2022 KNS Spring Meeting (2022.05.19 Jeju)

KAERI divertor plasma simulator for studying material damage by D ions & divertor cooling technique

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Acknowledgement: Changmin Shin @ KAIST, Hoongyo Oh @ Postech

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Divertor

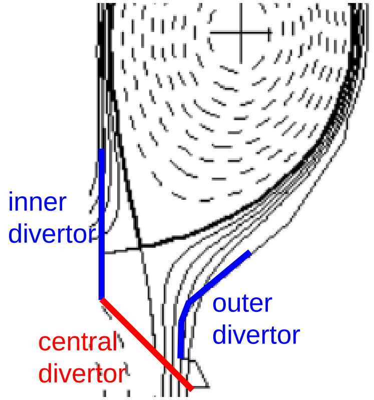
LCFS: Last Closed Flux Surface

- Divertor: device where open magnetic fields outside LCFS pass through in fusion reactor
- Role: remove helium ashes & impurities formed by fusion reaction & plasma-wall interactions

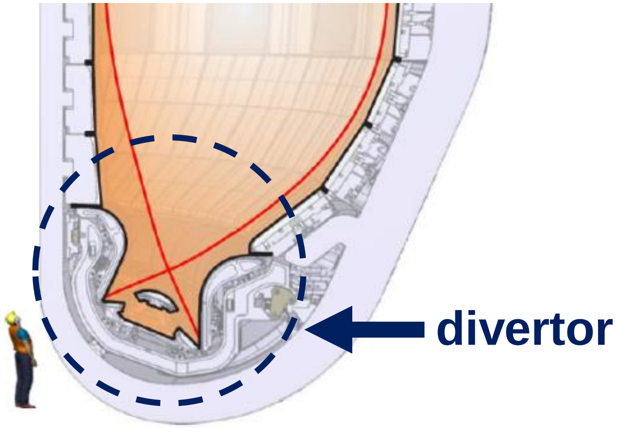
$$D^{+} + T^{+} \rightarrow He^{2+} \text{ (3.5 MeV)} + n \text{ (14.1 MeV)}$$

→ Acts like a “trash bin”

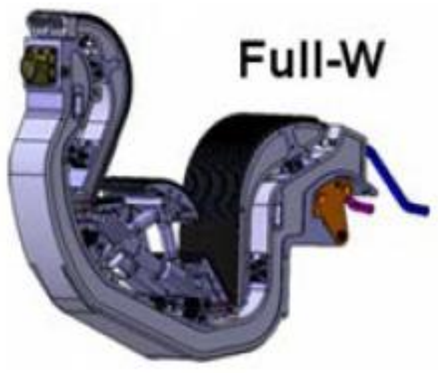
→ High heat and particle fluxes come to divertor target along open magnetic field



KSTAR divertor



ITER divertor



ITER divertor cassette

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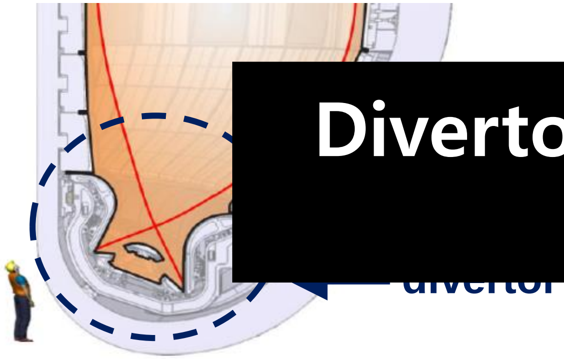
Divertor problem

CHF: Critical Heat Flux

- ITER & DEMO: expected heat flux 10-20 MWm^{-2}; expected particle flux 10^{24} $m^{-2}s^{-1}$
  - ➢ Need to develop divertor system working in extremely high heat/particle/neutron fluxes
- Issues:
  - ➢ Operation scenario to reduce incoming heat & ptl fluxes (e.g. detached divertor)
  - ➢ Advanced divertor concept such as super-X, snowflake, small-angle slot, etc.
  - ➢ Innovative heat sink design to enhance CHF of divertor (swirl tube, hypervapotron tube, …)
  - ➢ Divertor materials and bonding technology for extreme divertor condition

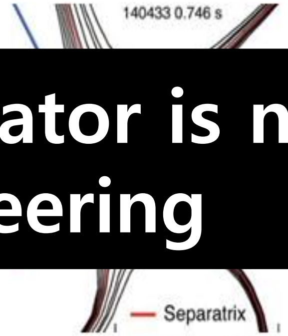


ITER divertor

ITER divertor cassette

Divertor heat & particle flux simulator is necessary to study divertor engineering

super-X



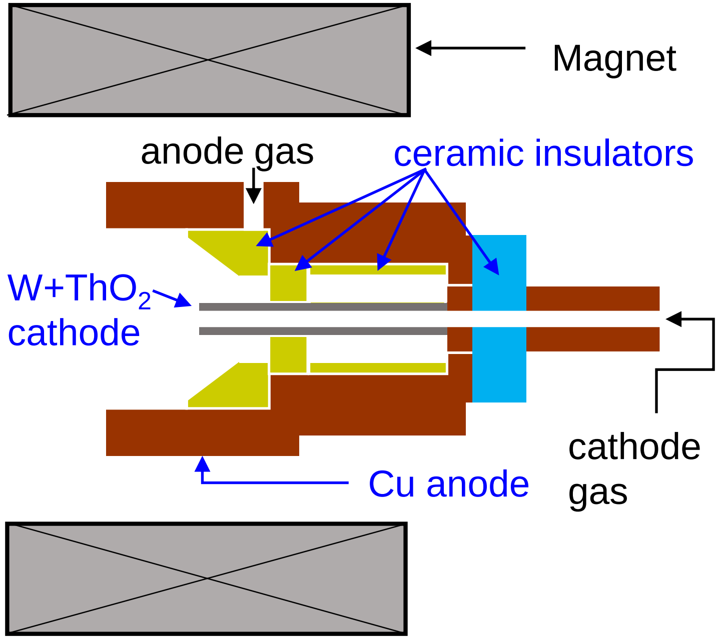
snowflake

Advanced divertor geometry

Heat sink design (swirl tube)

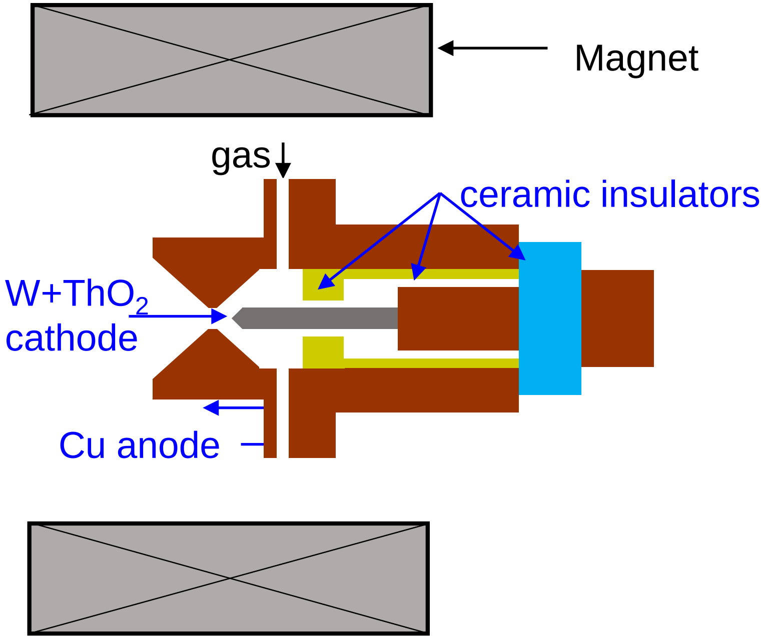
KAERI divertor heat & ptl flux simulator

- Plasma source: Applied-Field MagnetoPlasmaDynamic thruster (AF-MPD thruster)
- Two AF-MPD thrusters have been developed and used:
  - ➢ Open type (type 1): used for heat flux test with Ar/Xe gas
  - ➢ Closed type (type 2): used for particle flux test with H_2/D_2/He gas



[Type 1 (open type) – heat flux test

PPCF **62**, 035007 (2020)



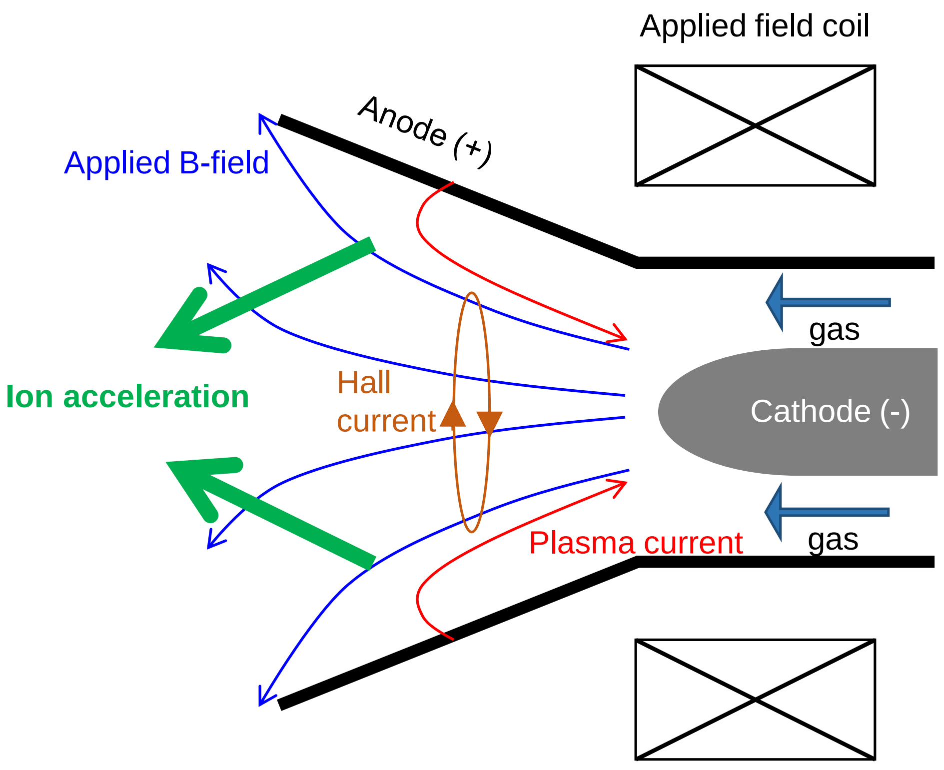
[Type 2 (close type) – ptl flux test]

PPCF **63**, 125020 (2021)

Vacuum chamber volume: 2.64 m^3
Pumping speed: 10,000 l/s (for Ar gas)

Principle of AF-MPD thruster

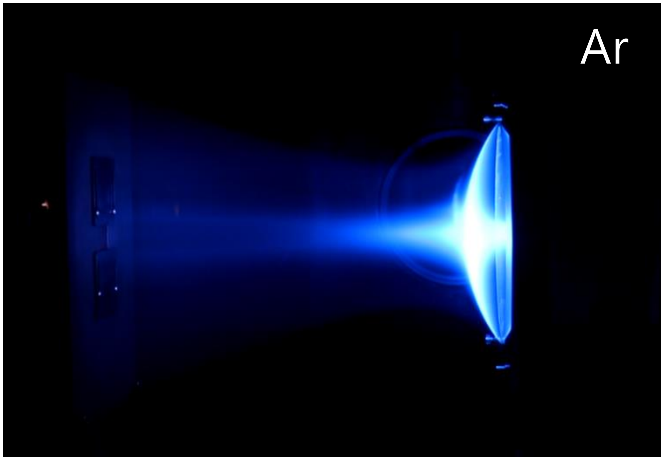
- Plasma is ignited by applying voltage across anode & cathode
- Electrons become magnetized by applied field (ions become weakly magnetized)
- Ions accelerated in the axial direction by magnetized electron-induced E-field (magnetic nozzle effect)
- Ions are additionally accelerated by swirl motion and hall current

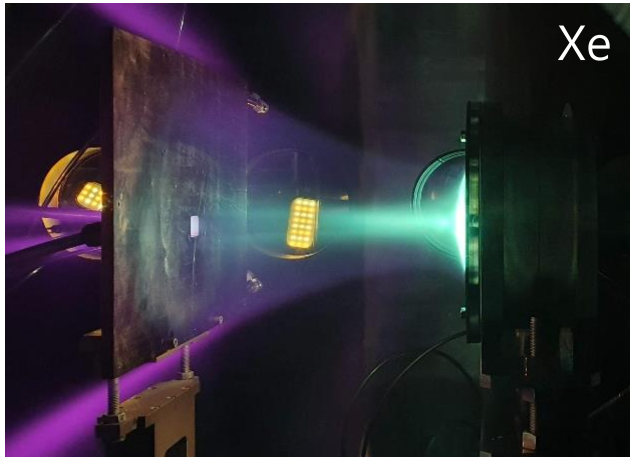


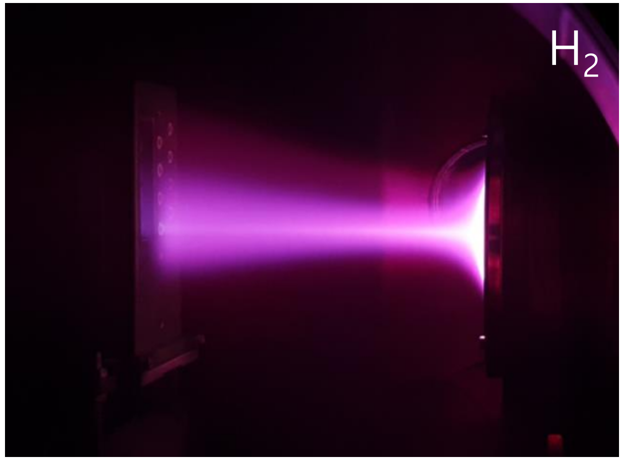
A.D. Kodys et al. AIAA-2005-4247

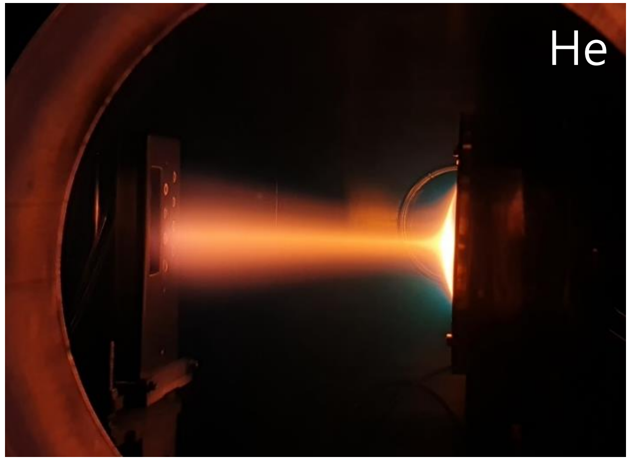
Plasma ignition

- Successfully ignited plasmas with Ar, Xe, H_2, D_2, He gases
- Ar, Xe plasmas obtained using type 1 source; H_2, D_2, He plasmas obtained using type 2 source
- Breakdown voltage: 600 V
- Operation pressure: (0.6 – 1) x 10^{-3} Torr



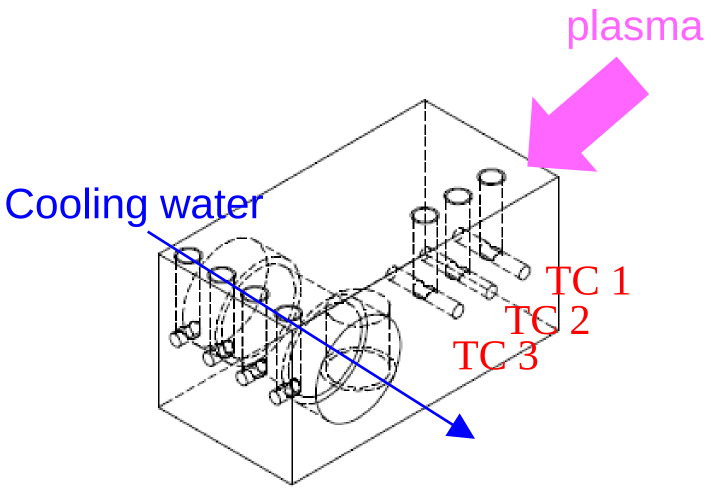


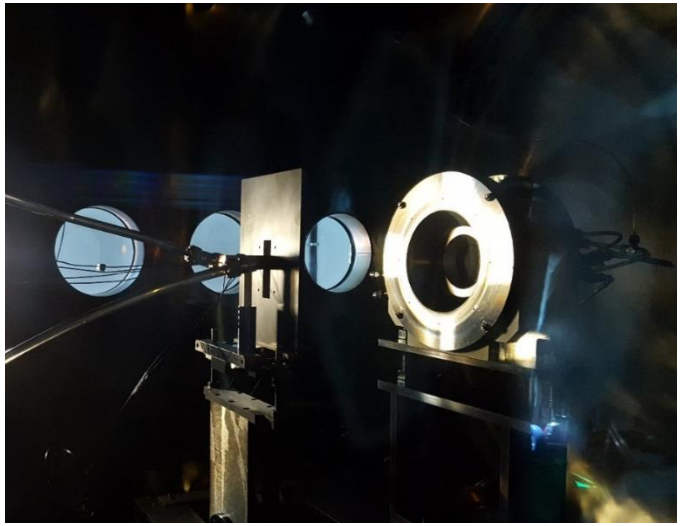


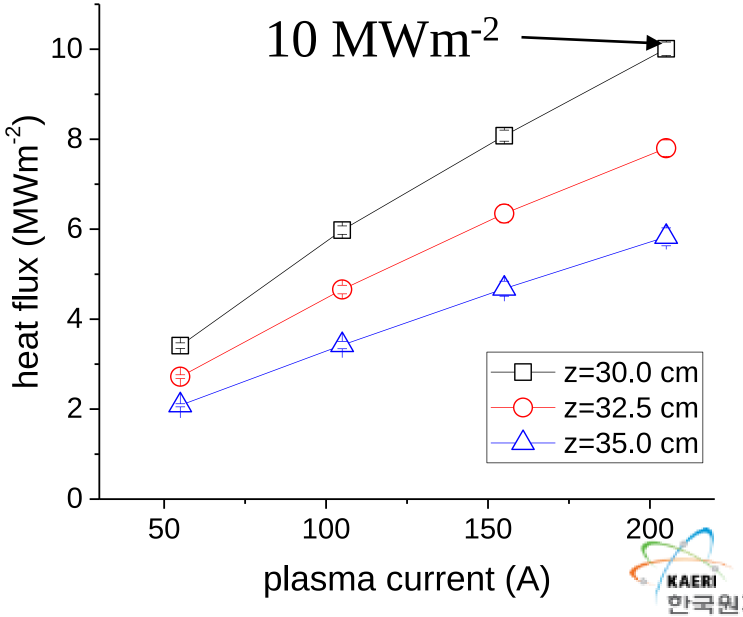


Heat flux measurement

- Developed and installed custom-made heat flux sensor
- Heat flux was measured by two different methods
  - Calorimetry equation: $Q = cm\Delta T$,
  - Heat conduction equation: $dQ/dt = \kappa A(\Delta T/\Delta x)$
- Successfully achieved heat flux of 10 MWm^{-2} with I_p = 200 A at z = 30 cm (area: 2×2 cm^2)



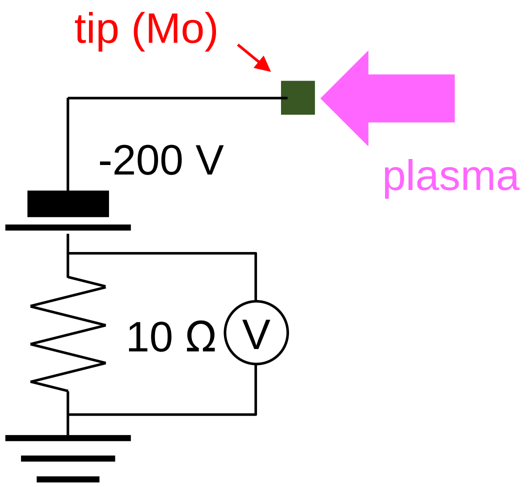


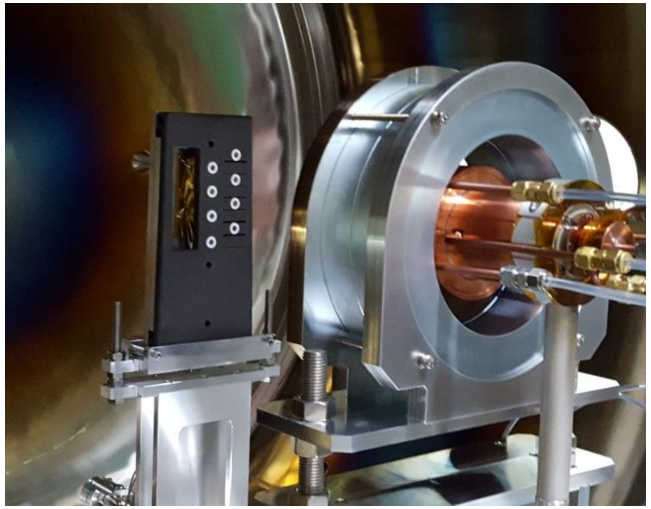


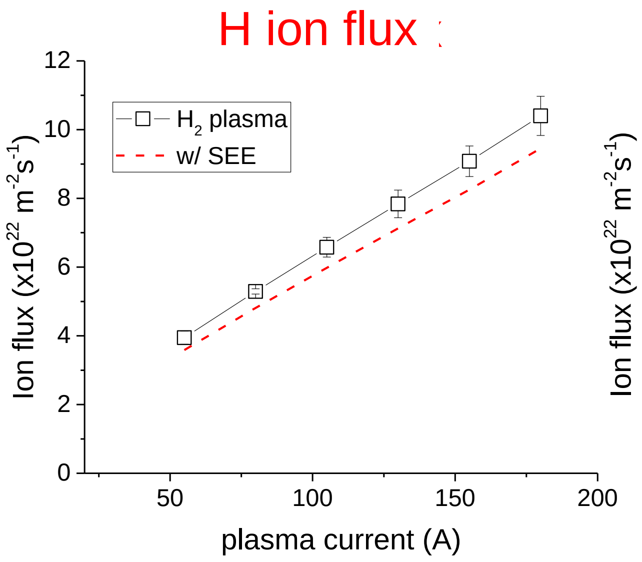
* z: distance between plasma source and target

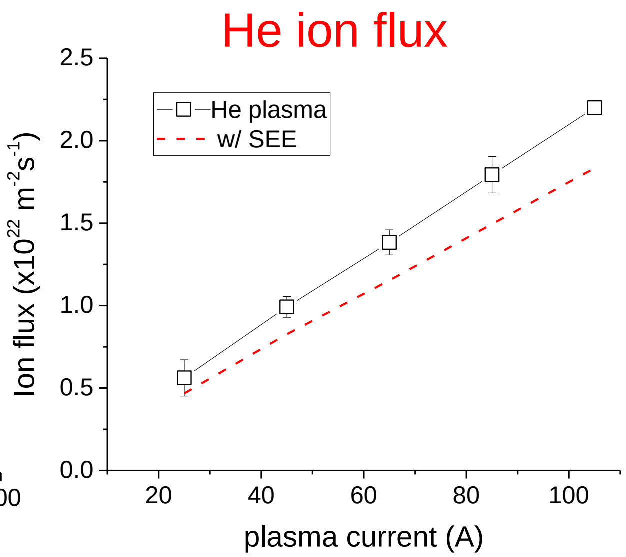
Particle (ion) flux measurement

- Ion flux was measured by Langmuir probe
- Ion flux (Γ_i) was obtained from $\Gamma_i = I_{is}/eA_p$ (A_p: tip area) by measuring ion saturation current (I_{is})
  - ➢ Hydrogen ion flux: 1×10^{23} $m^{-2}s^{-1}$ with I_p = 180 A
  - ➢ Helium ion flux : 2×10^{22} $m^{-2}s^{-1}$ with I_p = 105 A









*SEE: secondary electron emission

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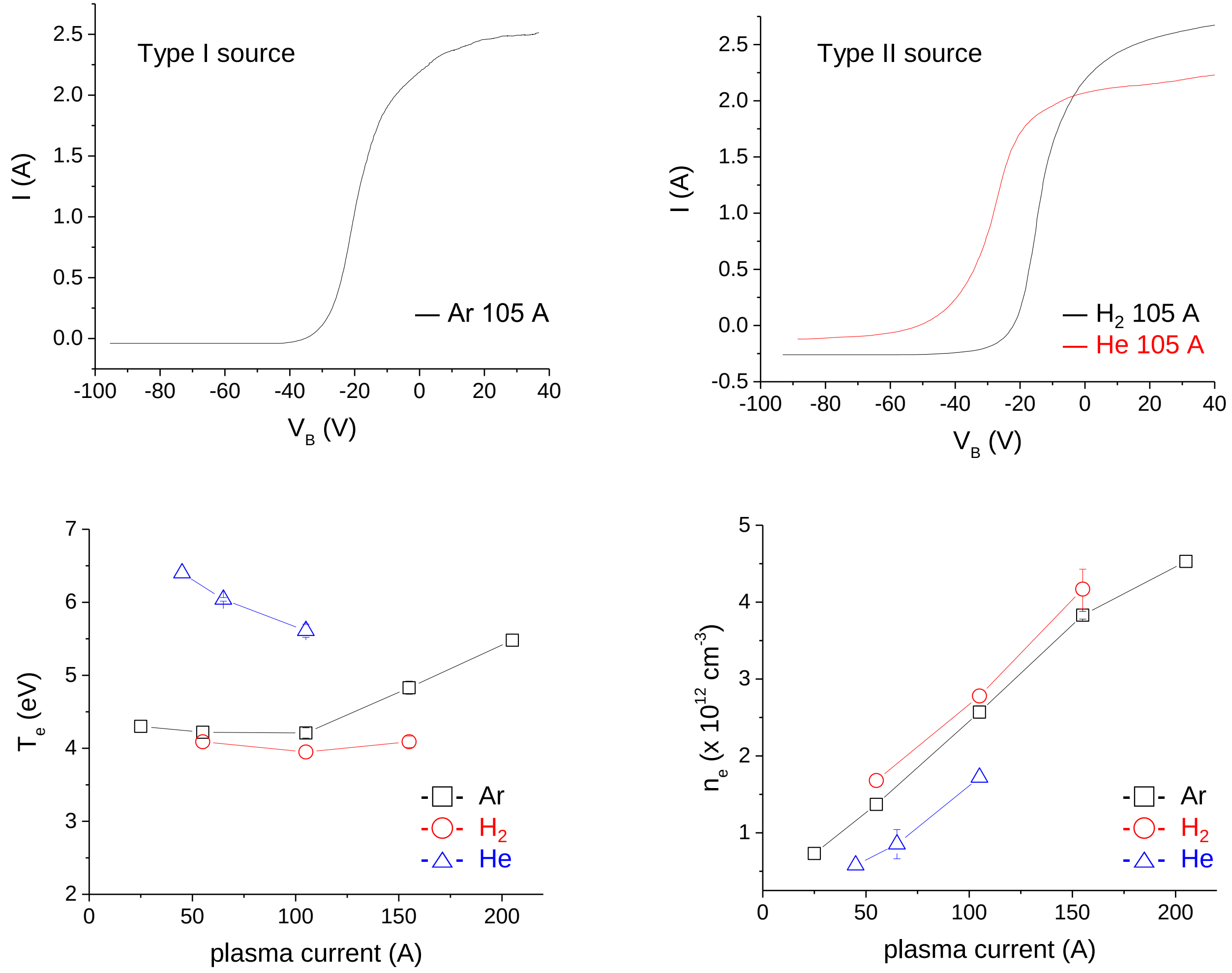
T_e & n_e measurement



- T_e and n_e of plasma plume were measured using Langmuir probe
- T_e:
  - ➢ Ar plasma: 4–5 eV
  - ➢ H_2 plasma: ~ 4 eV
  - ➢ He plasma: ~ 6 eV
- n_e:
  - ➢ Ar, H_2 plasma: $(1–4)\times10^{12}$ cm^{-3}
  - ➢ He plasma: $(1–2)\times10^{12}$ cm^{-3}

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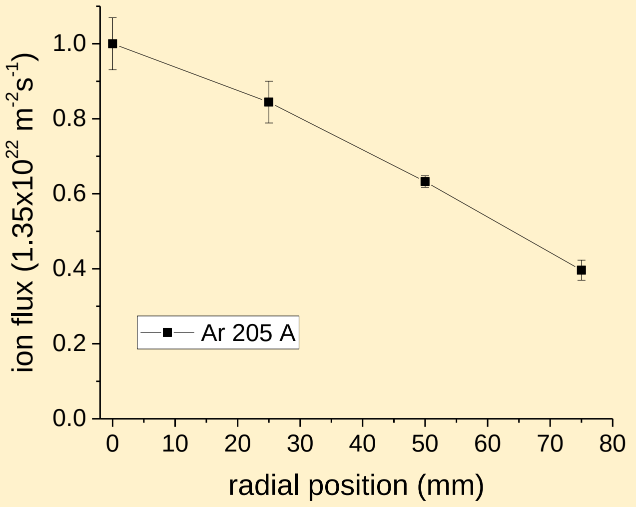
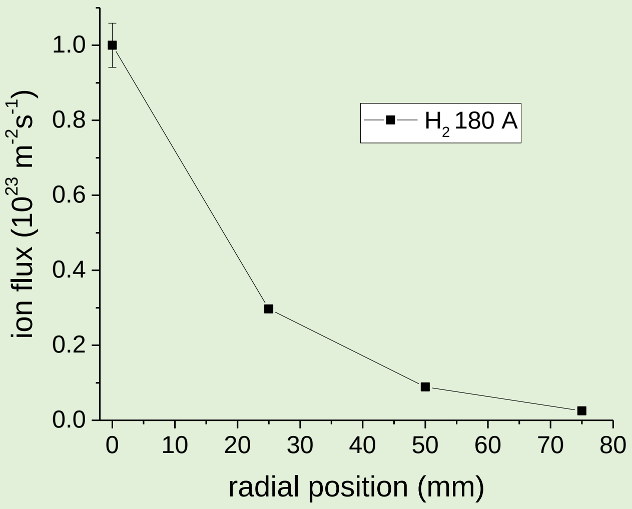
Plasma beam profile

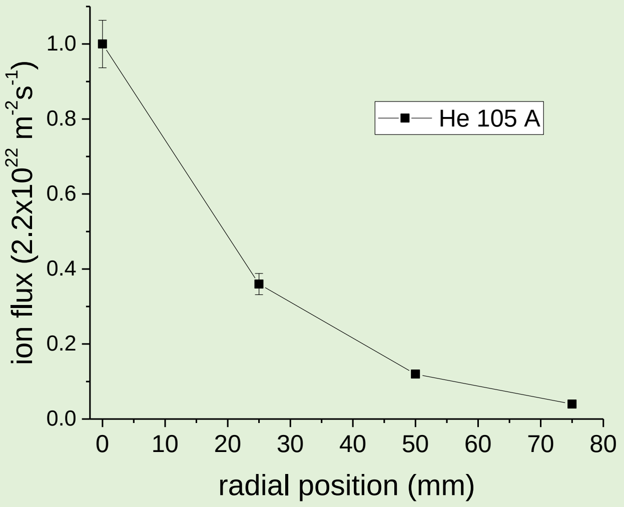
- Spatial beam profile was measured using Langmuir probe array
- Full Width at Half Maximum (FWHM):
    - Open type (type 1): 120 mm
    - Closed type (type 2): 40 mm

Type I source



Type II source





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PPCF **63**, 125020 (2021)

Contents

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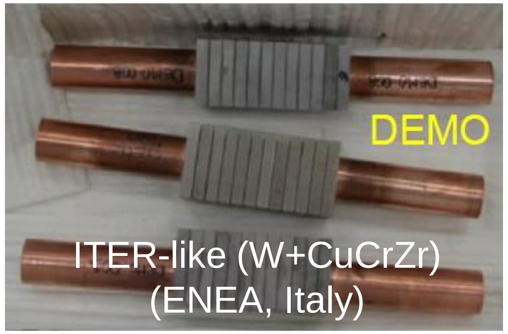
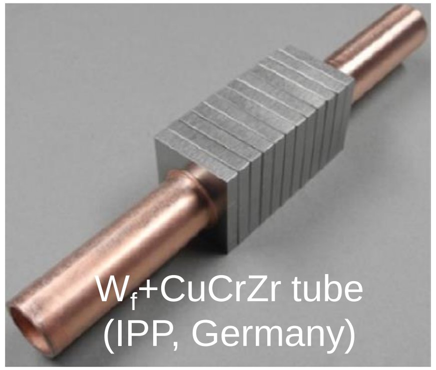
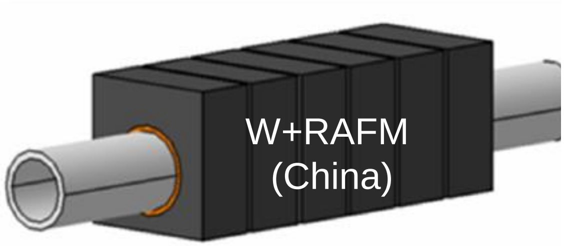
Motivation of tungsten damage Exp.

- Tungsten (W) will be used as armor material for ITER/DEMO divertor
- Issues relevant to divertor armor materials:
  - ➢ Surface damage by H, D, T (blister), & He (nanostructure, fuzz)
  - ➢ Effect of surface damage on material properties
  - ➢ Lifetime of armor materials
- Before addressing above,
  - ➢ Want to check our facility is suitable for studying divertor materials (by building DB for surface damage)

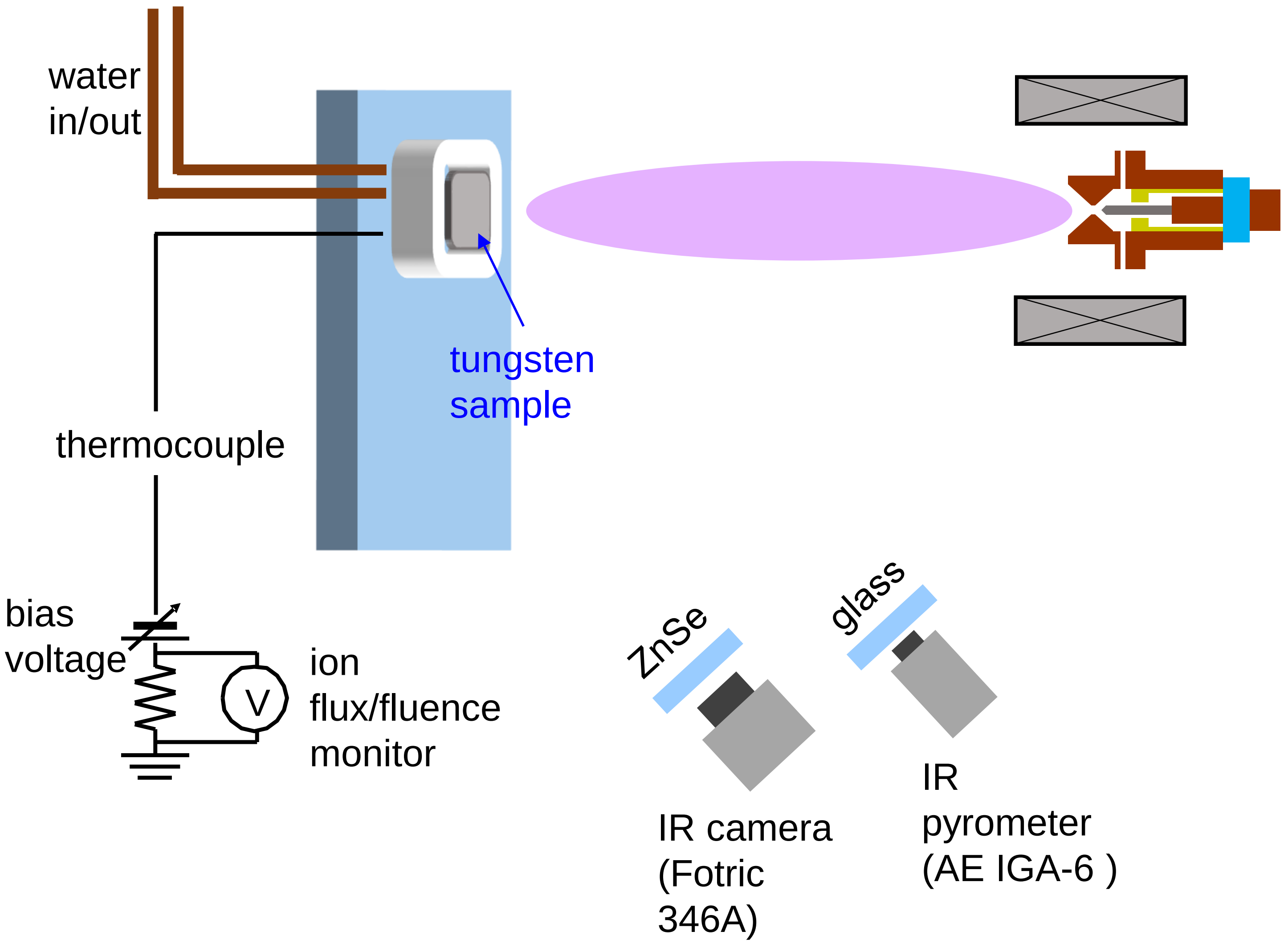




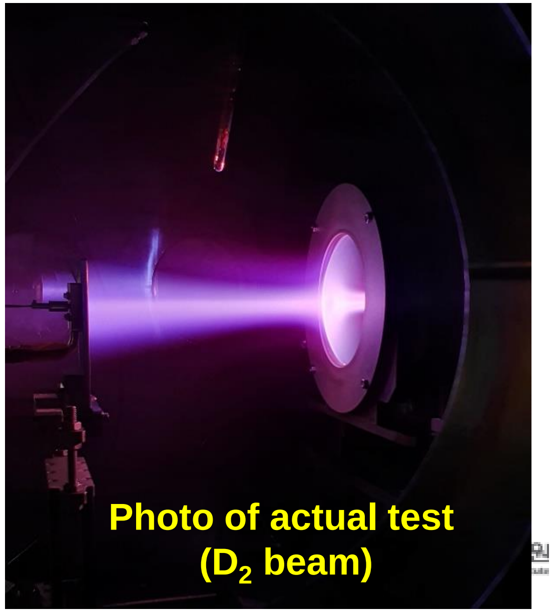


NME **16**, 1(2018)
NF **58**, 066014(2018)

Experimental setup

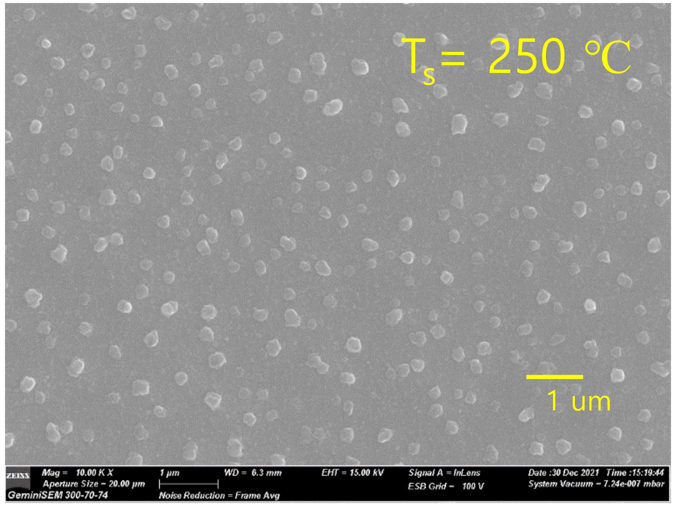


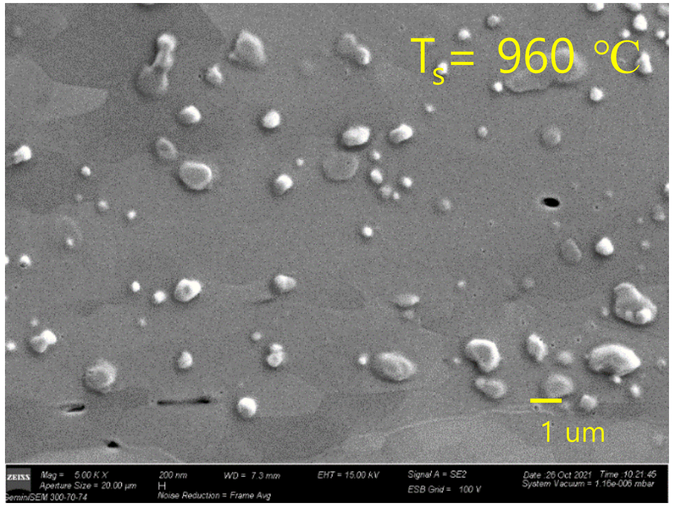
- Target: 5×8 mm^2 W sample
- Ion energy: 30-100 eV
- *In-situ* monitor ion flux & fluence
- IR camera: 2D temp. monitor
- Pyrometer: W surface temp. monitor
- T/C: W bulk temp. monitor



Preliminary results

- Dependence on W bulk temperature (T_s)

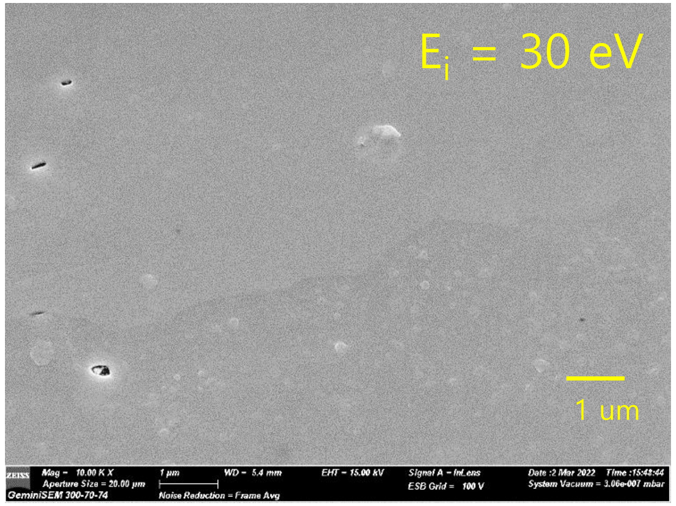


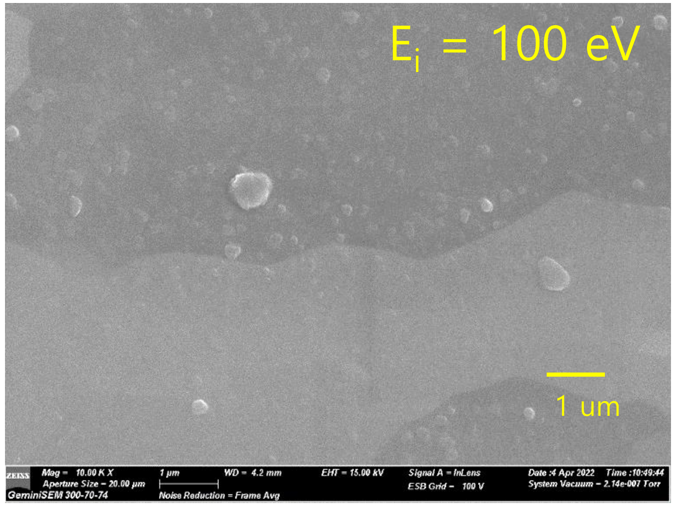


parameters	value
Ion energy	100 eV
Ion total fluence	2.5×10^{25} m^{-2}
Maker	ALMT

→ Size and number density of blisters depend on W temperature

- Dependence on ion incident energy (E_i)



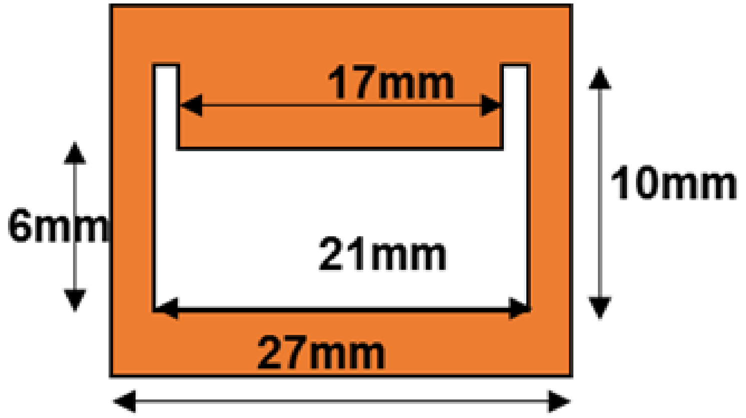


parameters	value
W temp.	100-200 °C
Ion total fluence	3.5×10^{25} m^{-2}
Maker	AT&M

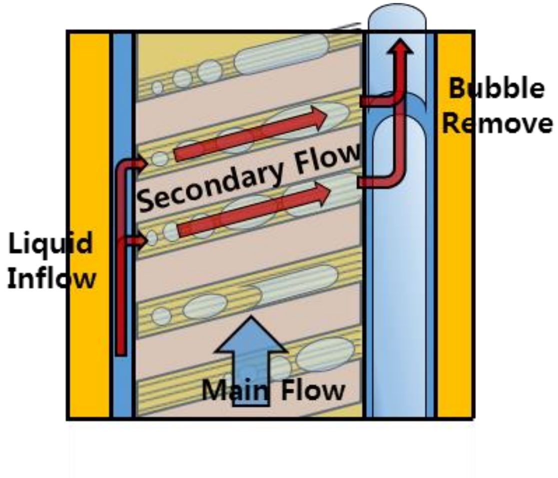
→ Size of blisters is similar between 30-100 eV ion incident energy

Test of Cu HV based W monoblock

- Postech team (Prof. H. Jo's group) developed and optimized Cu hypervapotron (HV)
  → Fin angle (45^o)+ micro-structure
- Then, Postech team bonded W monoblock to Cu HV



Postech's HV
(cross sectional view)



Postech's HV
(top view)

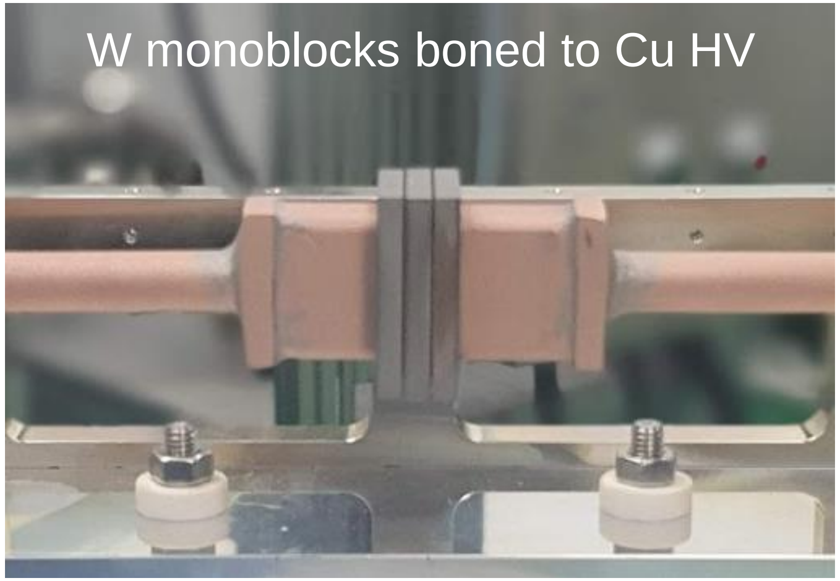
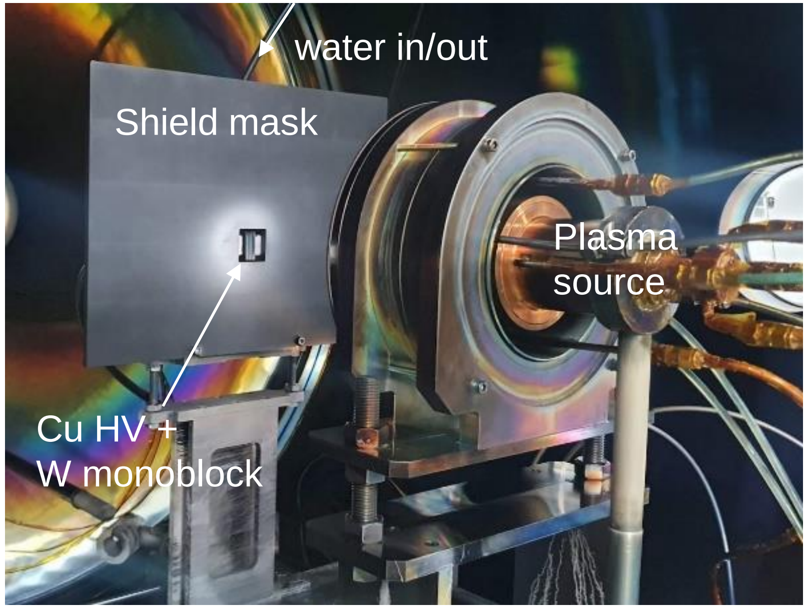
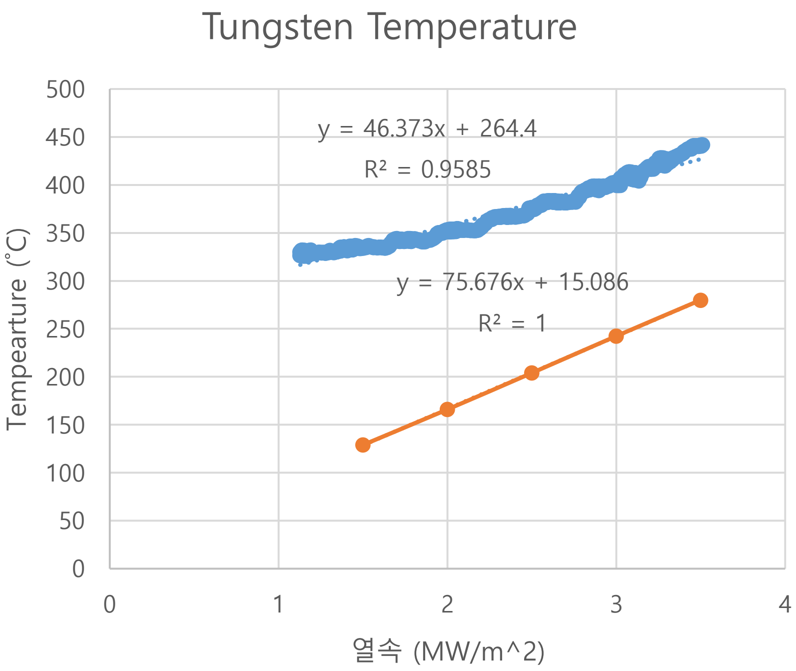


Figure credit: Postech

Heat load test setup and results



Experimental setup for heat load test



- Cu HV + W monoblock was installed in front of plasmas source
- Heat flux between (1–3.5) MWm^{-2} loaded and surface temp. of W measured by pyrometer
- Measured surface temperature > calculated temperature → bad thermal contact (bad bonding)

Summary and future plan

- Successfully developed divertor heat- and particle-flux simulator at KAERI
  - ➢ Heat flux: up to 10 MWm^{-2} (test area: 2×2 cm^2)
  - ➢ H/D Particle flux: up to 10^{23} $m^{-2}s^{-1}$
- Studied tungsten blister formation and performed heat load test for Cu HV + W monoblock
  - ➢ KAERI divertor simulator is more suitable for divertor material study than for heat load test
- Future plan:
  - ➢ Continue to build DB for tungsten blister formation
  - ➢ Study W fuel retention (collaboration with KFE)
  - ➢ Upgrade of our facility (higher particle flux and fluence)
  - ➢ Target upgrade for user service

Thank you for attention