Dynamic Response of Refractory Metal Electrode to ~GW/m² Plasma Heat Load in the Stabilized Arc Discharges

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Introduction

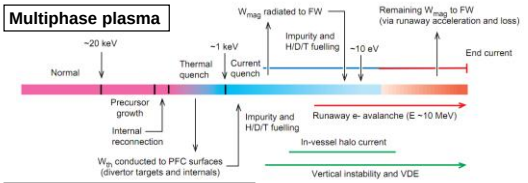
Fusion reactor

I_n Disruptions: ~ GW/m²
ELMs: >100 MW/m²

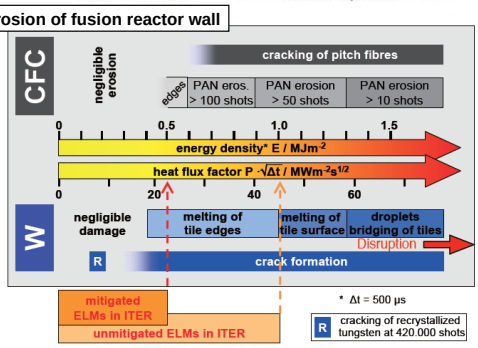
Divertor (plasma-facing components) is exposed to extremely high plasmas heat flux

- Divertor target materials are melted, evaporated and interacted with plasma
- Multiphase plasma (molten target, metal vapor, plasmas) are generated near the target

Multiphase plasma



Erosion of fusion reactor wall



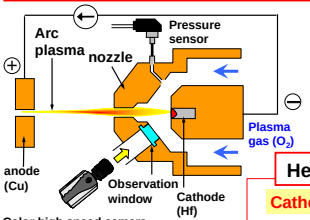
It is essential to study the interaction of high heat flux plasmas of ~GW/m² with refractory metal target

Aim of this study

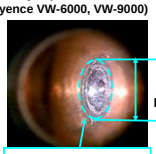
- Observation of the hot cathode spot under high heat flux plasma irradiation using high speed camera
- Dynamic behavior of molten cathode spot surface temperature measurement

Experimental setup

Plasma source (plasma cutting arc torch)



Color high speed camera (Keyence VW-6000, VW-9000)



High speed color camera

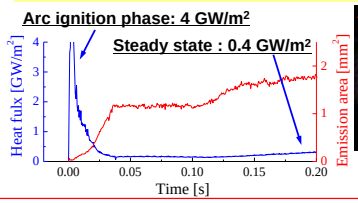
KeyenceVW-6000, VW-9000
Frame rate :4000fps, 23000fps
Resolution :128×120, 256×192 pixel

Experimental condition

Arc current	:30~150 A
Gas flow	:20 slpm
Gas pressure	:0.8 MPa
Nozzle diameter	:1.3 mm

Heat flux of plasma cutting arc torch

Cathode is exposed to dynamic high heat flux plasmas

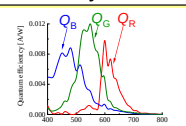


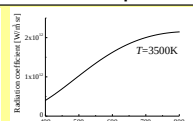
Observation of cathode spot

Experimental results

Analysis of cathode surface condition

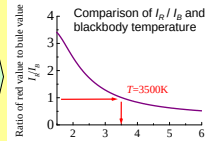
How to analysis of cathode surface temperature



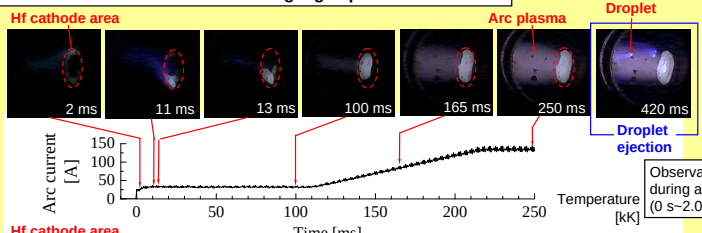


Red intensity $I_R = \int_{400}^{800} B_\nu(T) Q_R d\lambda$

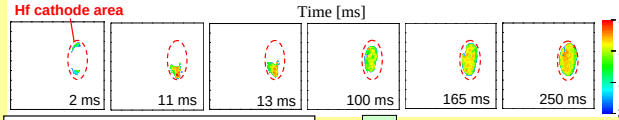
Blue intensity $I_B = \int_{400}^{800} B_\nu(T) Q_B d\lambda$



Observation of cathode surface using high speed color camera

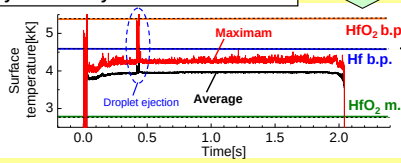


Observation of cathode during arc discharge (0 s~2.04 s)



Analysis of cathode surface temperature distribution

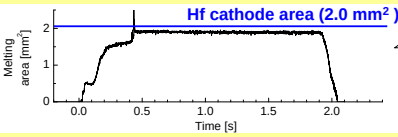
Dynamic analysis of cathode surface



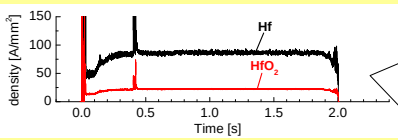
- Cathode surface temperature :3500 K~4300 K

⇒Cathode surface material is melted

Property of cathode material	Hf	HfO_2
Melting temperature [K]	2230	2812
Boiling temperature [K]	4600	5400

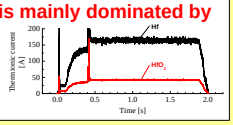


- Melting area (mean > 3500 K area) :1.9 mm² (89% cathode area)



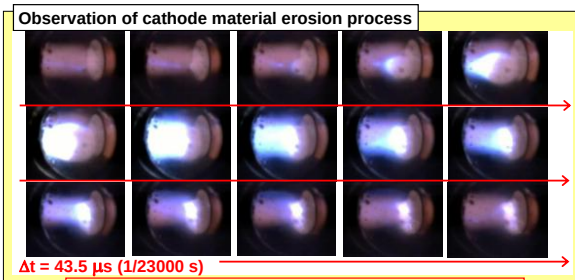
- Thermionic current density (Hf):80 A/mm²
- Thermionic current (Hf) : 160 A

⇒Arc current is mainly dominated by thermionic emission current



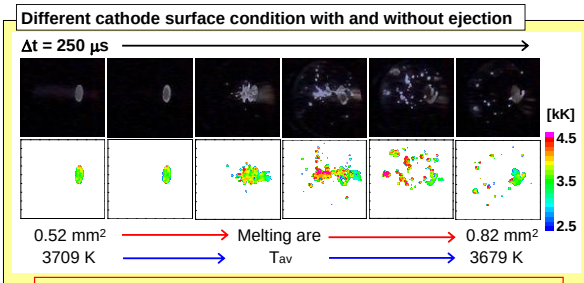
Visualization of cathode material erosion

Observation of cathode material erosion process



- Cathode material is boiled by arc plasma heat load
⇒Explosion of cathode surface
⇒Evaporation of cathode materials

Different cathode surface condition with and without ejection



- Ejection of molten cathode materials
⇒Cathode average temperature decreased after ejection
⇒Melting area increased after ejection

Conclusions

1. Dynamic analysis of cathode surface temperature, melting area, and thermionic current density of the cathode
   - Cathode material is melted during arc plasma generation
   - Arc current from Hf cathode is dominated mainly by thermionic emission current
2. Dynamic behavior of molten cathode spot observed from the molten area in the steady state arc current
   - Cathode material boiling occur abruptly
   - Abrupt boiling of molten cathode and ejection of metal vapor, which might come from the pressure balance