Scalability study on a low inductance pulsed power generator

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This work has been supported by New Energy and Industrial Technology Development Organization (NEDO).

Outline

- Schematic drawings of experimental setup

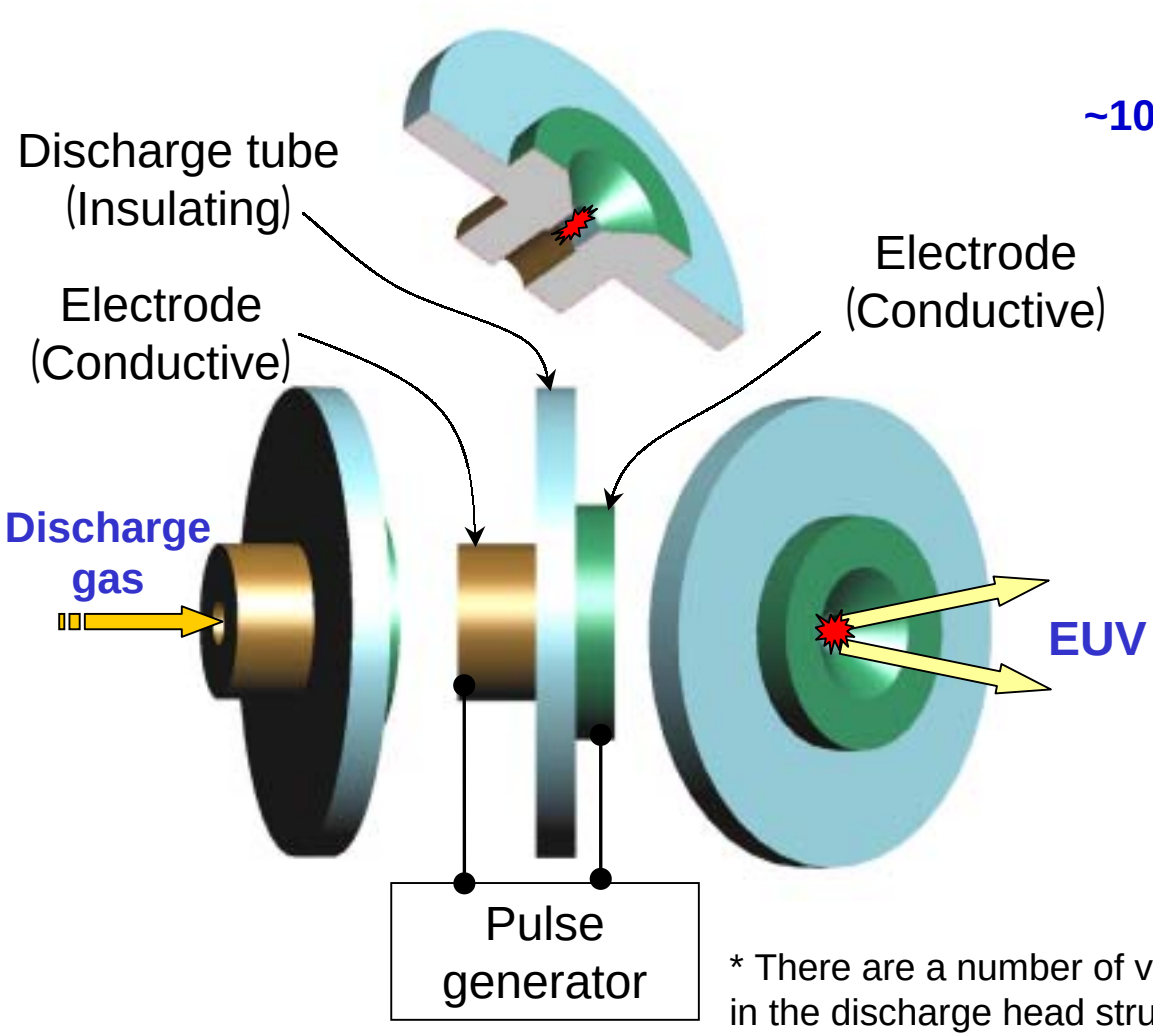
2. Experimental Results of former generator

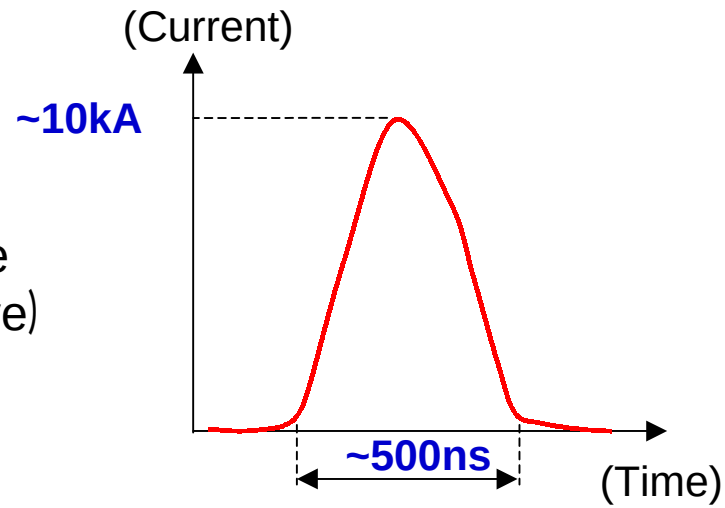
Inductance of MPC final compression stage was designed 56nH.

3. Experimental Results of new generator

Inductance of MPC final compression stage was designed as 10nH.

Overview of DPP source





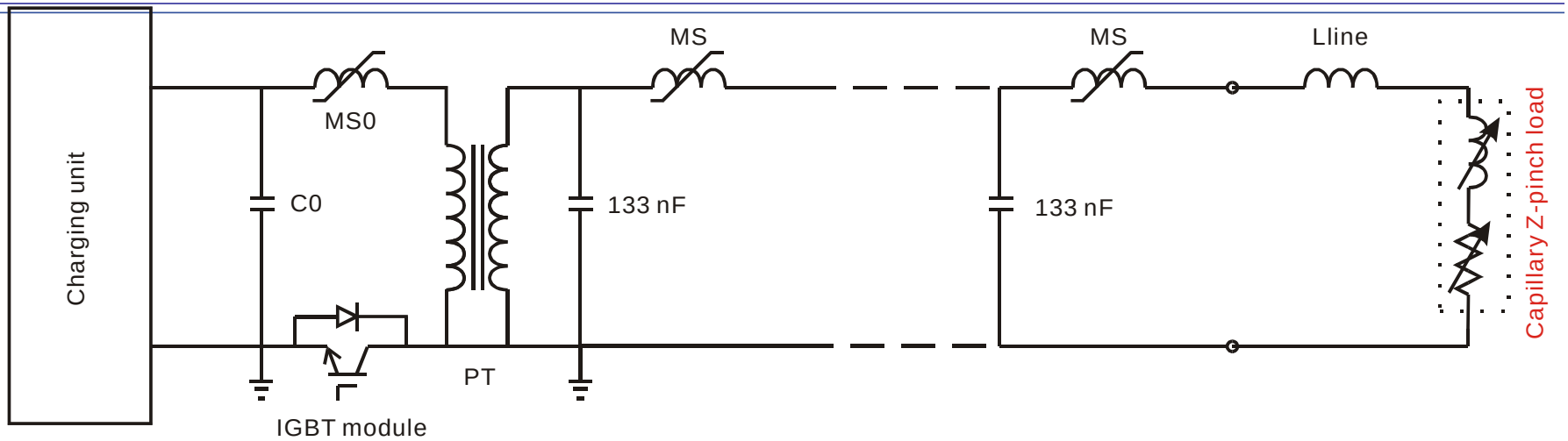
High current pulsed discharge

High temperature plasma

EUV emission

* There are a number of variations in the discharge head structure, the discharge gas, the current waveforms, etc.

Electrical circuit of “G-4” generator



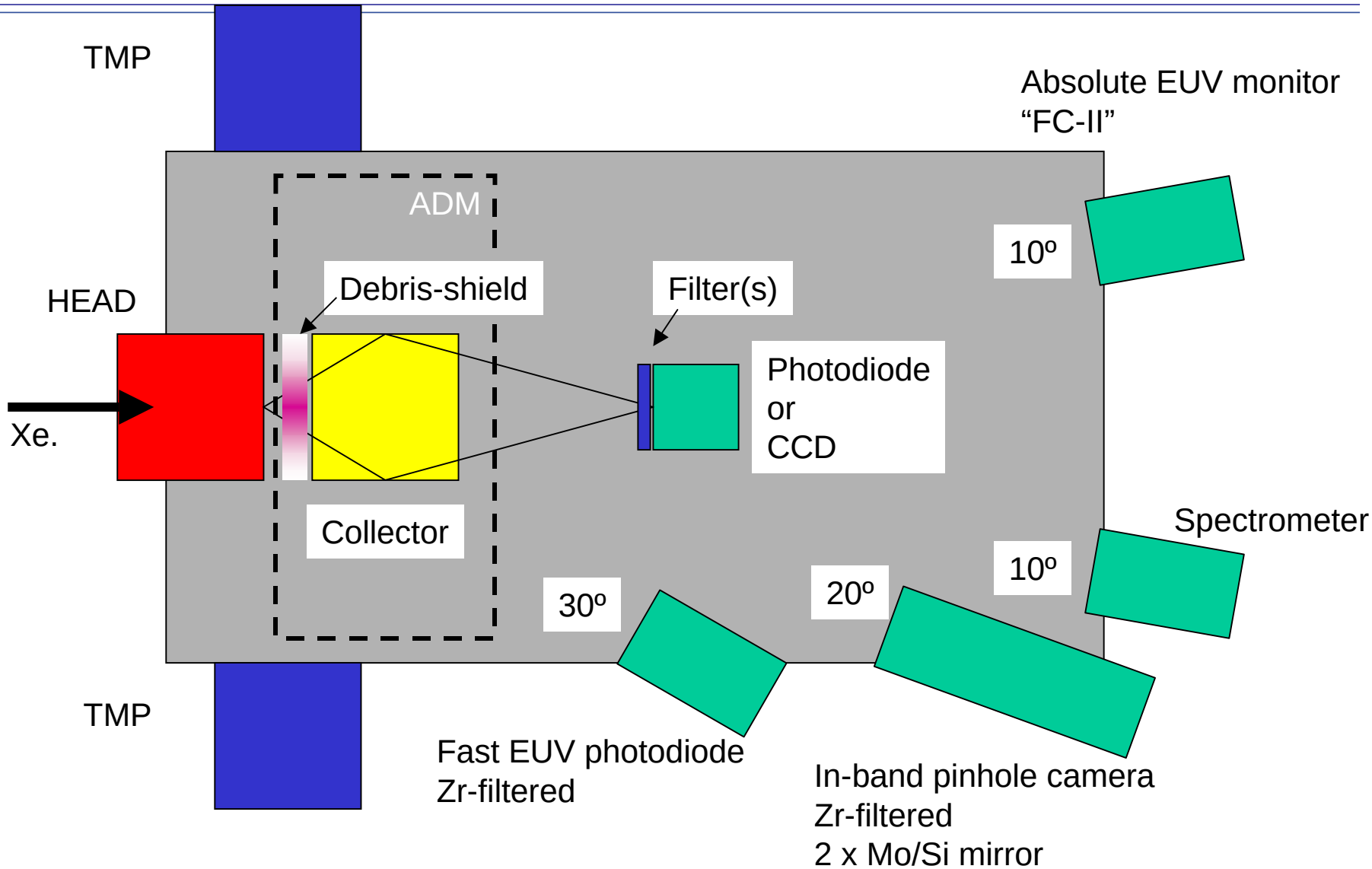
All-solid-state magnetic pulse compression generator (“G-4”)

- Peak current: 35-52 kA (for short-circuit load, depends on load)
- Pulse duration: 120-200 ns (for short-circuit load, depends on load)
- Stored energy: 14.0 J/pulse (rated output)
- Maximum repetition rate: 7 kHz
- Energy recovery system employed: 41 %(max) of stored energy recovered.

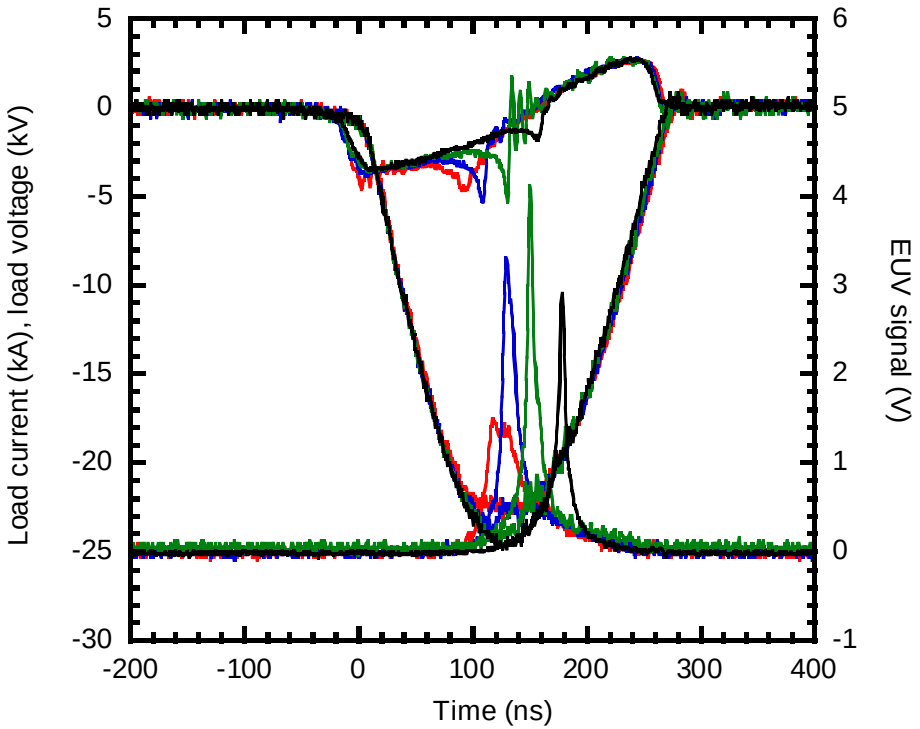
•Active pre-discharge by a surface flashover discharge unit placed upstream.

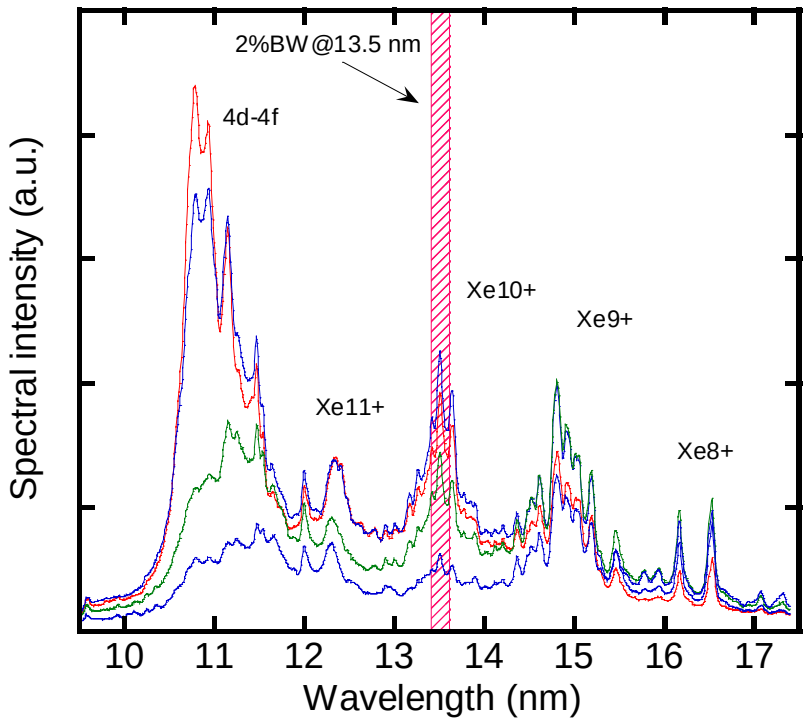
•Return energy is recovered in the generator and used for re-charge in subsequent pulse.

Experimental setup for source/IF characterization



Typical waveforms (current, voltage, EUV, spectra): Former generator





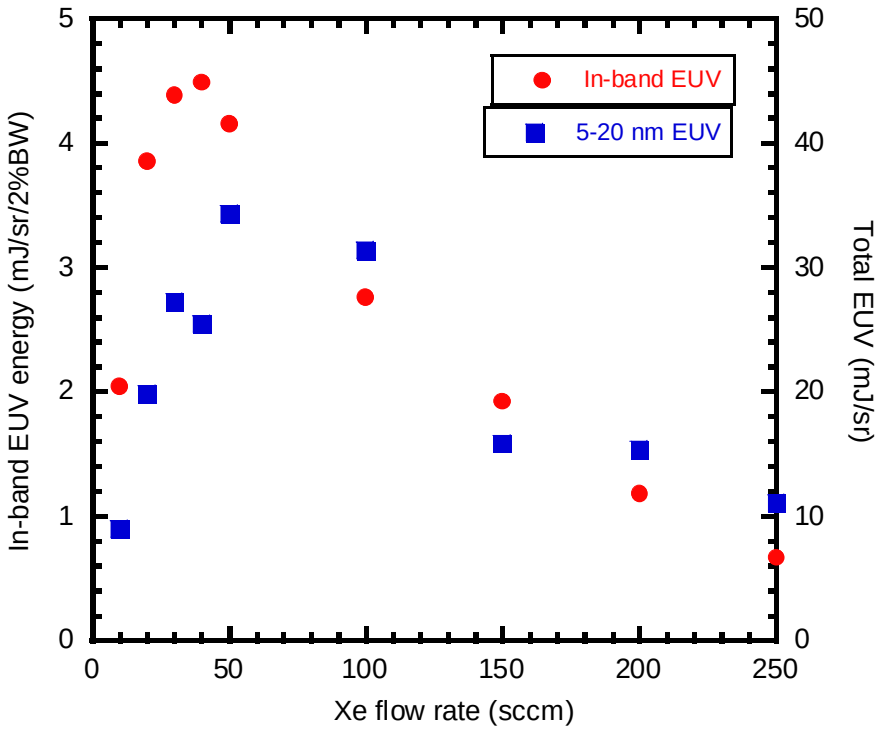
Z-pinch typical features:

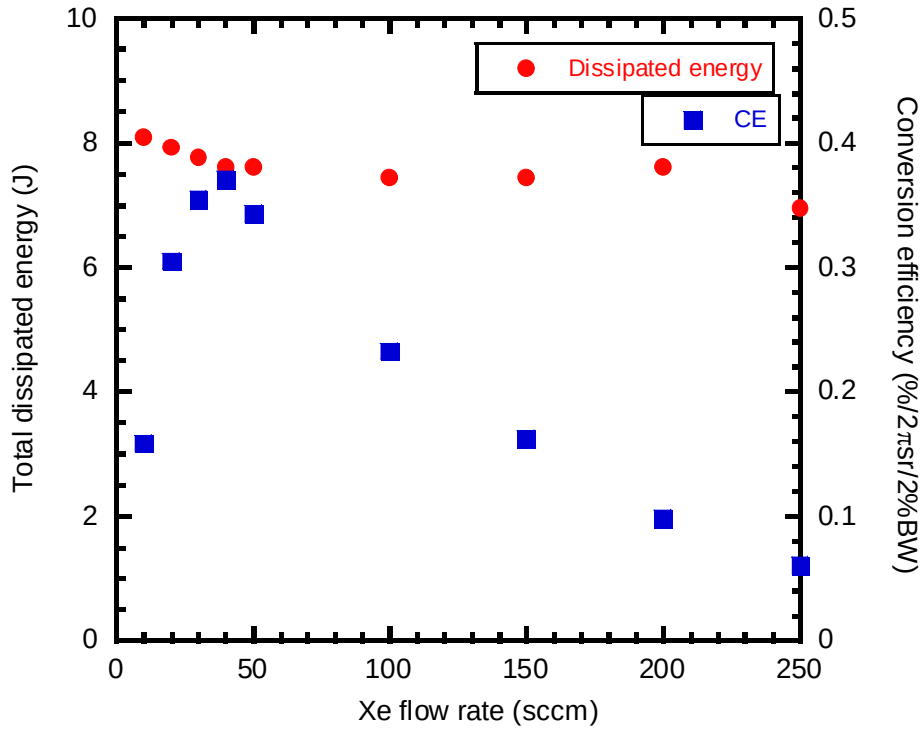
Pulse duration~275 ns, Ip~25 kA(max) (depends on L_{load})

Single EUV pulse appeared, its timing delayed with Xe flow rate.

There was optimum condition for given current shape to obtain 13.5-nm EUV.

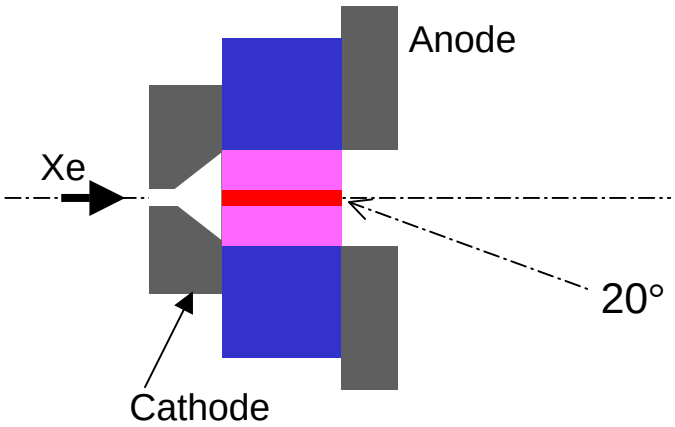
On-axis EUV energy & CE (low rep-rate result): Former generator

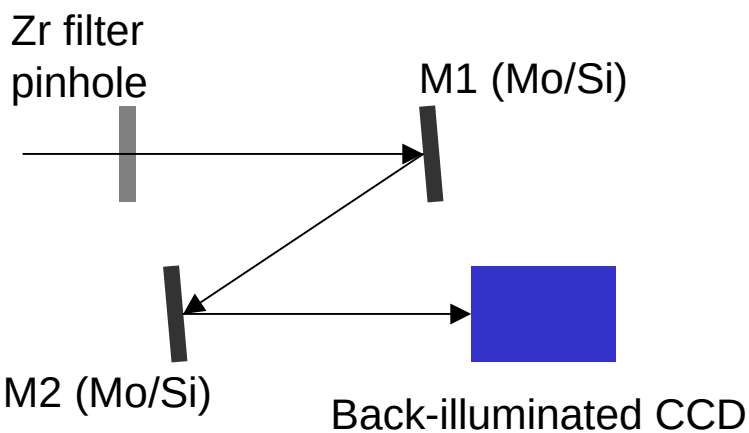


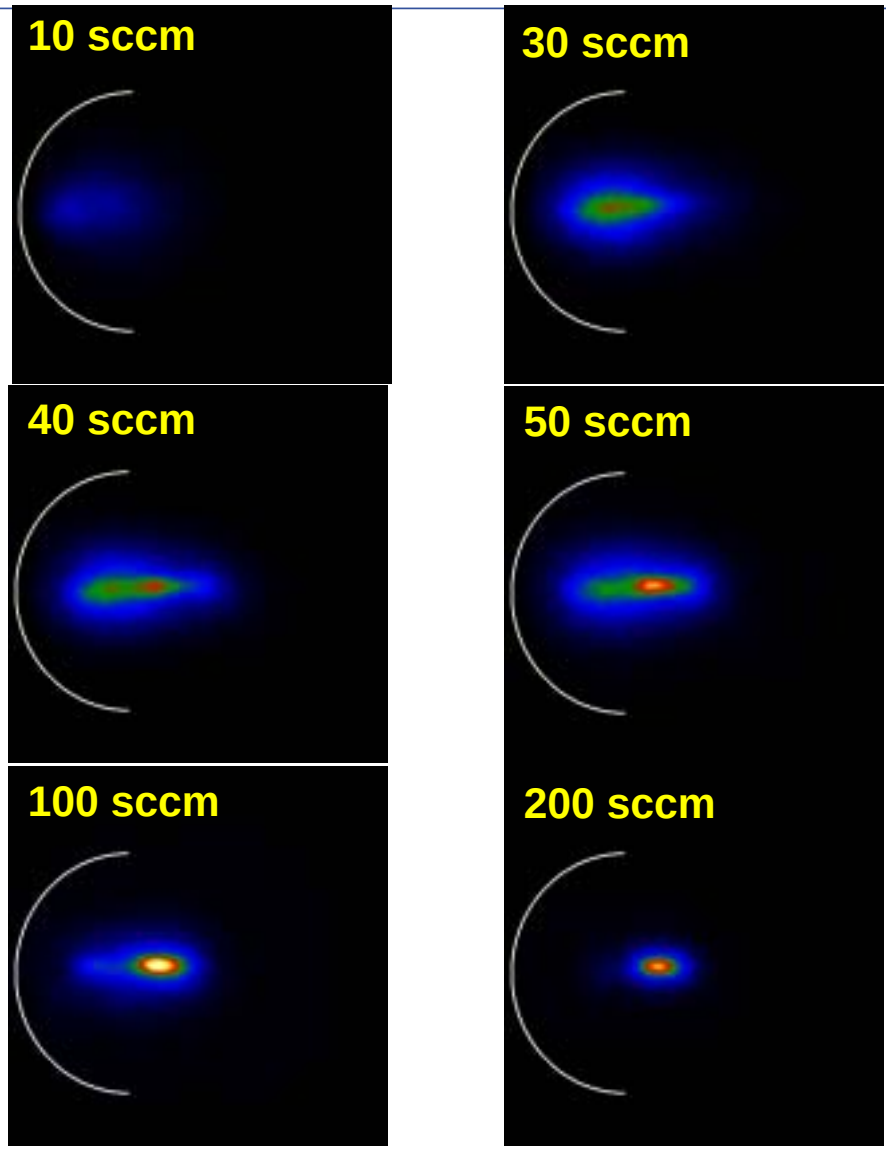


- Highest EUV: 4.5 mJ/sr (on-axis)
- CE: ~0.4 %/2π sr (including total energy loss in the circuit)
- CE: ~0.7 %/2π sr (based on energy input to the head)

Plasma observation by an “in-band” pinhole camera: Former generator







Angular distribution of radiated 13.5-nm EUV: Former generator

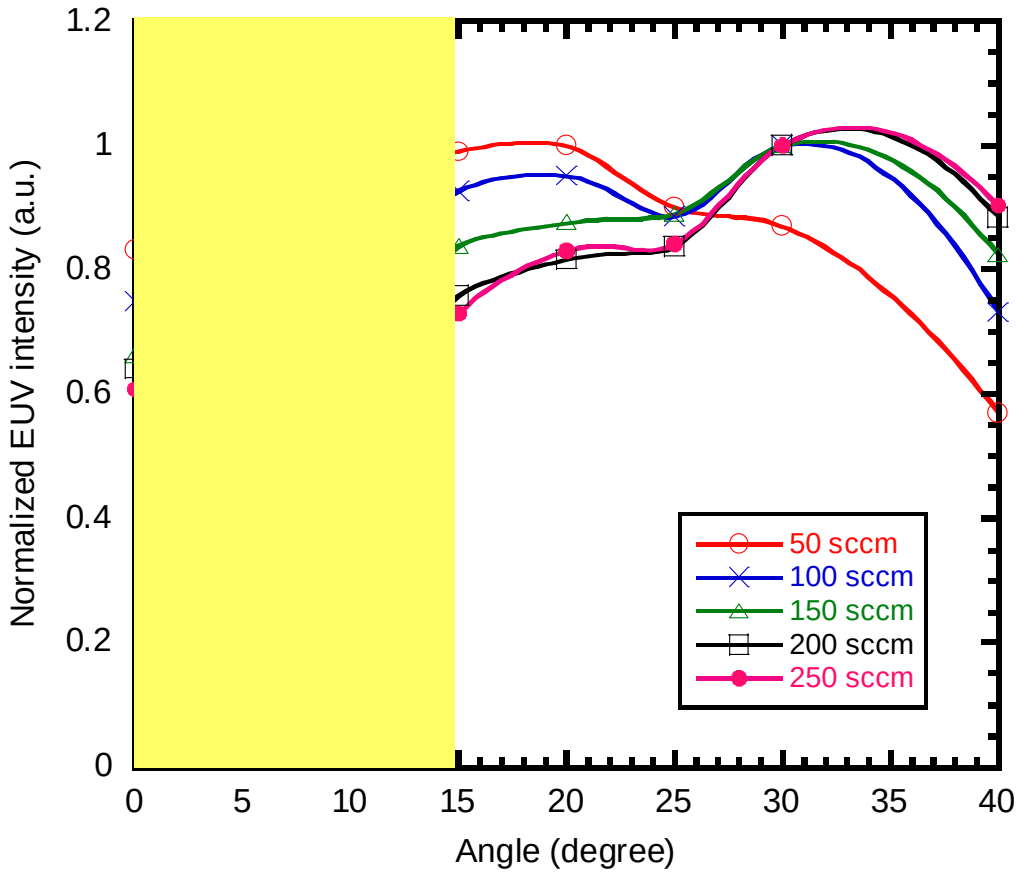
<Intensity drop on Z-axis>

High gas flow rate

Large capillary diameter

↓

leads to significant intensity decrease



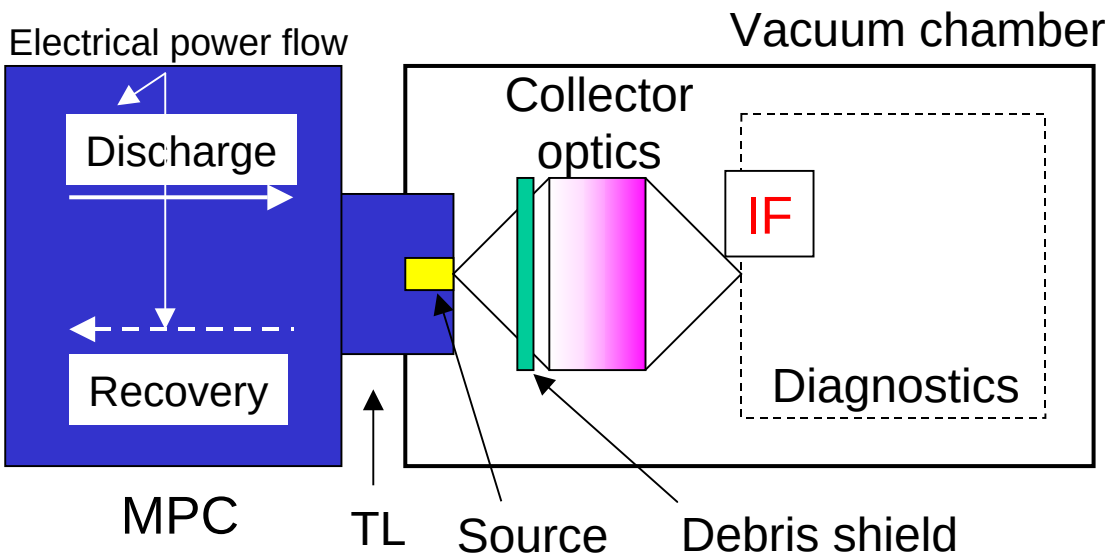
<Considerable reason>

Opacity effect

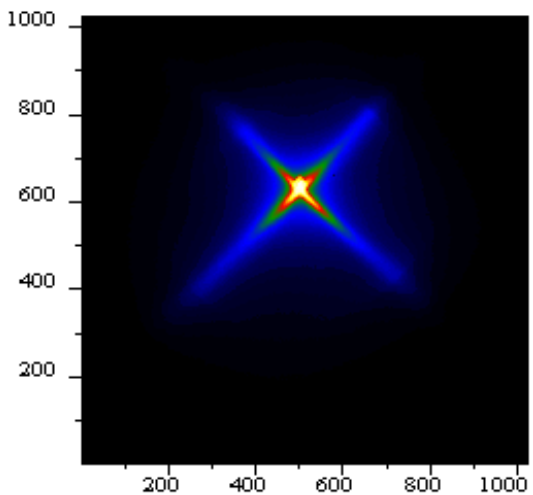
Absorption by Xe gas/plasma outflow

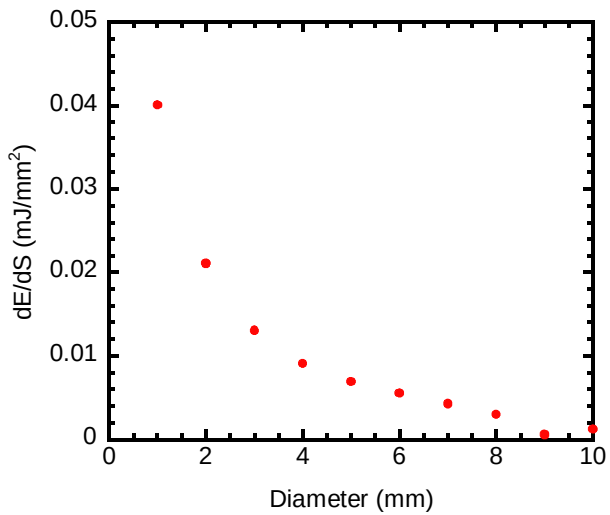
Almost uniform radiation obtained.

IF characterization: grazing-incidence collector: Former generator

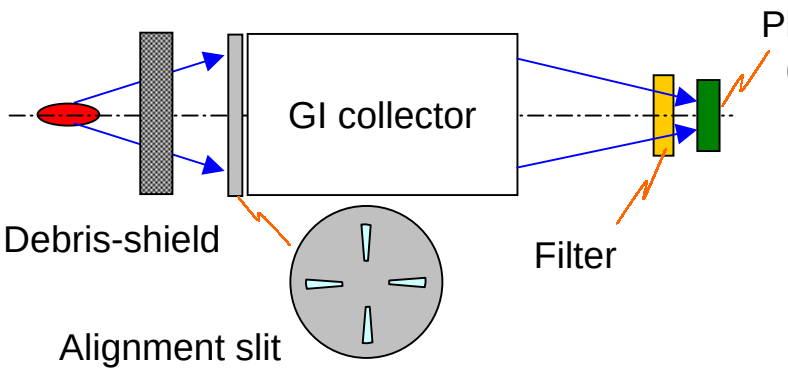


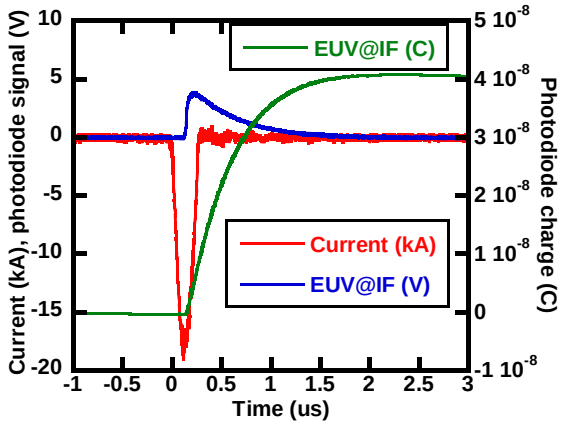
Fabricated by MEDIA LARIO s.r.l

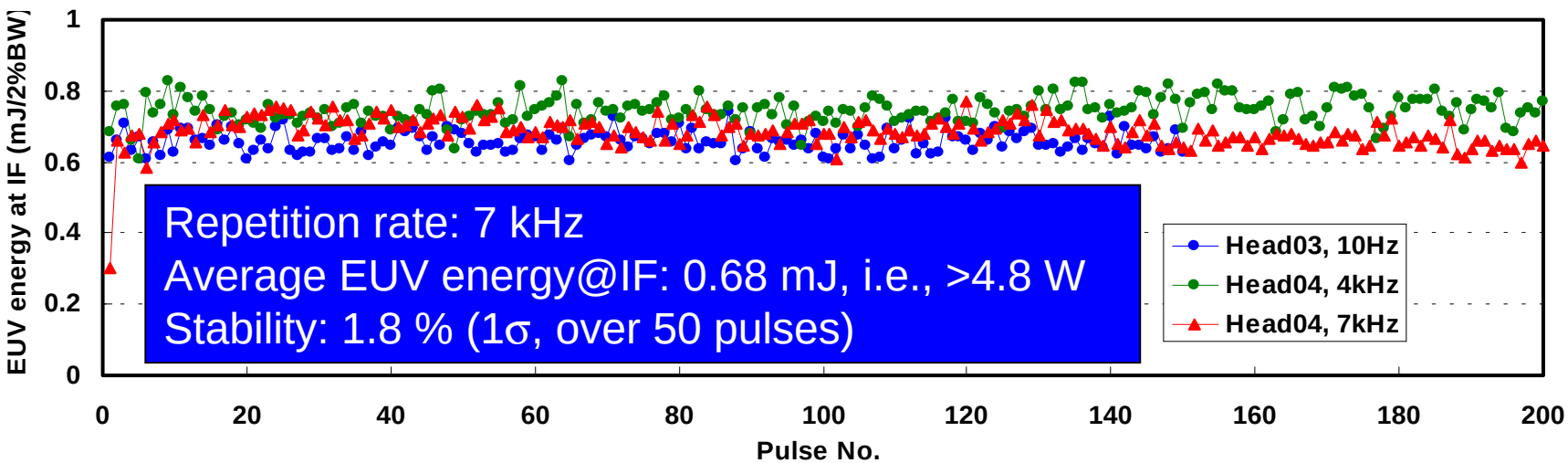




Characterization of EUV power/quality at IF: Former generator



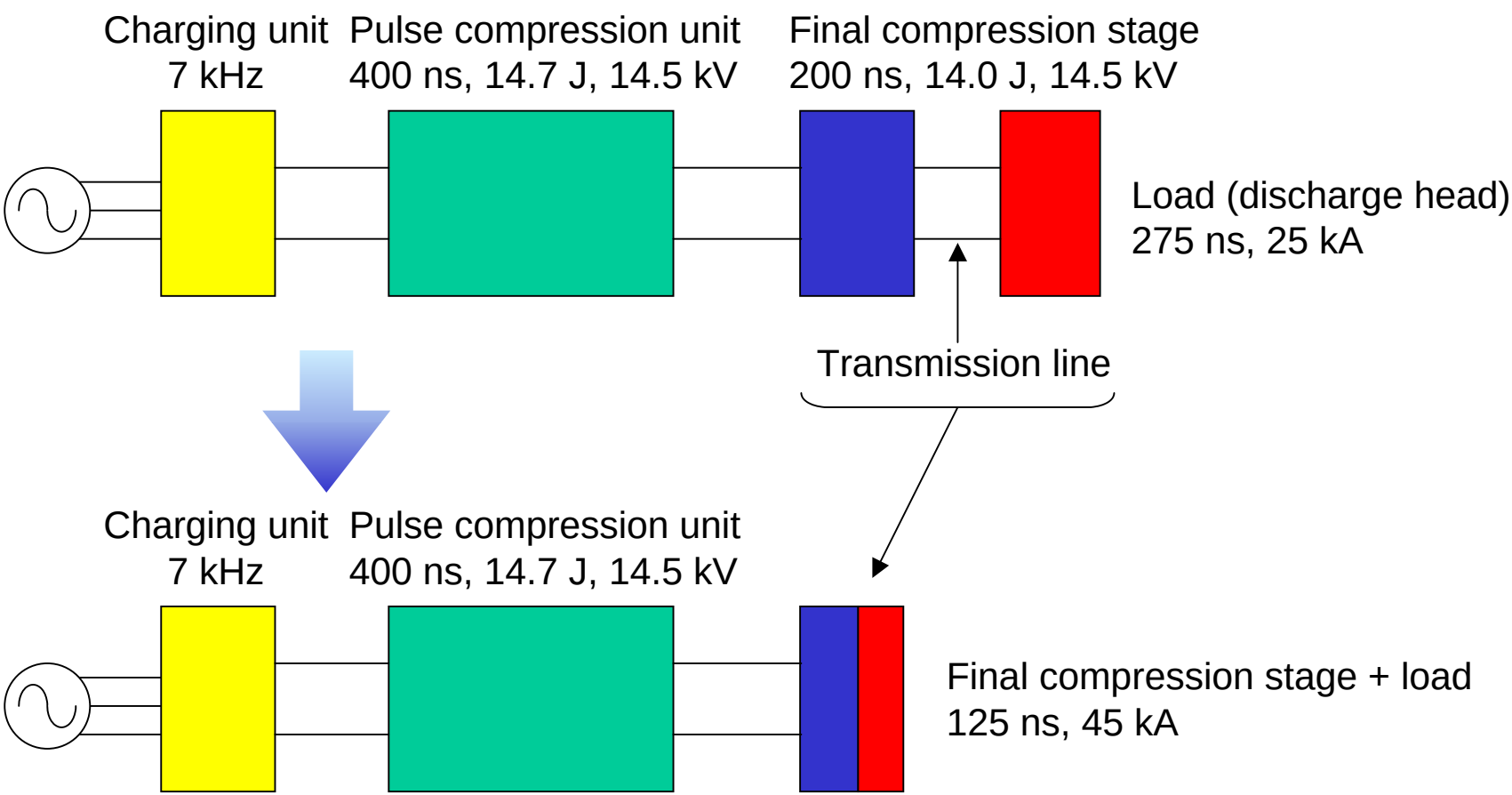




EUV pulse energy at IF in repetitive operation

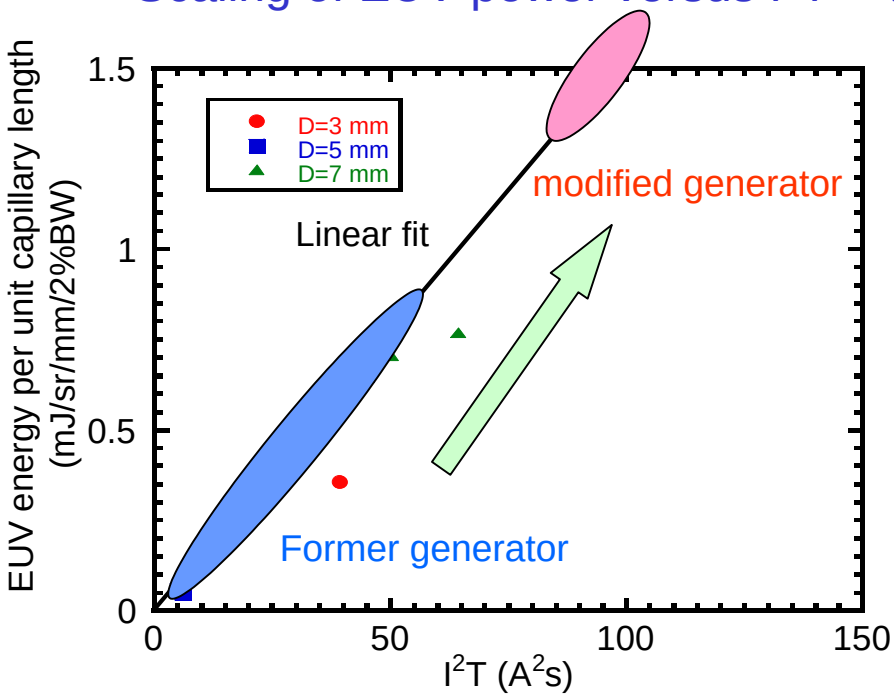
Modification of final compression stage for increasing EUV performance

Modification of pulsed power generator will lead to higher electrical energy input to plasma.

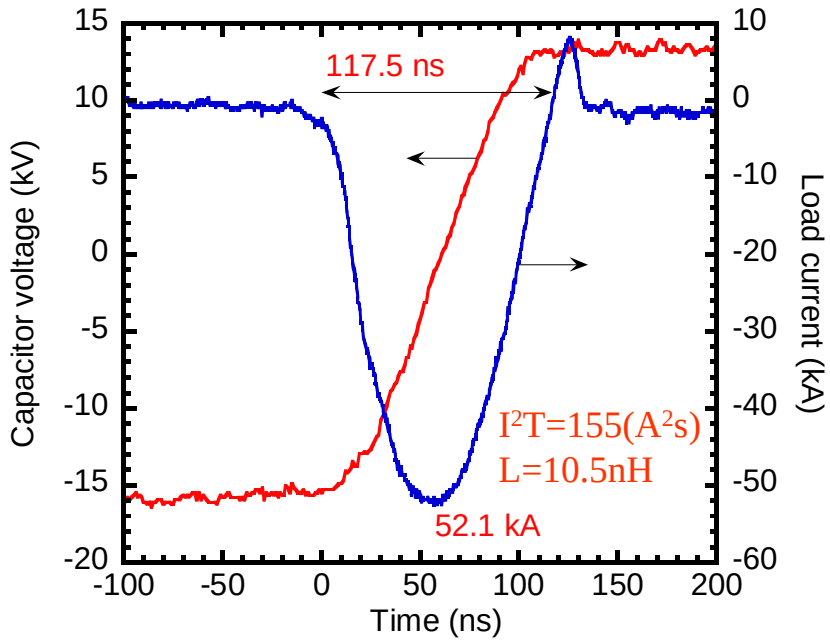


Scaling of EUV power and performance of modified generator

Scaling of EUV power versus I^2T



Short circuit waveforms of modified generator



Decrease in output circuit inductance

Increase in electrical energy input to plasma → Increase in EUV power

Significant short duration of current pulse → Stability & CE improvement

Summary

Terms	former generator	modified generator
Inductance of discharge head	56nH	10-13nH (depends on geometry)
Repetition rate	7kHz	7kHz
Gas	Xe	Xe
Source EUV power	40 W (@7 kHz, into usable solid angle) 120 W (@7 kHz, into 2π sr)	59 W (@7 kHz, into usable solid angle) 121 W (@7 kHz, into 2π sr)
IF EUV power	4.6 W (@ 7 kHz, measurement)	8.4 W (@ 7 kHz, calculation)
Dose stability over 50 pulses	Source: 1.6 % (1σ) IF: 1.8 % (1σ)	Source: 1.3 % (1σ)
Source conversion efficiency	0.37-0.48 %/2π sr (radiated energy into 2π sr / total dissipated energy including all losses)	