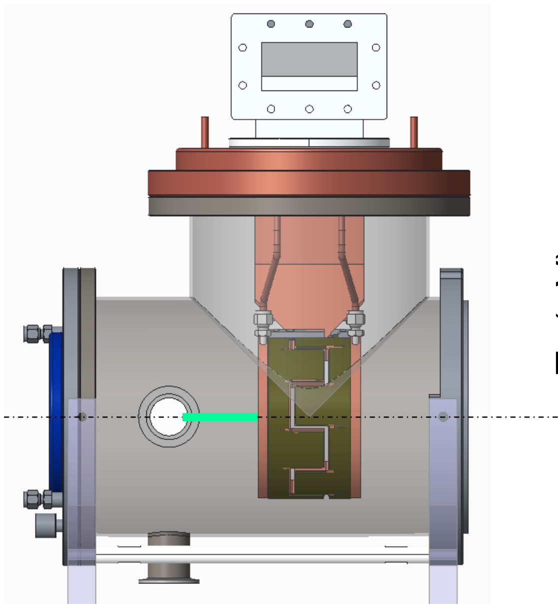
2 kW, 4×10^{-4} Torr

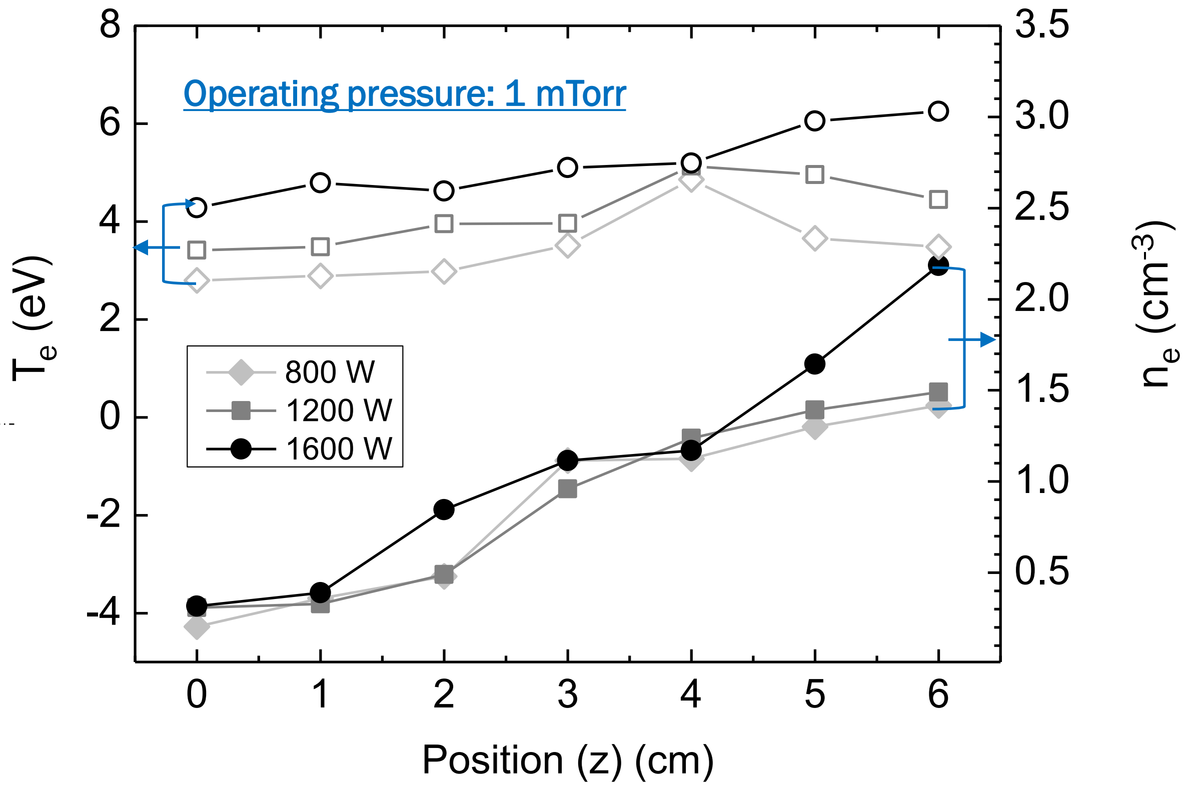


2 kW, 2×10^{-4} Torr

Measured plasma parameters

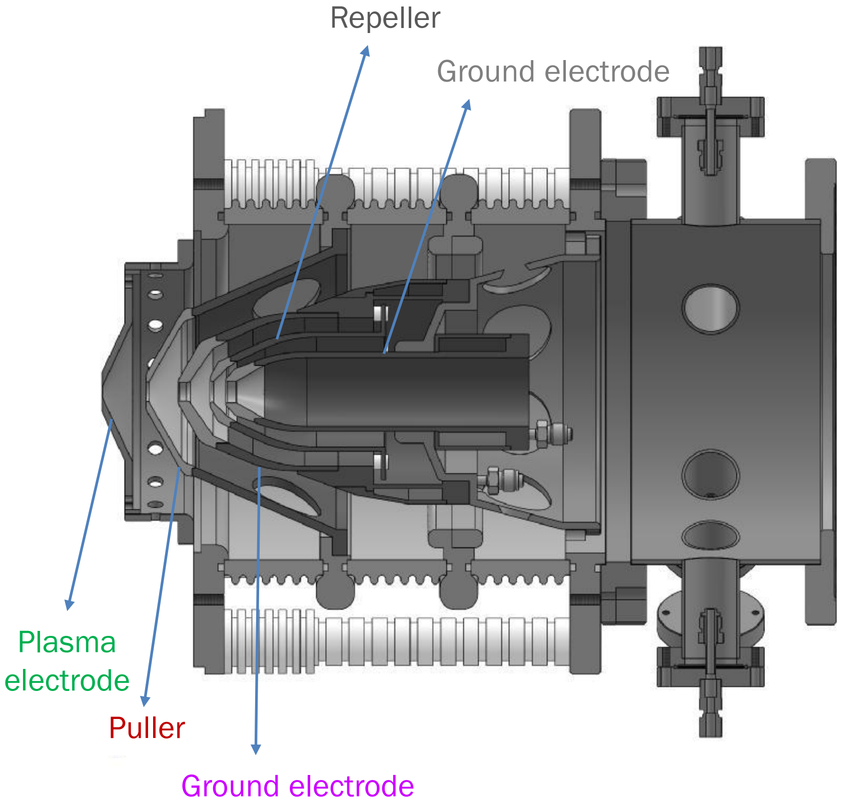
» **Plasma densities & temperatures** along the antenna axis for argon plasma





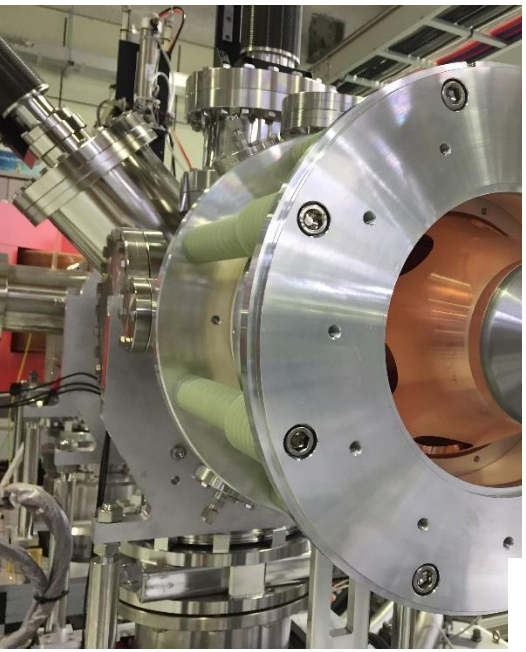
See the poster WEPP17
for more information & results

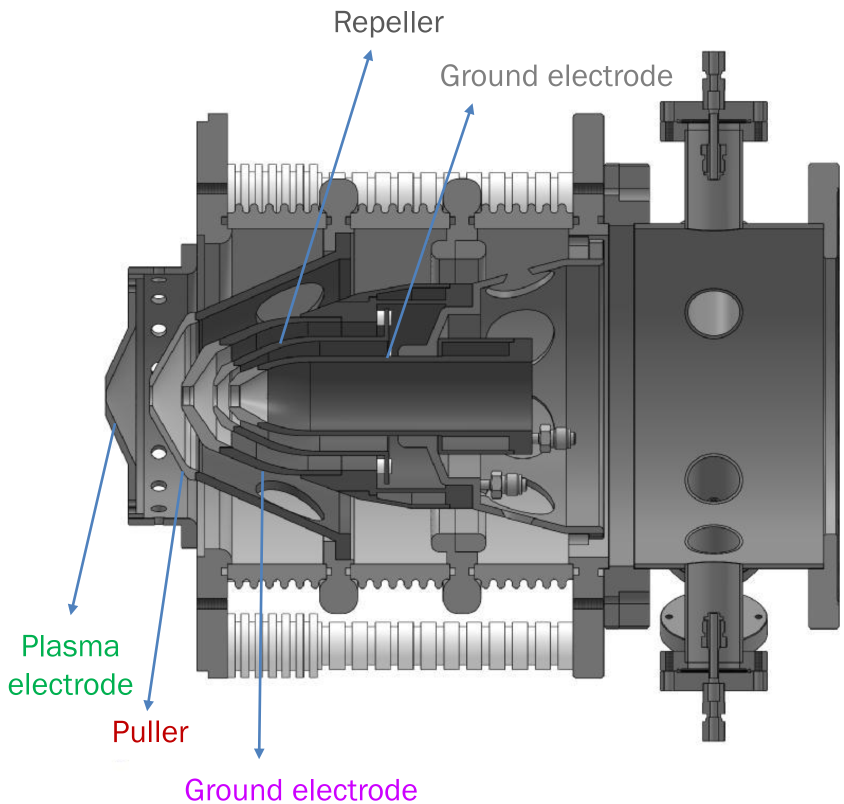
Pentode Extraction Structure



Pentode (5-electrode) extraction *(based on the extraction structure of Saclay/CEA source)*
Plasma electrode (100 kV), Puller (50 kV), Ground electrode 1 (0 kV), Repeller electrode (<-3 kV), Ground electrode 2 (0 kV)

Pentode Extraction Structure





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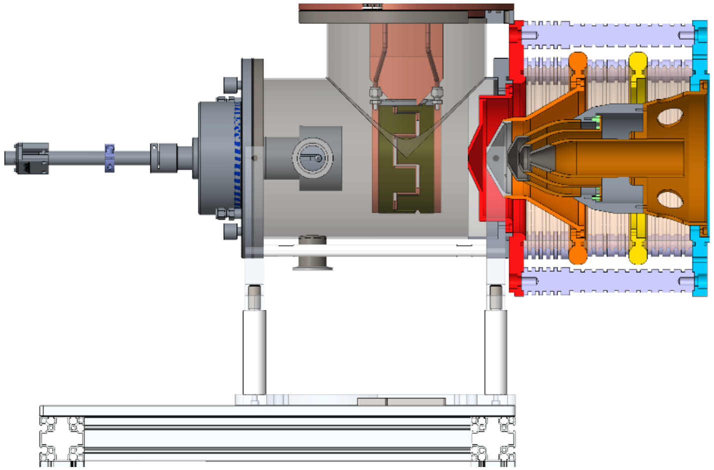
Summarized Features of MeLA



Summarized Features of MeLA

» **Easily-coupled ECR plasma→ High current ion source**

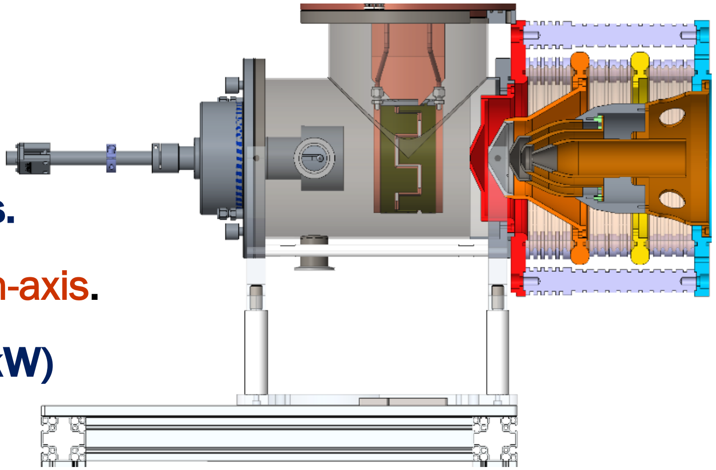
» **Free scalability of ion source size (antenna)**

» **Side-excitation by a Metal antenna**

→ Capability to generate **diverse gas to metal ions.**

→ Metal ion production by locating metal target on-axis.

» **Waveguide directly-coupled (power capability >2 kW)**



» **Permanent magnet-embedded antenna**

→No electric power & water cooling for magnet; so, No high-voltage platform

» **5-electrode (pentode) extraction geometry** (100 kV) for high current space charge-compensated beam & low beam emittances (High brightness)

» Low operating pressure < 1 mTorr (small gas/metal usage)

Commissioning schedule

Commissioning schedule

» **More plasma study:** Sep./2016

1) Plasma characterization by diagnostics (optimization of sputter position)
2) plasma density at extraction region plasma electrode position)

» **Extraction system commissioning:** Nov./2016

1) Optimum extraction field with plasma condition
2) All power supplies are ready to be used.
3) High-power FC, BPM are ready, & Emittance scanner is in fabrication.

» **First beam results are expected in Dec./2016**

고맙습니다
(Thank you so much)