Characteristics of Ar Z-Pinch Plasmas Generated by Different Pre-pulses*

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Abstract

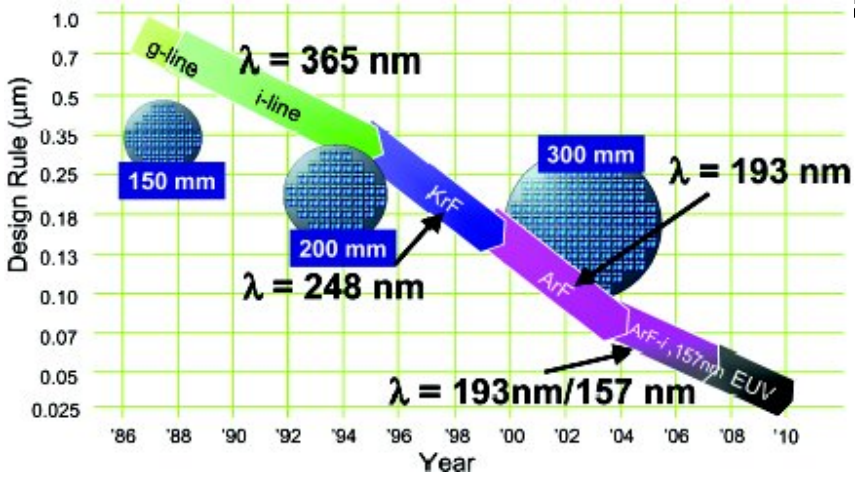
An extreme ultraviolet (EUV) source of ~13.5 nm is required for lithography under 40 nm line definition in the near future. For EUV lithography sources, a discharge-produced plasma (DPP) which we adopted is widely being investigated for much higher-power compared to laser-produced plasmas (LPP). It is known that the pre-pulse in DPP system leads the ignition of a uniform discharge in the main discharge gap, repeatability of EUV energy and increased conversion efficiency. Thus, our experiments were focused on finding influence of pre-pulses on Z-Pinch plasmas by varying the delay time between pre and main pulses and dI/dt of pre-pulses. In this paper, we present the effect of different pre-pulses on the main discharge current.

Introduction

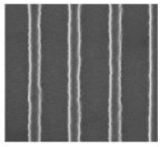
❖ **Modern lithography using KrF or ArF almost reaches the lower limit of 65nm dimensions. ➔ An extreme ultraviolet(EUV) source of ~13.5nm is required for lithography under 50nm line definition.**

❖ **There are two leading technologies of producing EUV light.**

➔ **Laser-produced plasma(LPP) and discharge-produced plasma(DPP)**



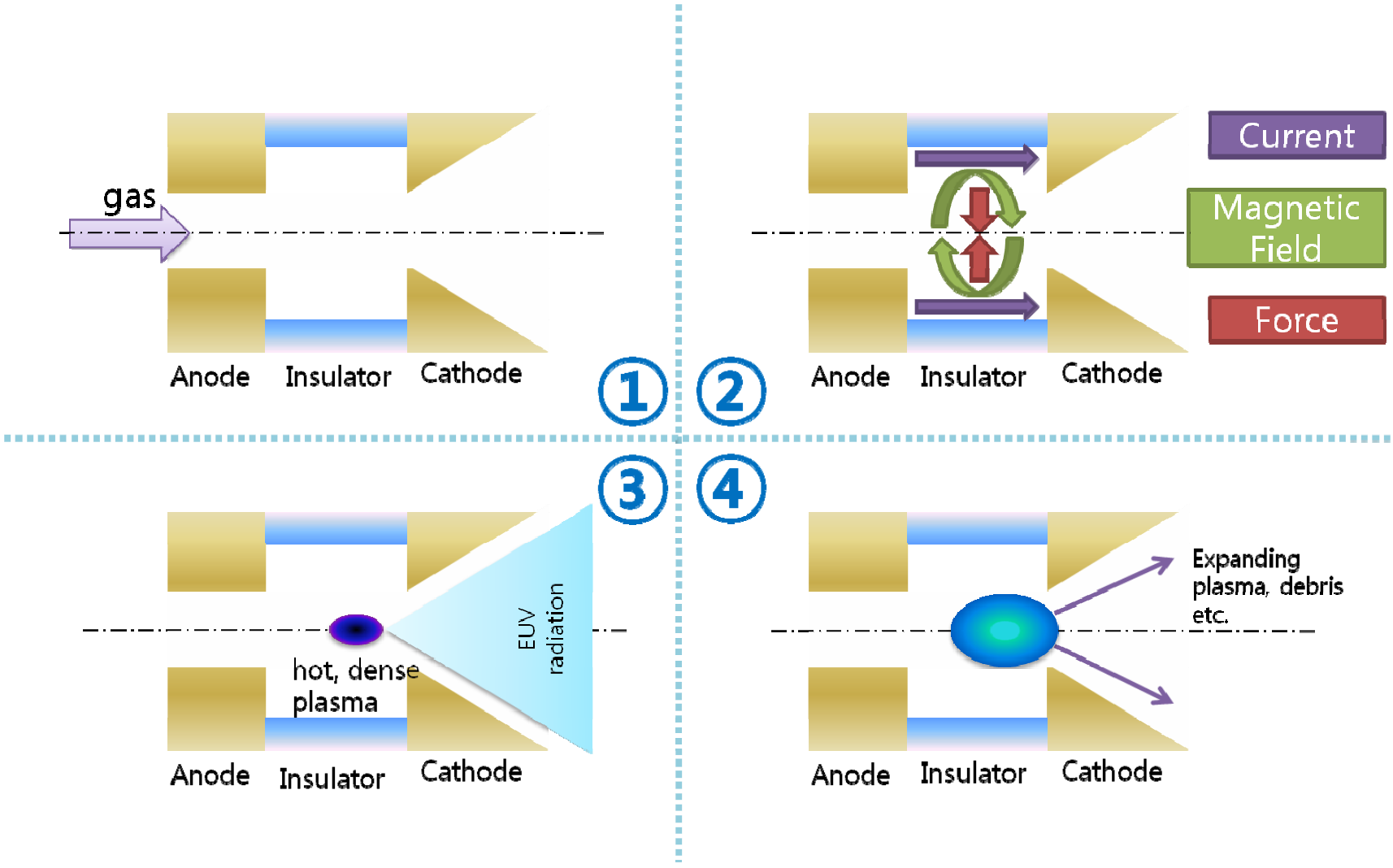
EUV Lithography ➔



32 nm!

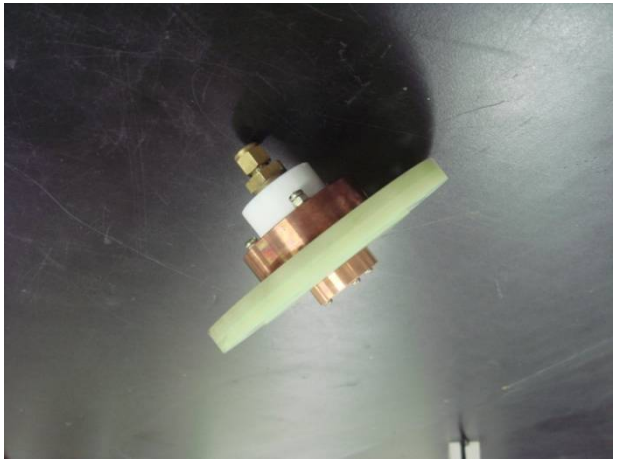
EUV power at the intermediate focus	115 W in 2 % BW
Repetition rate	· 7 – 10 kHz
Energy stability	± 0.3 %, in 3 σ over 50 pulses
Lifetime	· 30,000 hours of operation
Maximum etendue of source output	· 3.3 mm² sr
Maximum solid angle input to illuminator	0.03 – 0.2 sr
Spectral purity: 10 – 40 nm 40 – 130 nm 130 – 400 nm · 400 nm	TBD (To be determined) TBD · 3 – 7 % TBD
Pulse-to-pulse positional stability	10 % of source size
Angular distribution of power symmetrical	TBD (must be axially with respect to the optical axis)
Rotational symmetry of power	TBD
Long term power drift	· ± 2% (optical monitor module)
Stability of repetition rate	· ± 0.1 % (long term)
Spatial distribution of power	TBD
Vacuum before intermediate focus	TBD
Source emission volume	Φ≈1.3 x 1.5 mm²

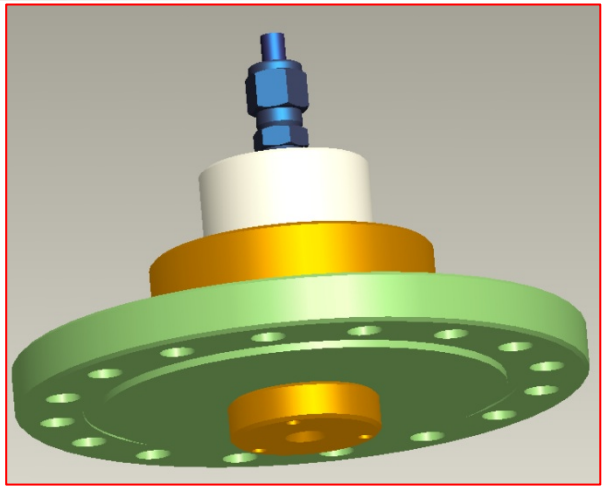
Z-pinch Effect

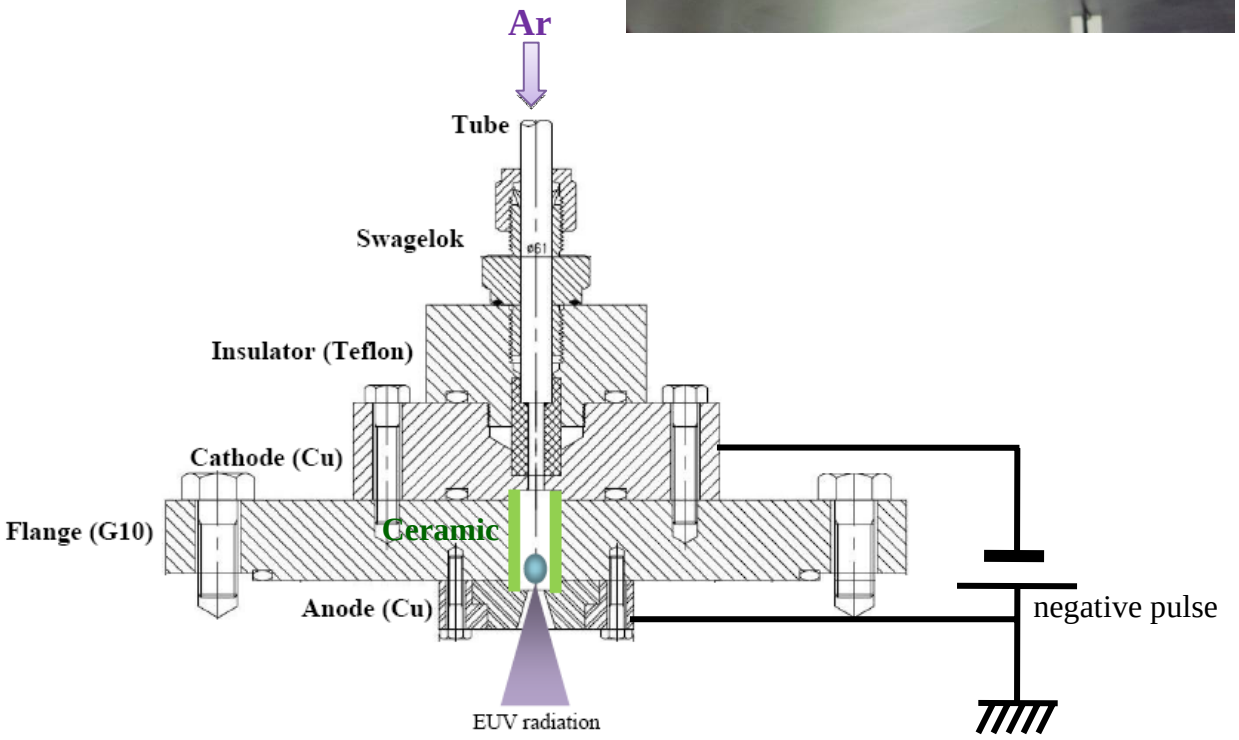


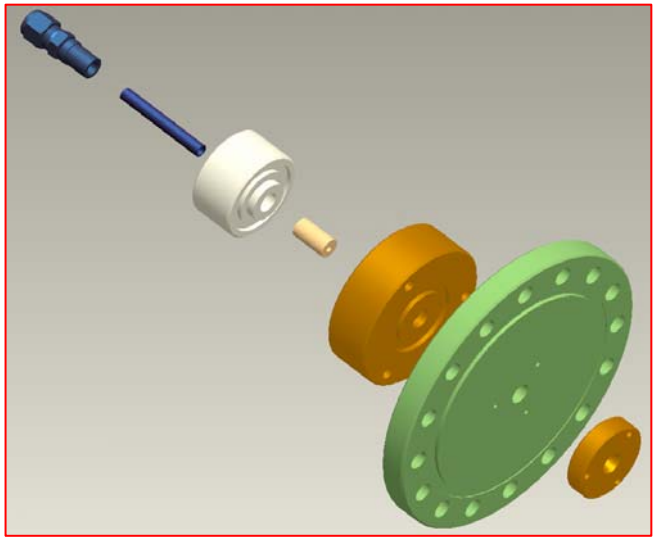
Electrode Configuration

Electrode material	Normalized erosion rate
Tungsten	1
Molybdenum	1.3
Copper	2
Stainless steel	3
Aluminum	5.5
Graphite	9

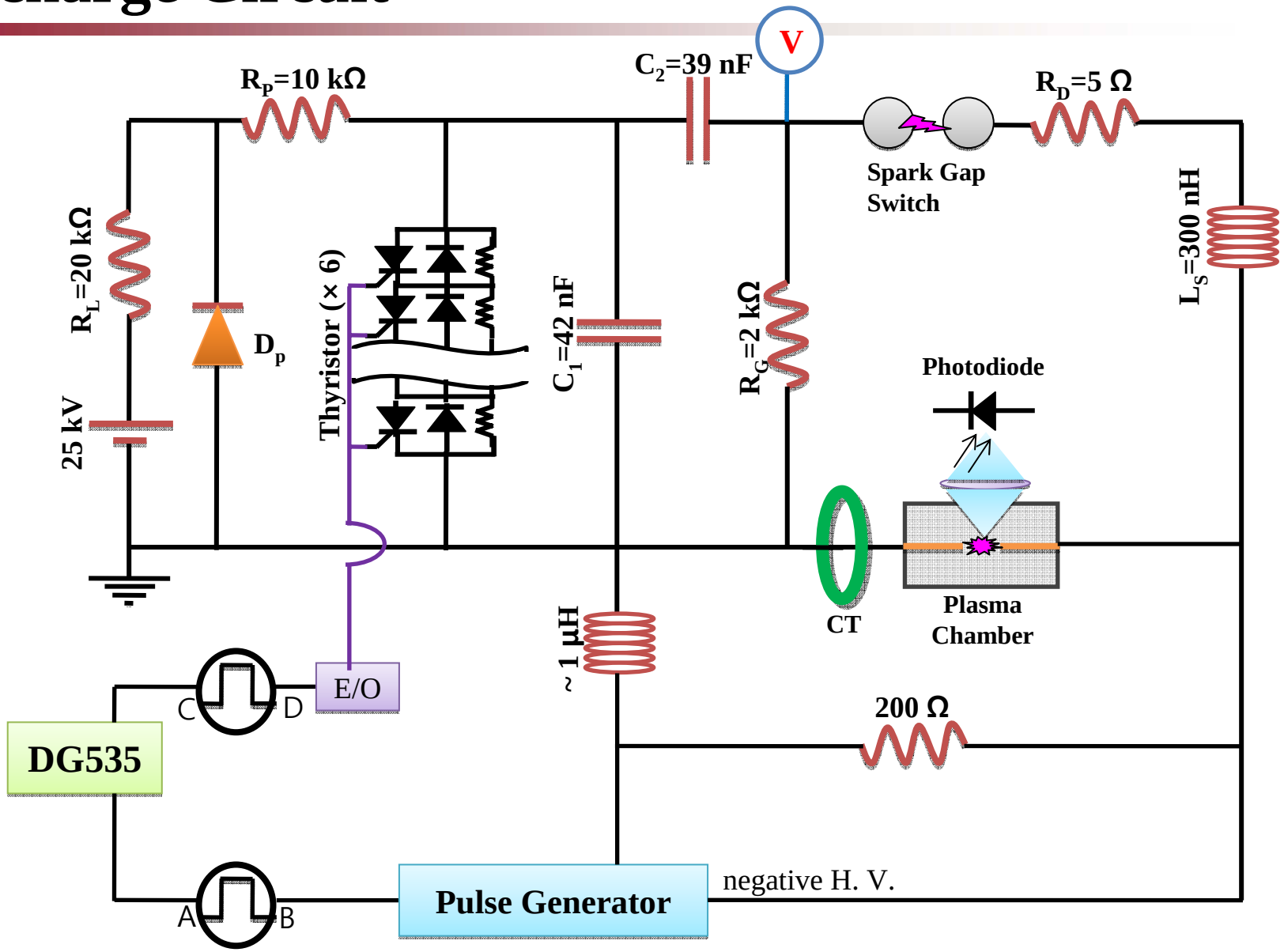




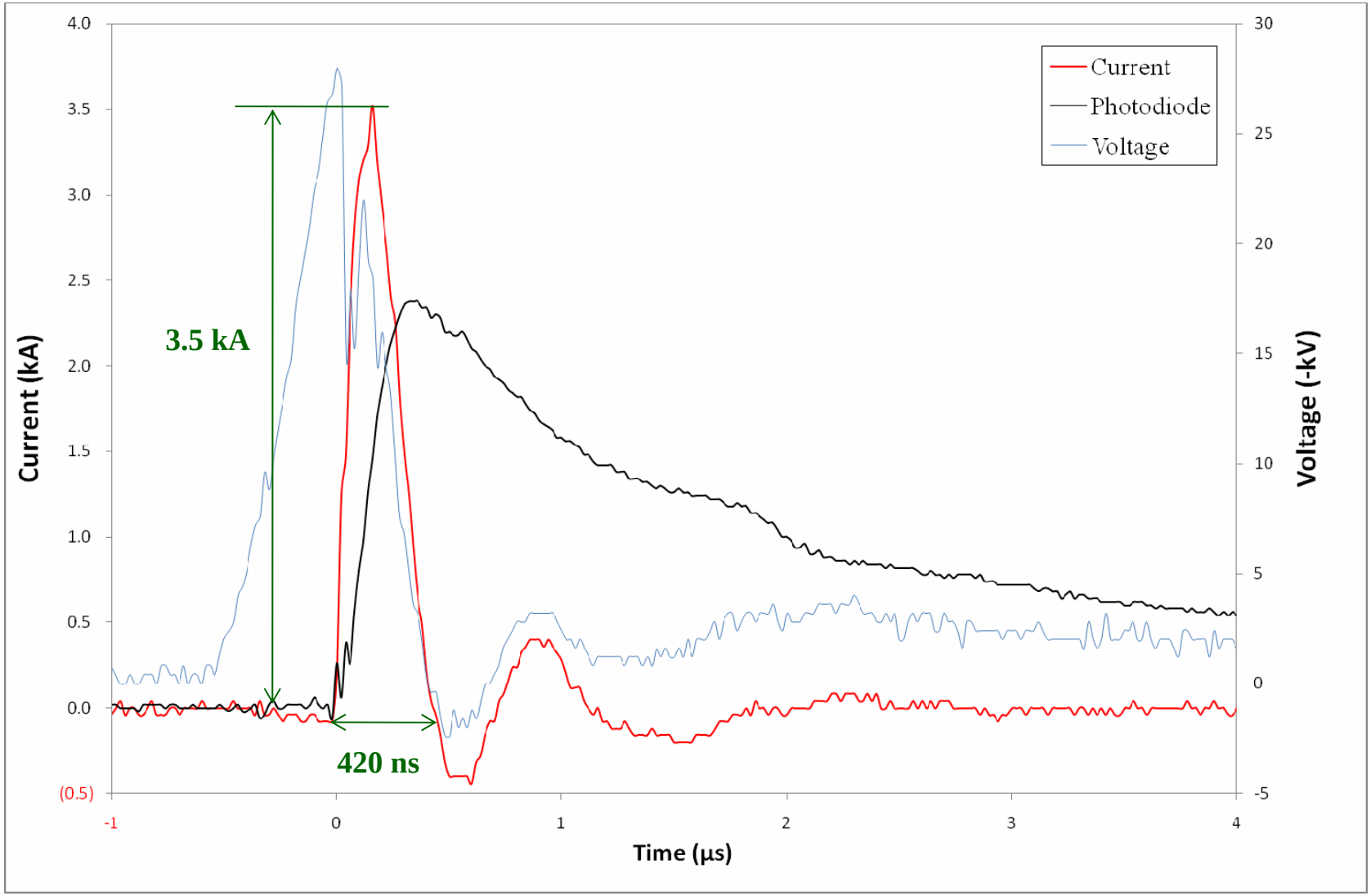




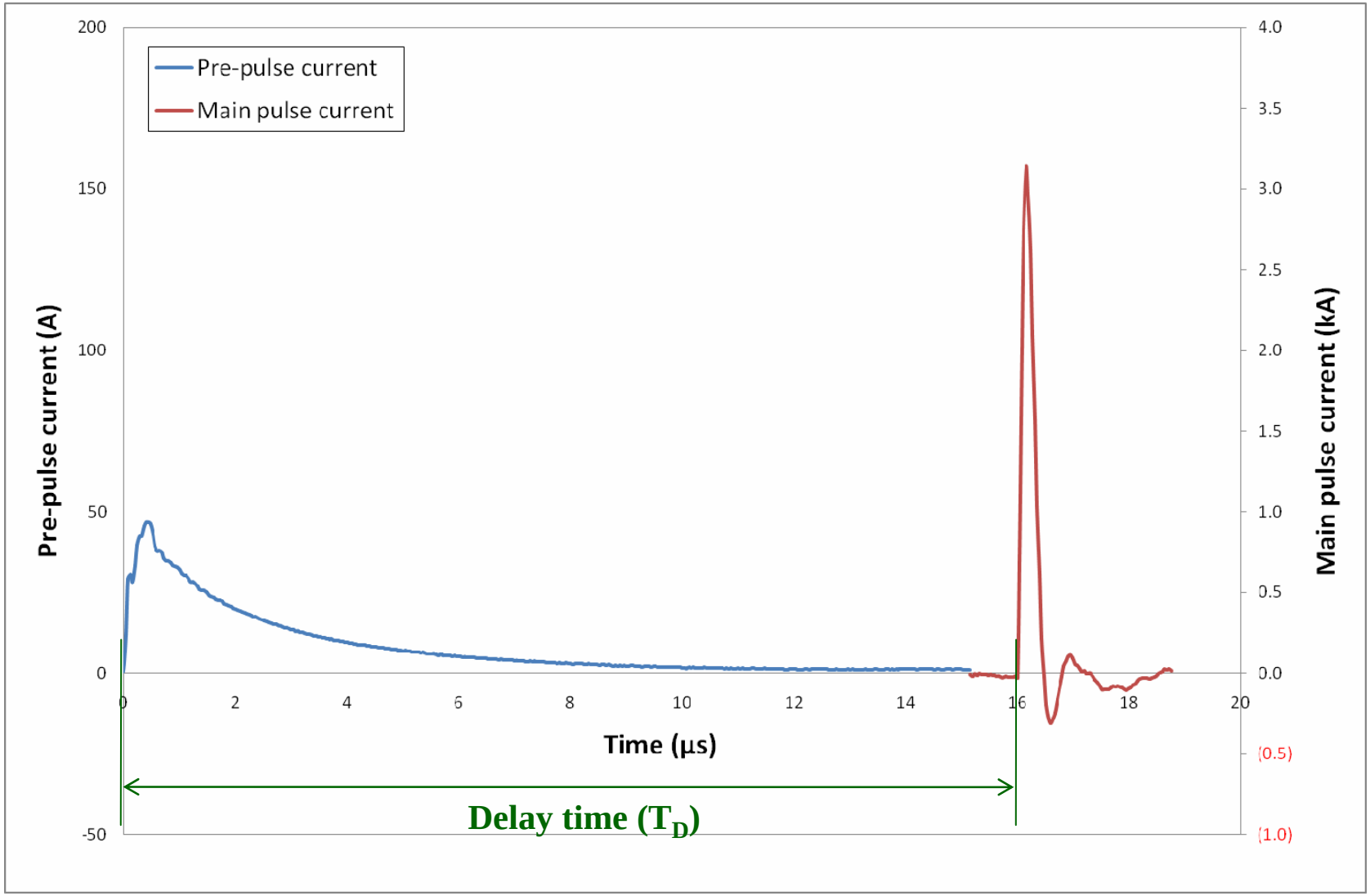
Discharge Circuit



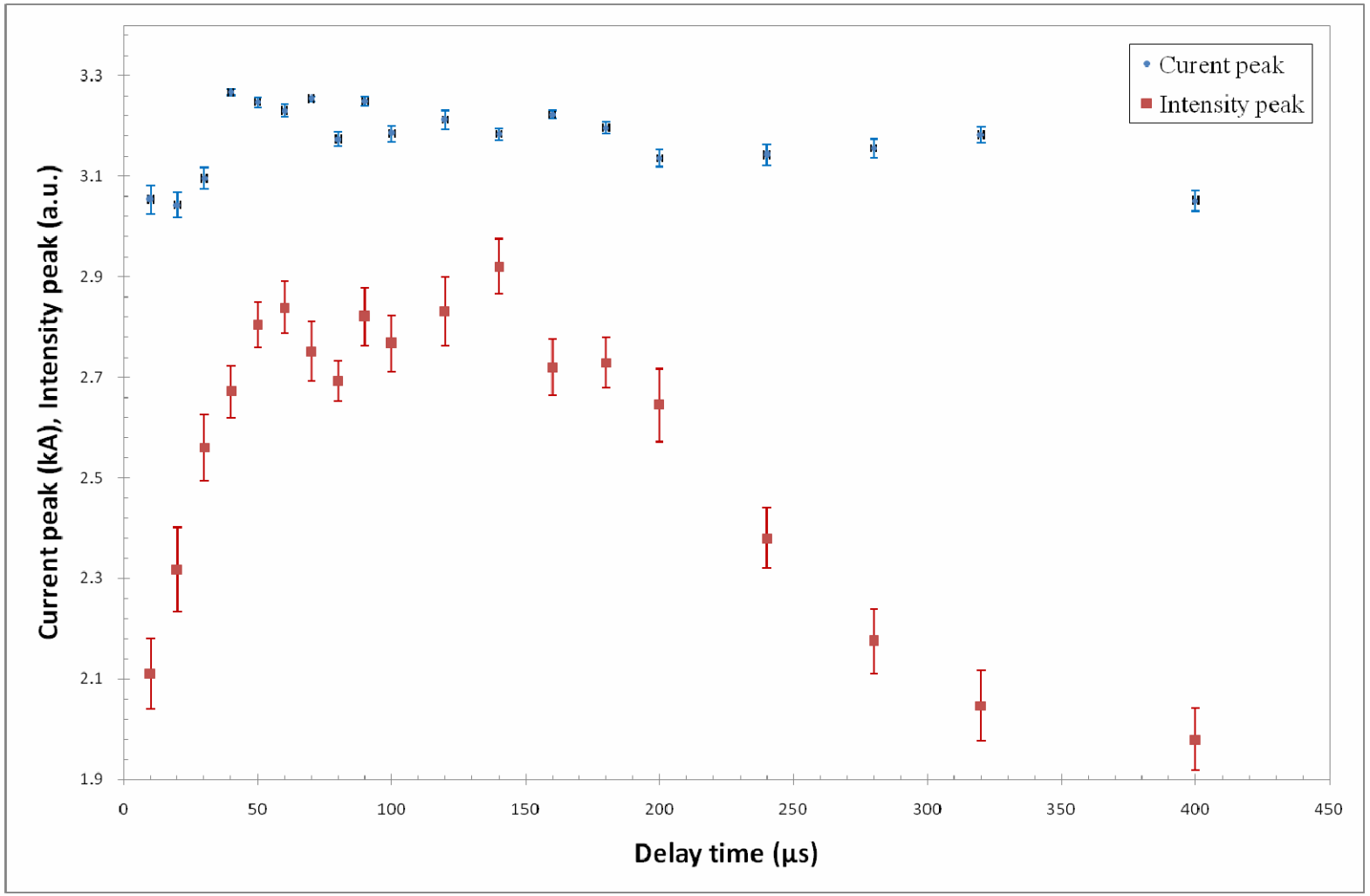
Output Waveforms (charging voltage: 21 kV)



Pre and Main Pulse Waveforms



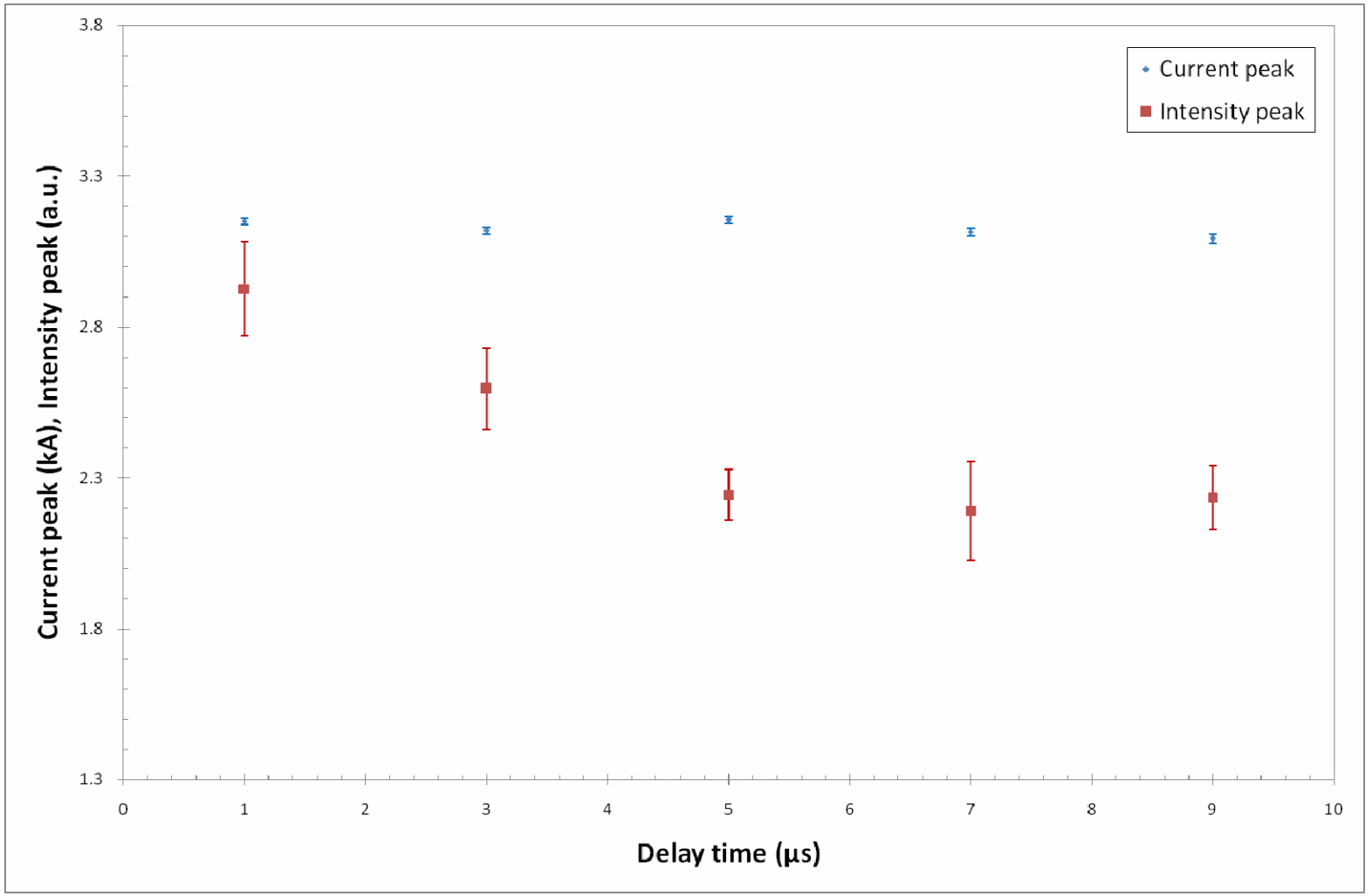
Effect of Delay Time on Main Discharge Current (T_D: 10 ~ 400 μs)



Current peak *without* pre-pulse: 3.191[8] kA
Intensity peak *without* pre-pulse: 1.937[56] (a.u.)

Gas pressure: 6 torr
Charging voltage: 19 kV

Effect of Delay Time on Main Discharge Current (T_D: 1 ~ 9 μs)



Current peak *without* pre-pulse: 3.191[8] kA
Intensity peak *without* pre-pulse: 1.937[56] (a.u.)

Gas pressure: 6 torr
Charging voltage: 19 kV

Summary and Future Work

- **Summary**

  - The discharge current of amplitude of 4 kA and pulse width of 400 ns was obtained at the charging voltage of 25 kV.
  - Main Current waveform is hardly relative with delay time.
  - Light intensity from Z-pinch plasmas varies with delay time. In our experiment, pre-pulses of delay time from 50 μs to 200 μs produce stronger light intensity than the others.
  - Main pulse when pre-pulse still exits emits very unstable light. It is seen that the pulses interact with each other so that light intensity is not stable.

- **Future work**

  - Increase of reproducibility
  - Measurement of main pulse and light intensity by varying amplitude of pre-pulse
  - Design of cooling system to prevent debris and erosion for high repetition rate
  - Construction of EUV discharge system