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HIGH REPETITION RATE PULSED POWER GENERATOR
FOR EXTREME ULTRAVIOLET LIGHT SOURCE

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Abstract

Recently, all solid-state pulsed power generators, which are operated with high repetition rate, long lifetime and high reliability, have been developed for industrial applications, such as high repetition rate pulsed gas lasers, discharges plasma in water and high energy density plasma for extreme ultraviolet (EUV) light sources.

We have studied and developed a new high repetition rate all solid-state pulsed power generator for microlithography to discharge produced plasma (DPP) EUV light source. The developed generator consists of a charger a capacitor bank, a semiconductor switch (IGBT), a pulse transformer and a multi-stage magnetic pulse compression circuit. This system can generate an output peak voltage of 30 kV with voltage rise time of about 85 ns, pulse repetition rate is over 10 kiro pulses per second (kpps) in burst operation.

In this work, high repetition rate discharge plasmas were produced by the developed system and this discharge plasma used to EUV light source with simple circuit.

I. INTRODUCTION

In recent years, researches on practical industrial applications of repetitive pulsed power generated by a magnetic pulse compression circuit (MPC) have been increased. These researches have focused on lasers. In particular, the excimer laser, which is used as a microlithographic light source in semiconductor fabrication, requires a short wavelength, a high repetition rate, a high stability, and a long lifetime. Therefore, most of the excimer lasers for microlithography use a semiconductor switch and a MPC for their exciter. Moreover, a next generation lithography light source expect to a EUV system. EUV generation methods are 2 kinds of systems. There is laser produced plasma (LPP) system and DPP system. A cost of LPP system is very high. On the other hand DPP system is low efficiency. Requirements of DPP system are high power and high repetition operation system.

We have so far used repetitive operation all solid-state pulsed power generator using static induction thyristor and MPC of 200 pps for EUV light sources. This system was contributing those good results about observing pinched plasma and evaluates EUV light source. On the other hand, generally requirements of EUV are high repetition rate operation and high-power.

In addition to a requirement of high-power of the EUV light source. Other motivations, we have the interest of a repetition from the limitation of circuit elements, and a plasma phenomena.

II. REPETITIVE PULSED POWER GENERATOR

A Circuit diagram of repetitive pulsed power generator that we developed is shown in Figure 1. The developed generator consists of a command charger, a static induction thyristor, a pulse transformer, and a 2 stage MPC. The charger is high voltage power supply using resonant inverter (802A, LAMBDA EMI Inc.). An average capacitor charging rate is 8000 J/s (Joule per second). The maximum charging repetition rate is 200 pps.

The static induction thyristor can high-speed turn-on and low loss switching. It was adding magnetic assist that used the saturable inductor to the switching of the thyristor. Magnetic assist has the effect that reduces the switching loss of the thyristor [1]. The switching voltage and current waveforms of static induction thyristor using magnetic assist shown in Figure 2. The switching voltage is 3.8 kV, and the peak current is 6 kA, the current pulse width is 3.3 µs. However, turn-off is not high-speed.

The MPC consists of a pulse transformer (PT), saturable transformer (ST), inductors (Sl0, Sl1, Sl2) and low inductance capacitors (C0, C1, C2). A Fe-based nanocrystalline magnetic core (FT-1H, Hitachi metals Ltd) was used as the coupling core of the PT. The PT have function of step-up transformer. The ST has two functions of step-up transformer and magnetic switch. The nanocrystalline soft magnetic alloys were used as the magnetic switches and transformers (Sl0, Sl1, Sl2, PT, ST). The voltage gain of the PT and the ST is 9 (PT and ST winding ratio, primary : secondary = 3 : 9 and 2 : 6). The capacitances of C0 and C1, C2 are 3.3 µF and 42 nF, 42 nF respectively.

Typical output voltage and current waveforms of the MPC shown in figure 3. A C2 peak voltage and output
current are 30 kV and 34 kA, respectively. The current pulse width is 130 ns.

Figure 4 shows pinched plasma by repetitive pulsed power generator. The diameter of pinched plasma is about 350 µm. An EUV is emitted from this pinched plasma.

**III. HIGH REPETITION RATE PULSED POWER GENERATOR**

**A. IGBT switching from 20kpps demonstrating**

The main switching device is high voltage IGBT module (CM1200HC-66H, Mitsubishi Electric) of high repetition rate pulsed power generator. This IGBT module consist 3 parallel IGBTs in 1 module include reverse parallel diodes. Main specifications of this high voltage IGBT module are as follows.

- Collector-emitter voltage : 3300V.
- Peak collector current : 2400A.
- Turn-on rise time and the turn-off fall time : 1µs.

Figure 5 shows the IGBT switching and resonant charge test circuit. A capacitor $C_0$ has very large capacitance compare to a capacitor $C_1$. The capacitances of $C_0$ and $C_1$ are 2 mF and 8µF, respectively. Figure 6 shows voltage and current waveforms of the IGBT. The switching voltage is 1 kV, and the peak current is 2 kA, the current pulse width is about 20µs.

Figure 7 shows voltage waveforms of $C_0$ and $C_1$ from 20 kpps operating. It turns out that $C_1$ charges on the twice about as many voltage of $C_0$ as this by resonance charge to $C_1$ from $C_0$. Repetition rate is 20 kpps.

**B. Design of pulsed power circuit**

A design circuit diagram of a high repetition rate magnetic pulse compressor shown in figure 8. Semiconductor switch is used high voltage IGBT module. Pulse compression stages are four stages. Design specifications are as follows.

- Input voltage : 1 kV.
- Output voltage : 29 kV
- Output current : 35 kA
- Output current pulse width : 85 ns
- Maximum repetition rate : 20 kpps
Figure 9 shows photograph of high repetition rate pulsed power generator without final compression stage and discharge chamber. The generator consisted of a high voltage IGBT, a capacitor bank (C₀), an oil capacitor (C₁), ceramic capacitors (C₂-C₄), a magnetic switch (S₁₀-S₁₄), and a high voltage step-up pulse transformer (PT). The voltage gain of the PT is 15 (winding ratio, primary : secondary = 2 : 30). Those magnetic device material is used a Fe-based nanocrystalline magnetic core (FT-3H, Hitachi metals Ltd).

C. Simulation and test results

Figure 10 shows voltages and currents simulation results of high repetition rate pulsed power circuit. We used simulator is PSpice. On the other hand, measurements results of voltage and current waveforms shown in figure 11.

Figure 12 and figure 13 shows burst operation result of high repetition rate pulsed power circuit. Repetition rate are 8 kpps and 20 kpps respectively.

Figure 5. IGBT switching and resonant charge test circuit

Figure 6. Voltage and current waveforms of IGBT

Figure 7. Voltage waveforms of C₀ and C₁ from 20 kpps operating

Figure 8. Circuit diagram of a high repetition rate pulsed power generator
IV. SUMMARY

We have developed the high repetition rate pulsed power generator for EUV light source. Summarize are as follows.

- High repetition rate pulsed power generator was developed without final pulse compression stage.
- IGBT switch and MPC are capable of operating at 20 kpps.

V. REFERENCE