P71B

Development of PWI-plasma Gun as Transient Heat Load Source for ELM-simulation experiments

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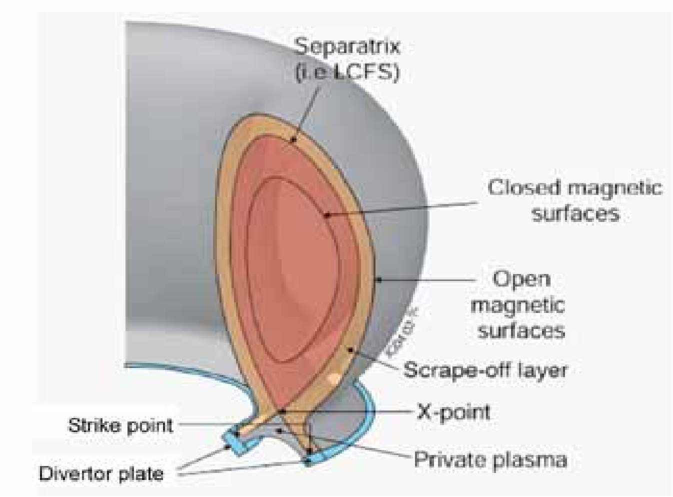
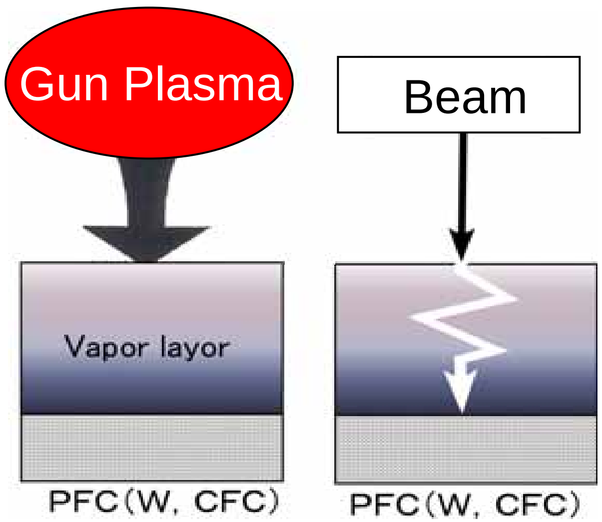
13th International Workshop on Plasma-Facing Materials and Components for Fusion Applications and 1st International Conference on Fusion Energy Materials Science, May 9-13, 2011 Rosenheim, Germany

Background and objectives





Vapor shielding effect

Damage reduction 1/10~1/100

ITER-R&D issues

Tritium retention、 Tungsten (W) R&D、 Dust、 Sputtering erosion, Transport of PFCs、 Steady state and transient heat load tests for PFCs

Advanced operation scenario of ITER
(ELM 20 MJ／pedestal 100 MJ)

TypeI－ELM： 0.2-3 MJ/m^2, 0.1-1 ms, 1-10 Hz
Disruption: 10-100 MJ/m^2, 1-10 ms,

Remarks:

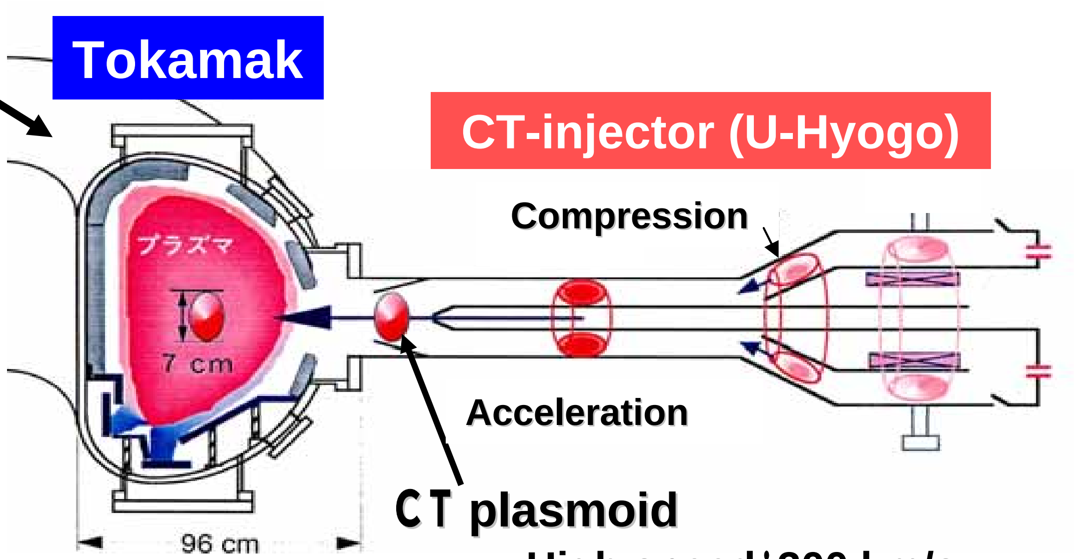
Fusion conditions typical for their transient events are difficult to achieve in existing tokamak and plasma simulators.
Vapor shielding effect reduces the erosion rate substantially; Electron beam penetrates dense vapor cloud in front of the material surface which acts as a thermal barrier.

Plasma guns are suitable facilities to incorporate the shielding effect into erosion simulation of the ELMs/disruptions.

Fusion applications of CT plasma gun technology

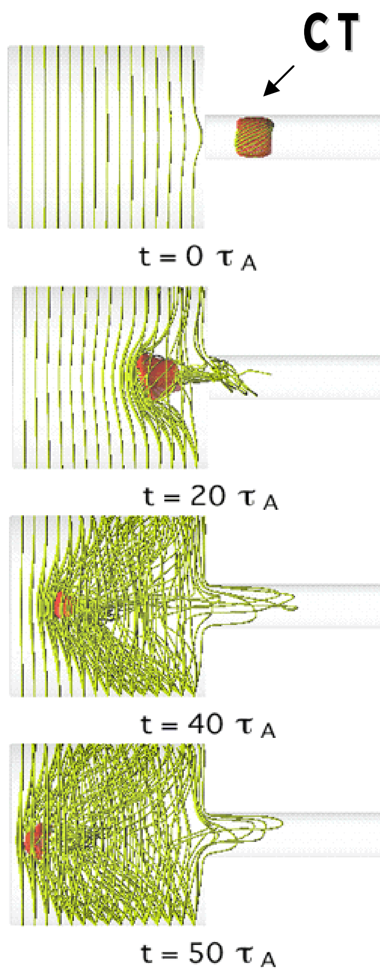
- Central fuelling [1,2]
- Mitigated disruption
- ITER-ELM simulation exp. [3]
- Dust injection exp.

Tokamak: JFT-2M
(JAERI, JAEA)
CT injection for
central fuelling



High speed：300 km/s
High density：10^{22} m^{-3}

Tokamak field



3D MHD Simulation

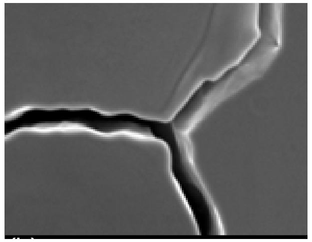
[1] M. Nagata, et al. Nucl. Fusion **45**, No 9,1056 (2005).
[2] N. Fukumoto, et al. Fusion Eng. and Design **81**, 2849 (2006).
[3] M. Nagata, Y. Kikuchi and N. Fukumoto, IEEJ Trans., 4, 1 (2009).

Advanced ELM-Simulation experiments

Type I ELMs
0.2-2 MJ/m^2, 0.1-1 ms

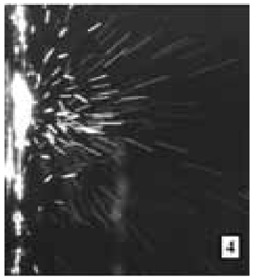
Transient heat loads

Tools: Plasma gun



Crack formation on W

Surface damages:
Erosion, melting,
Cracks,
droplet splashing

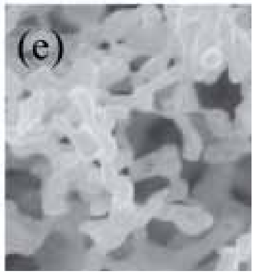


by QSPA Kh-50

High flux of ~ 10^{24} m^{-2}s^{-1}
High fluence of ~ 10^{26} m^{-2}

Steady-state heat loads

Tools: Linear divertor plasma simulators



W fuzz

Surface damages:
Erosion, dusts,
W surface structures
- He bubbles,
- D blisters,
- He-induced fuzz

Combined steady-state/pulsed heat and particle fluxes

Measurements of melting threshold, mass loss and erosion rate of W and CFC as a function of energy density, pulse number and etc.

Japanese ELM-PSI research projects/collaborations

New tool for pulsed heat load tests

Magnetized Coaxial Plasma Gun (MCPG) producing Compact Toroid (CT) plasmoids at Univ. of Hyogo

Developments of the up-grade MCPG device as an ITER-ELM simulator

On-going experimental studies of ITER divertor PFCs erosion by the MCPG

- **Off-line experiment with the linear divertor plasma simulator, PISCES-A at University of California, San Diego : Influences of pulsed plasma irradiation on surface morphology (D blisters, He-induced fuzz) and deuterium retention in W**

  # The results will be presented by Dr. D. Nishijima at this conference (P75B).

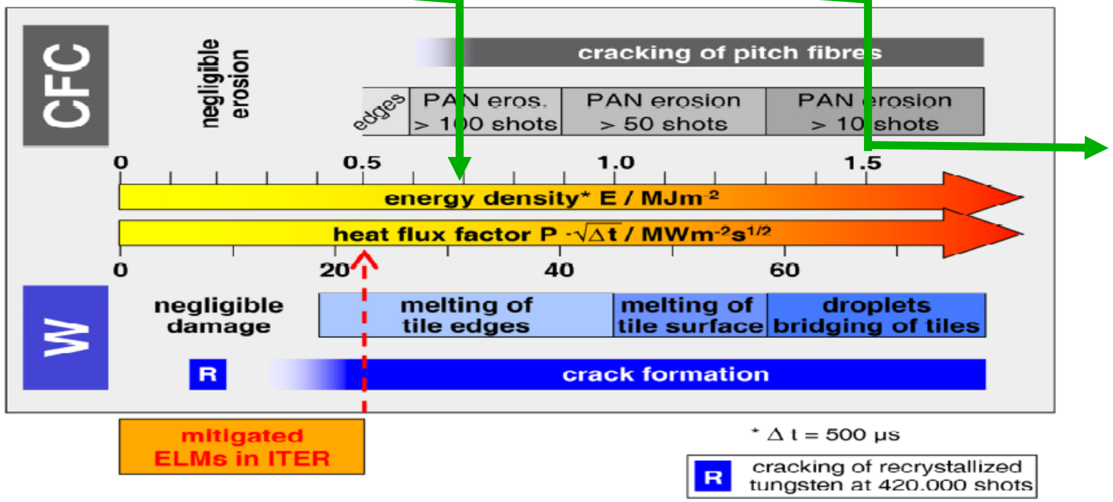
- **On-line experiment with the steady-state divertor plasma simulator, NAGDIS at Nagoya Univ..**

  # A reference study of effect of neutral particles on a gun plasma production will be presented here.

- **Off-line experiment with the electron beam (JEBIS at JAERI, Osaka univ.)**
  Electron beam irradiation study (10-20 MW/m^2) of W mono-block material with a gun-pulse irradiation damage.

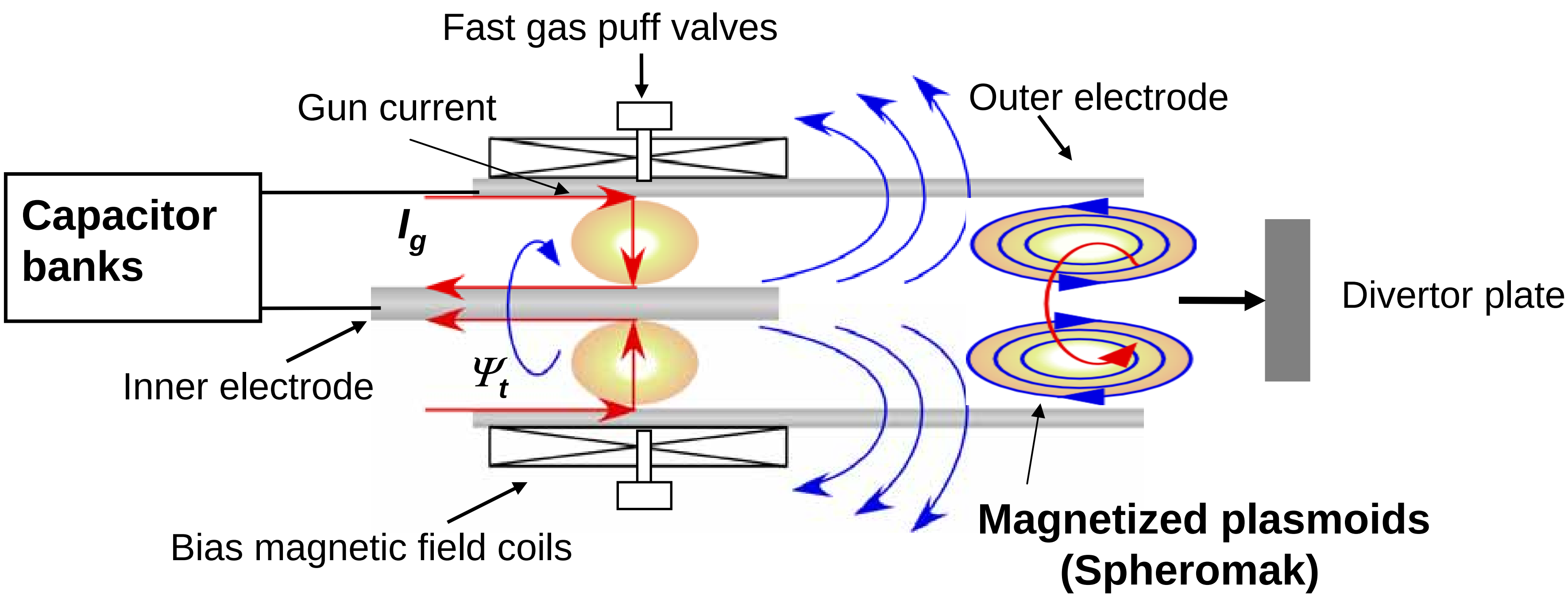
Optimization of the up-grade MCPG

	Present MCPG [1]	Up-grade MCPG	ITER Type I ELM [2, 3]
Energy density	0.7 MJ/m^2	2 MJ/m^2	0.2-2 MJ/m^2
Pulse duration	0.5 ms	1 ms	0.1-1 ms
Capacitor bank energy	24.5 kJ (7 kV, 1 mF)	70.6 kJ (7 kV, 2.9 mF)	-
Plasma speed	50 km/s	>50 km/s	-
Ion energy (D^+)	30 eV	>30 eV	12.5 keV
Electron density	1x10^{21} m^{-3}	>1x10^{21} m^{-3}	7x10^{19} m^{-3}
Ion flux	5x10^{25} m^{-2}s^{-1}	>5x10^{25} m^{-2}s^{-1}	7x10^{25} m^{-2}s^{-1}
Particle fluence	7.5x10^{21} m^{-2}	>1.5x10^{22} m^{-2}	-



[1] Y. Kikuchi et al., J. Nucl. Mater., in press (2011)
[2] G. Federici et al., PPCF 45 (2003) 1523.
[3] A. Hassanein, I. Konkashbaev, J. Nucl. Mater. 313-316 (2003) 664.

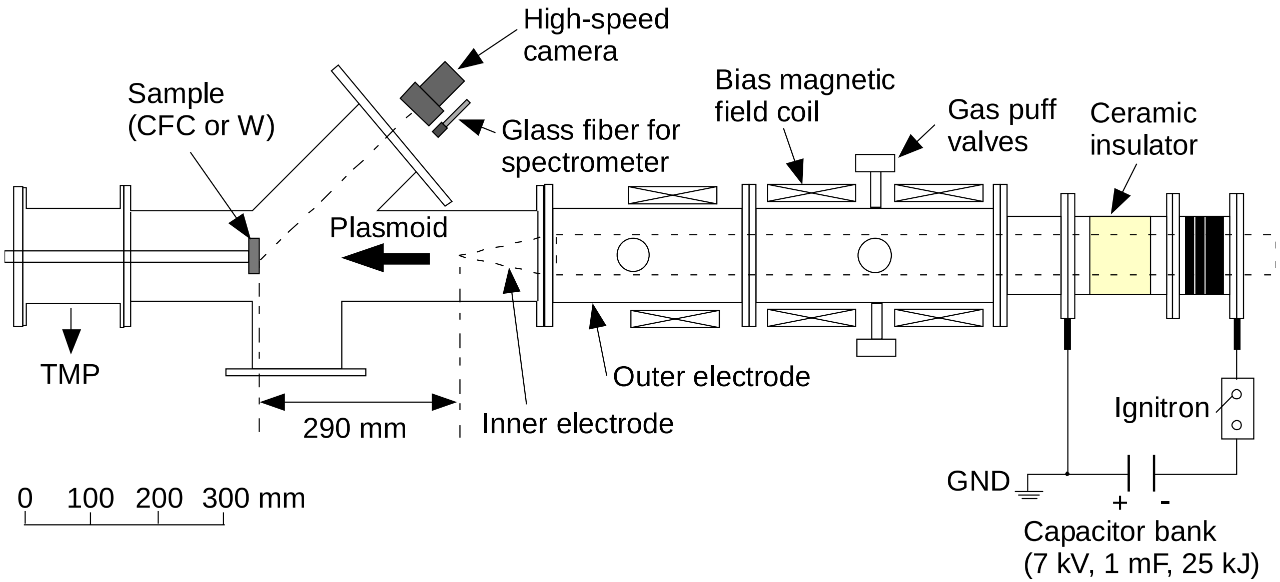
Formation scheme of MCPG plasmas

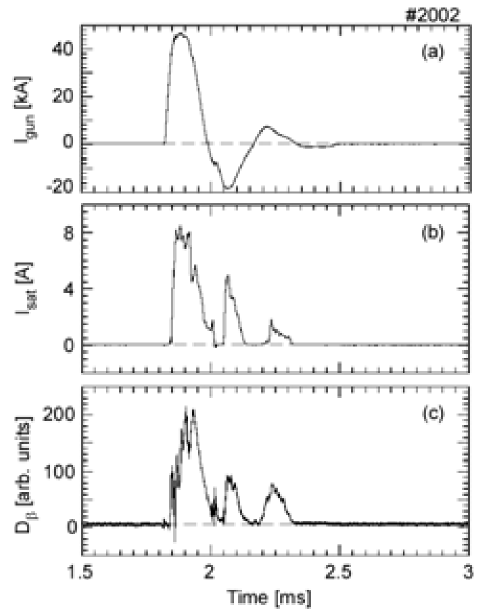


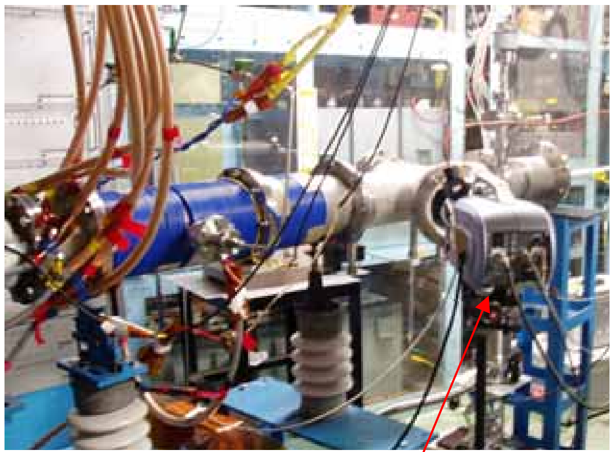
Characteristics

High density and high speed due to magnetized plasma
Various discharge gas species (H, D, He, Ar etc.)

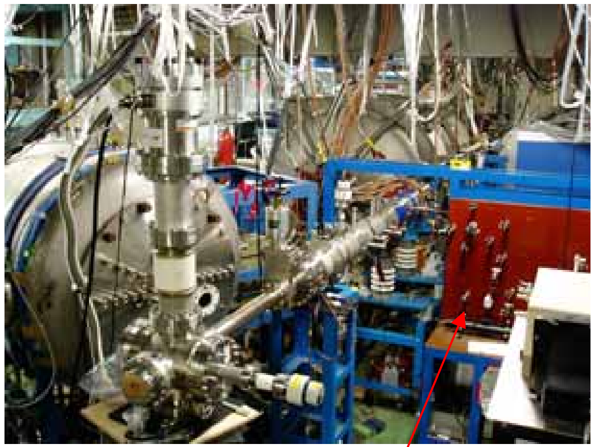
MCPG at University of Hyogo







High speed camera



He-Ne laser interferometer

Gun current: ~ 50 kA

Pulse length: ~ 0.5 ms

Working gas: D_2

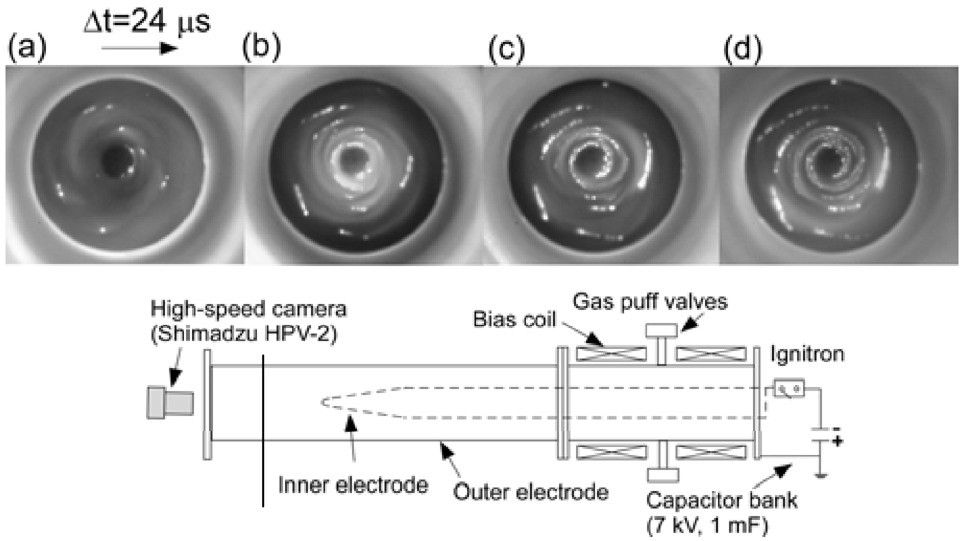
Operation cycle: 8 min

Plasmoid speed: ~ 50 km/s

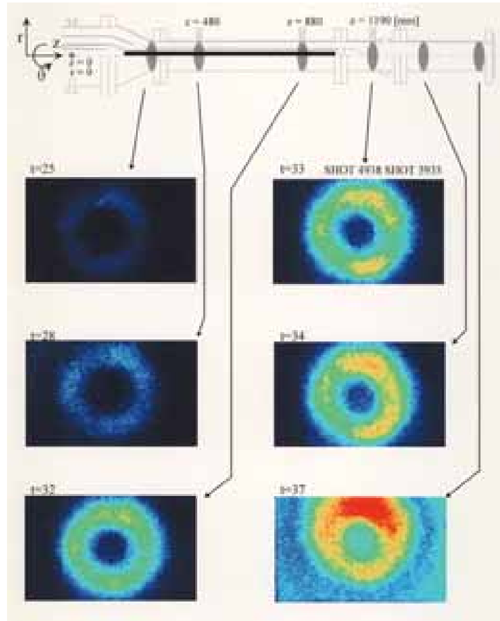
Electron density: ~ 1×10^{21} m^{-3}

Magnetic field: ~ 5 kG

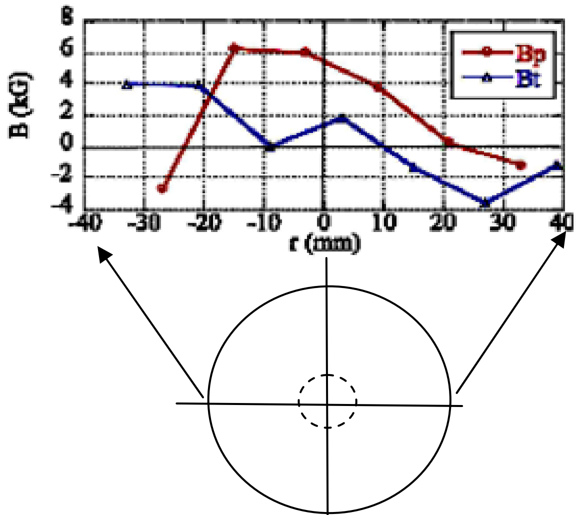
Properties of MCPG plasmas



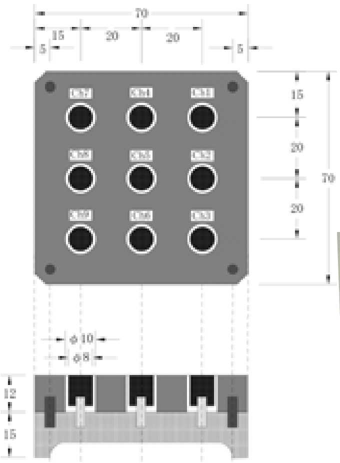
Rotation of plasmoid



Formation of ring plasmoid

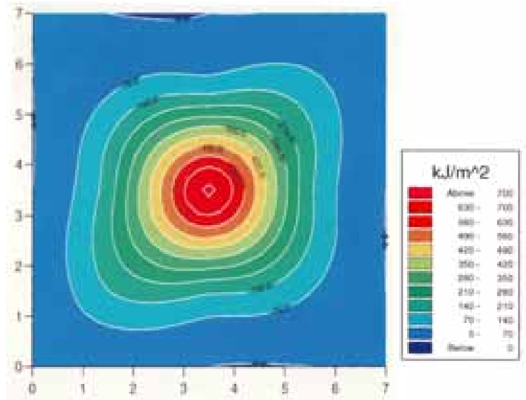


Magnetic field configurations



2D calorimeter

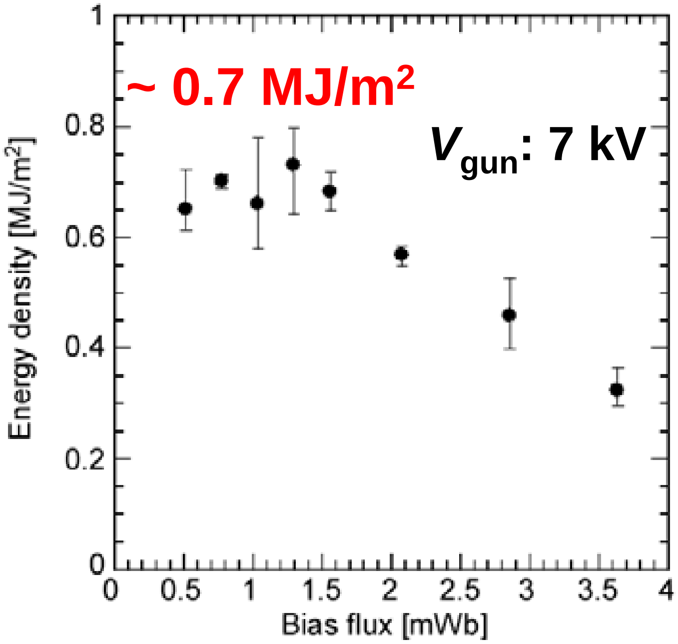
IG-430U



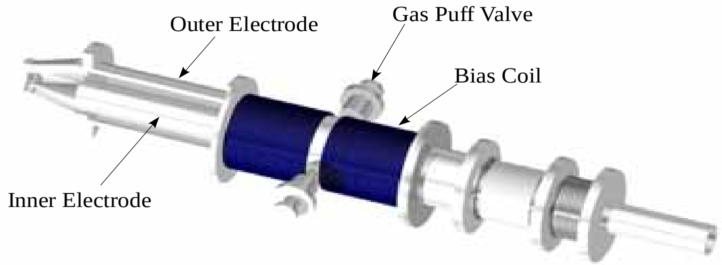
2D energy density distribution

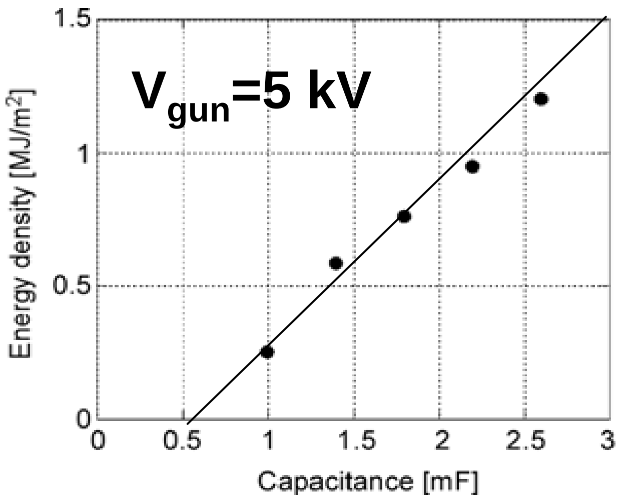
Energy density Q_{ab} vs Bias flux and Gun voltage

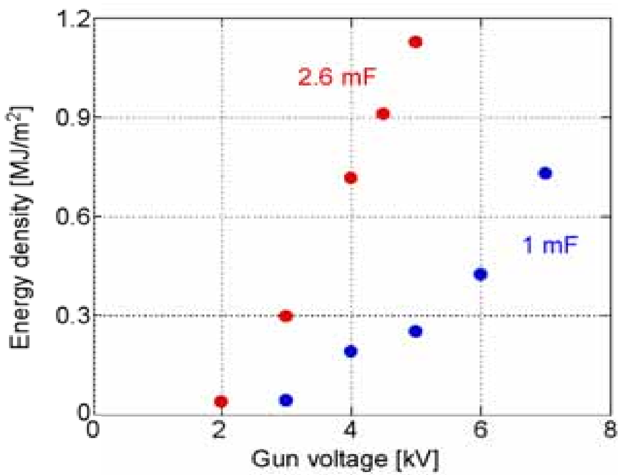
Q_{ab}



- Control of the absorbed energy density Q_{ab} by gun operating parameters of the bias flux and the gun voltage





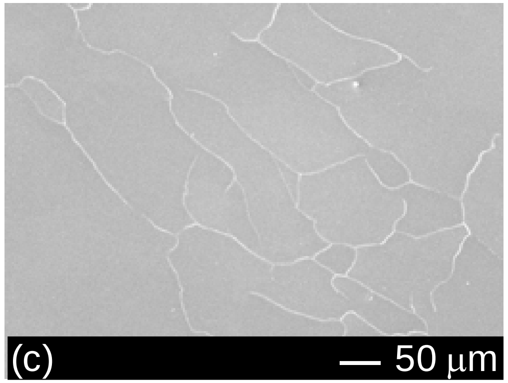


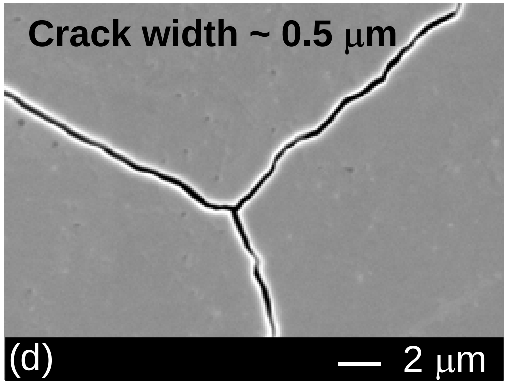
$$E = \frac{1}{2} C V_{cap}^2$$

Results from gun plasma irradiation to W

Surface morphology of W sample exposed to pulsed plasma irradiation

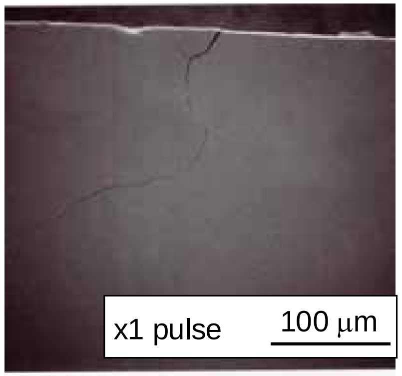
Cracks **0.7 MJ/m^2 x 10 pulses**

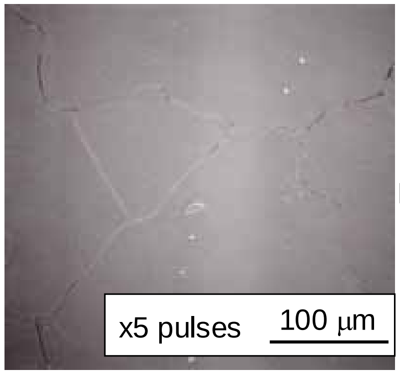


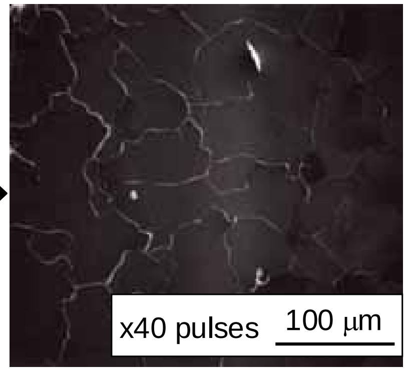


40 pulses

Melting







Expansion of crack area with the increase of the gun pulse number

Crack depth ~200 µm

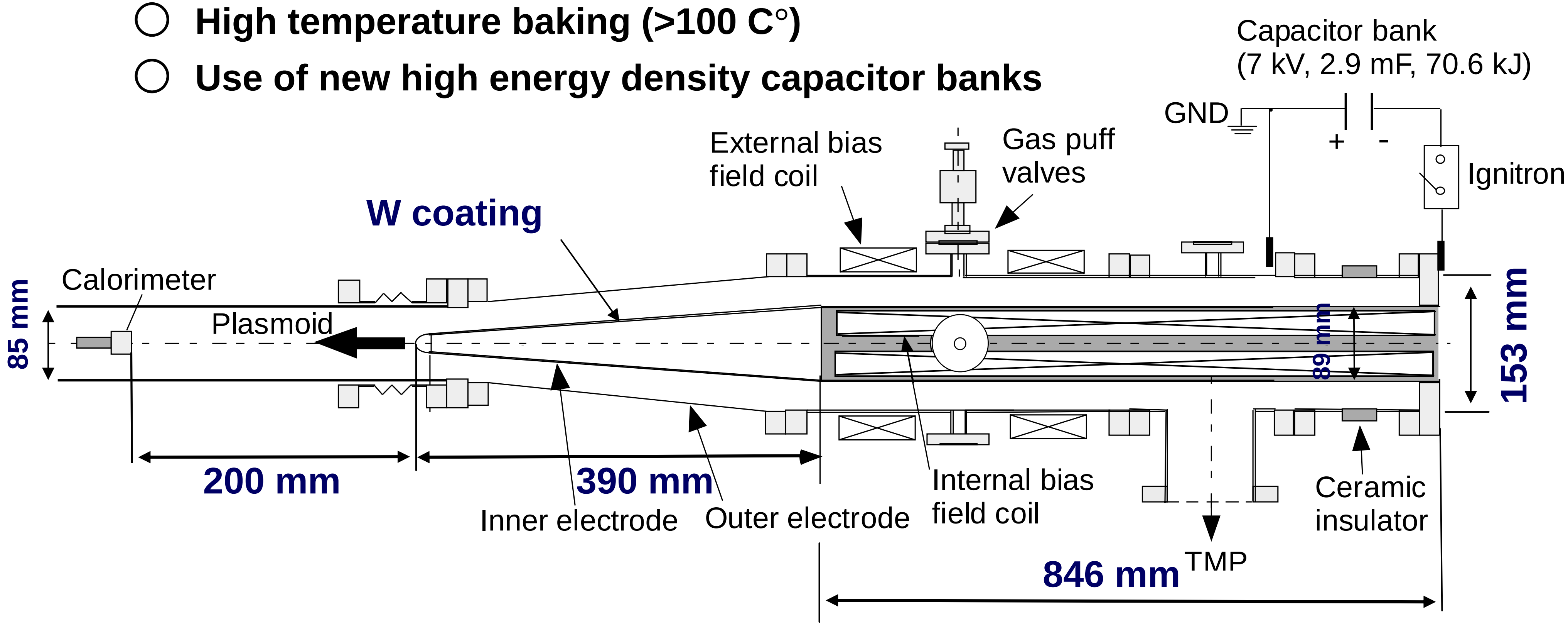
Sample holder

W sample: Diameter 25 mm
Thickness 1.5 mm

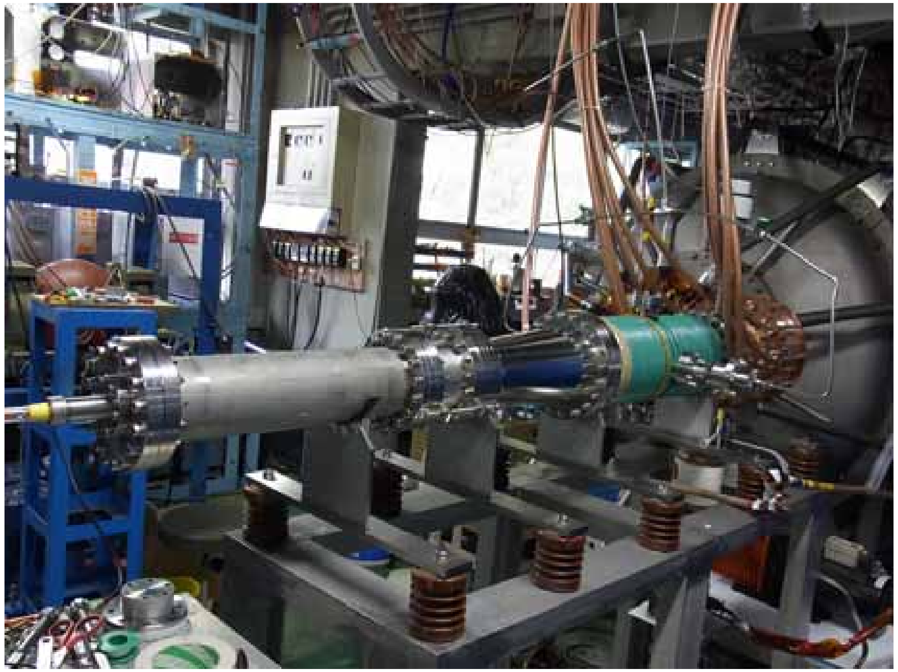
Newly up-graded MCPG device

Characteristics

- ○ Velocity control by the inner and outer bias coils
- ○ W coating (200 μm) for decreasing metal impurities
- ○ Compression of density by the focus cone
- ○ Density control by two fast gas puff valves
- ○ High temperature baking (>100 C°)
- ○ Use of new high energy density capacitor banks



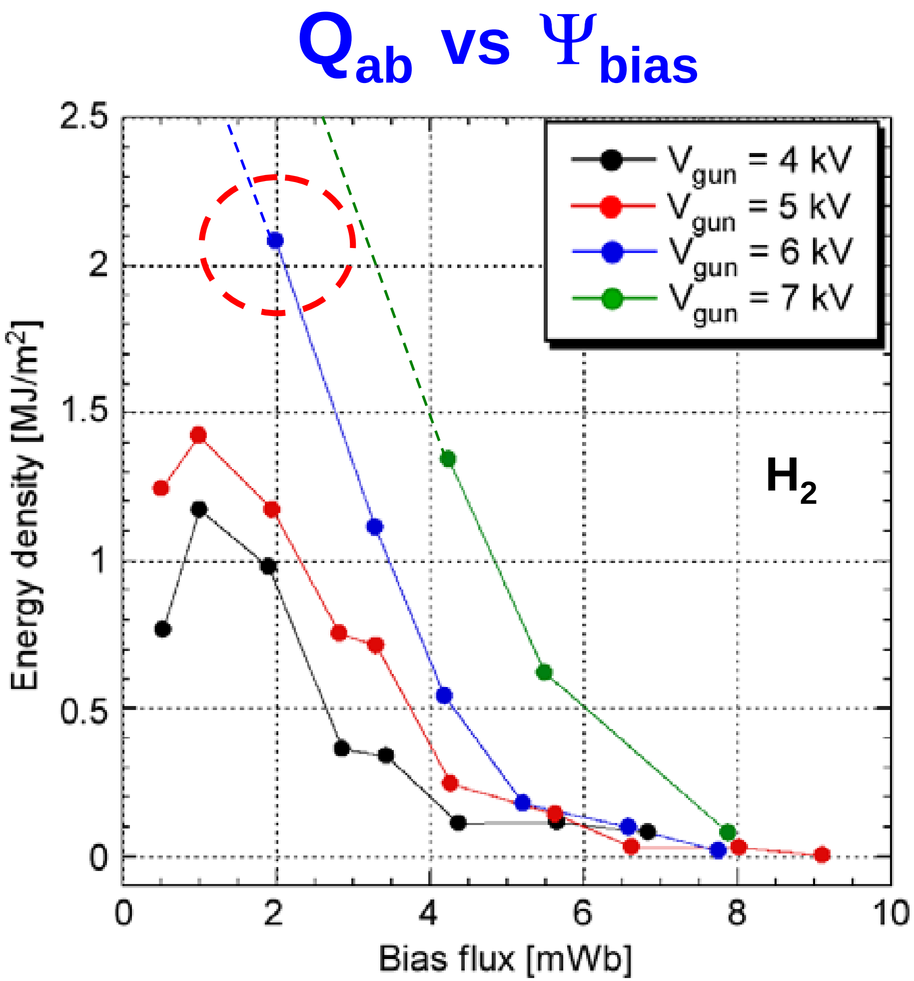
Newly up-graded MCPG device



W coated inner electrode

High energy density capacitor bank

Surface absorbed energy density (at Up-graded MCPG)



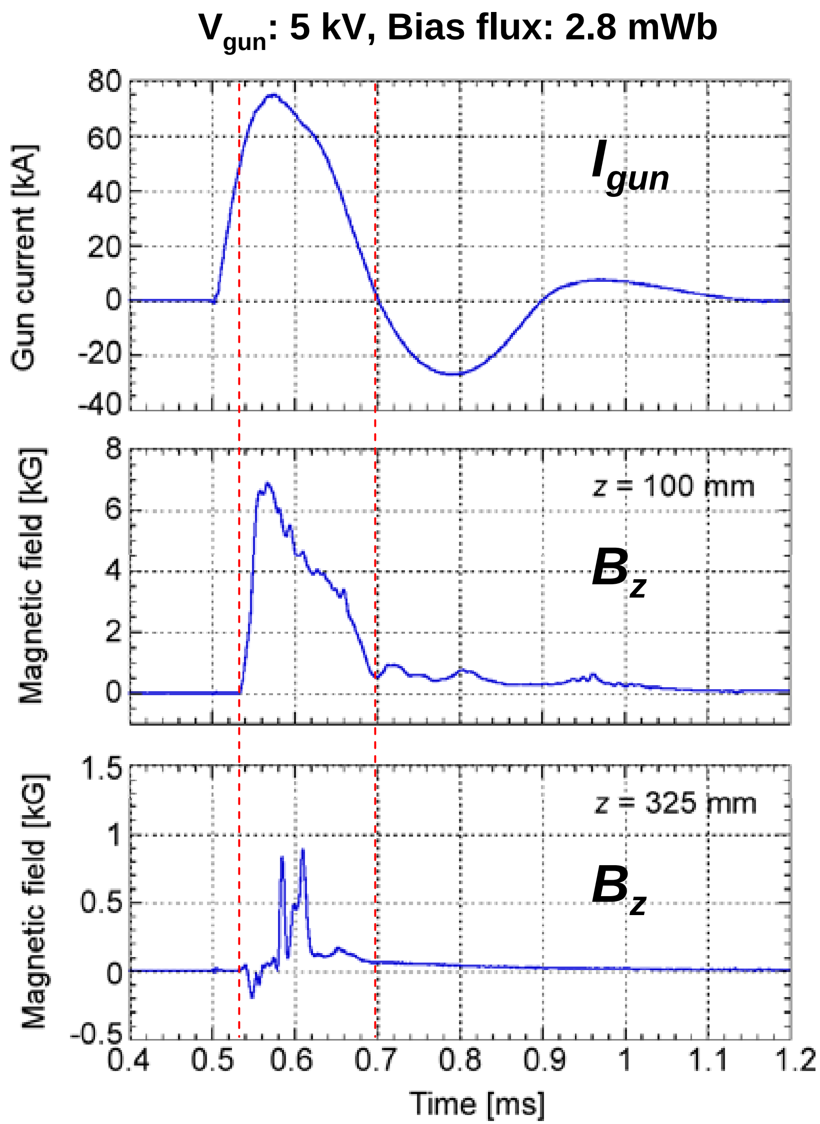
The higher energy density have been successfully obtained at the low charging voltage of 6 kV (Max.10 kV) in the up-graded MCPG device.

2 MJ/m^2 >> Melting threshold

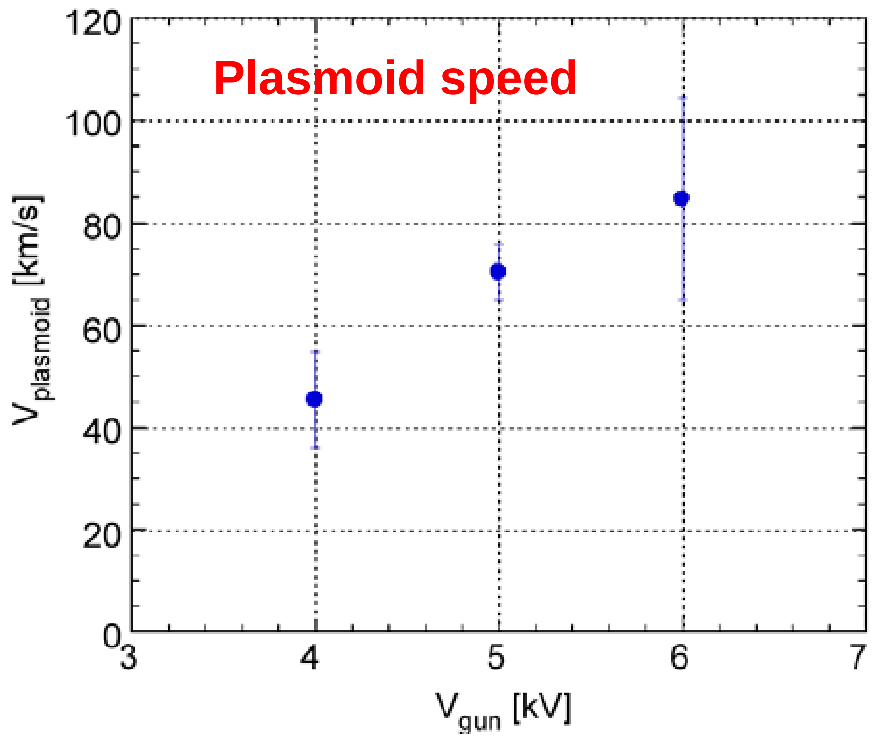
 # Magnetic pressure of the applied bias flux prevents ejection of plasmoid from the gun formation region.

 # The application of the bias magnetic field contributes on a stable breakdown between electrodes.

Discharge waveforms of Up-graded MCPG



- Gun current: ~ 100 kA (at 7 kV)
- Pulse length: 0.2 ~ 0.5 ms
- Operation cycle: 8 min.



Plasmoid speed: ~ 100 km/s
(ion energy for D^+: ~ 120 eV)

Summary

A) The divertor PFMs in ITER are exposed to both the steady-state divertor plasma and the intense transient heat and particle fluxes of ELMs. The transient heat load tests for R&D of ITER-PFMs using a MCPG have been recently started in Japan.

B) The present MCPG at Univ. of Hyogo provides that the electron density and the ion energy of the gun-produced plasma is ~1×10^{21} m^{-3} and ~30 eV for deuterium (D) ion, respectively. The initial W irradiation experiment reported that although cracks were formed on a W surface at the energy density Q~0.7 MJ/m^2, and a partial melting of the W surface was observed under a multi-pulse (x40) exposure.

C) We have successfully developed the well-controlled MCPG with higher performance (C=2.9 mF, Max V_g=10 kV) so that Q > 2.0 MJ/m^2 (at V_g=6kV) and the speed ~100 km/s (120 eV for D) have been obtained. These values make it possible enough to cause melting of the W surface. We have been investigating more detailed properties of the plasmoid produced by the up-graded MCPG facility toward the R&D of ITER-PFMs .