Pulse Generator for Gas-Discharge Source of the Extreme Ultraviolet.

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Abstract – The generator is designed for pseudo-spark gas discharge pumping in the xenon. The arising radiation is supposed to be used in the new generation of microchip lithography. The generator output characteristics are: the pulse energy – 10 J, the voltage – 6 kV, peak current during operating at the short circuit – 40 kA, the base current impulse time – 200 ns, frequency – up to 500 Hz.

1. Introduction

One of advanced trend of nanotechnology is building up of next generation lithography systems for chip production with feature size less than 30 nm. Main producers of lithography equipment specify wavelength of extreme UV radiation for this purpose – 13,5 nm [1]. A variety of concepts are being investigated for use as an extreme UV light source. One of the way based on using high-temperature plasma produced in pseudospark discharge [2]. Description of pulse generator for pumping pseudospark discharge in xenon is presented in this paper.

2. Electric circuitry and design.

Fig. 1 shows the design of the generator. The generator is made as a thyristor-magnetic generator with two compression stages as it made in [2]. The line voltage comes in the filter capacitor C1 through the ac/dc converter and the three-phase transformer. By means of the IGBT-module VT the voltage on the C2 is charged and stabilized at the level (0.6…1) kV. The thyristor switch, consisting from 12 parallel thyristors VS1…VS12, commutates the capacity C2 in the primary winding of the set-up pulse transformer TV1. The capacity C3 is charged up to 6.5 kV, further the pulse duration is reduced by two magnetic compression stages (C3, L3 and C4, L4). The first stage is reduced the pulse duration up to 0.6 μs, the second one is up to 200 ns. Because of the low resistance of the gas discharge of low pressure (~ 10 mOhm), the generator was tuned basically at work on the short circuit. In the generator the following basic elements are used: the thyristors VS - TB343-500-18, capacitors C2 – K78-2 - 2kV - 0.47 μF – 4, chokes L2 – 23 turns in

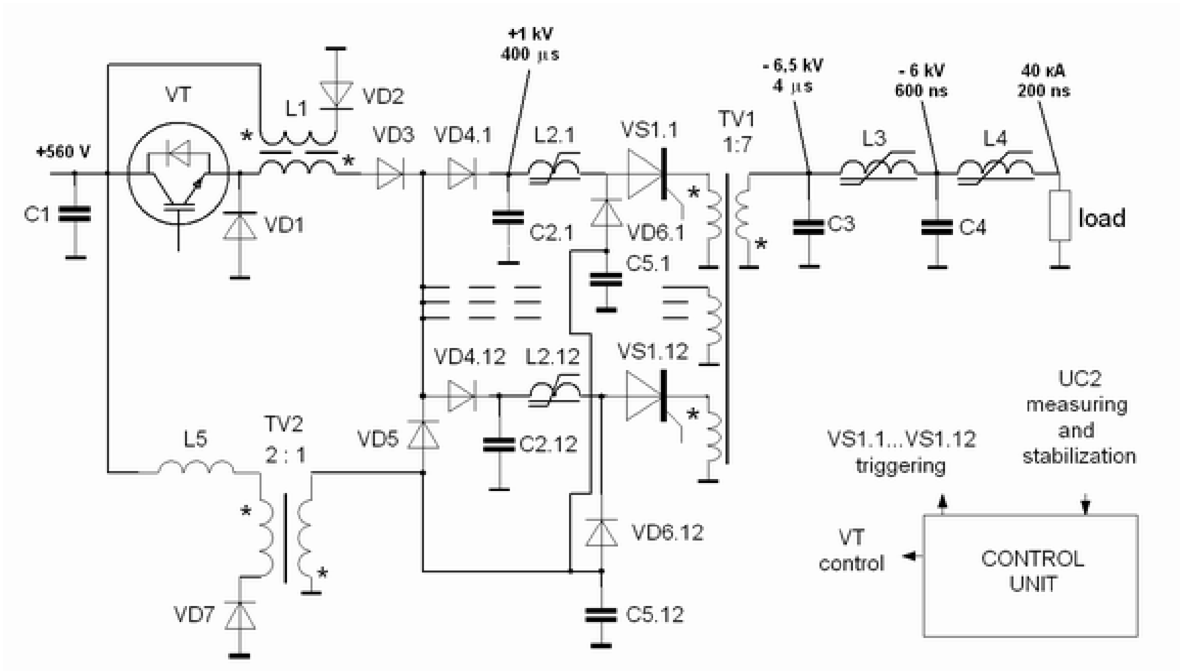

Fig. 1. Principal scheme of the generator.

the ferrite core 2K(65x40x6) – 200VNP. The pulse transformer TV1 is made in the core of metal-amorphous alloy 2NSR (300x180x20), the primary and the secondary turns number are 2 and 14 accordingly. The compression stages capacitances are 0.5 μF and were selected from 70 capacitors KVI3 – 12 kV – 6800 pF each one, the chokes of the magnetic compression stages were made in the cores from the alloy 2NSR (300x180x20) – 0.025 mm (L3) and from the permalloy 50 NP (300x180x25) – 0.01 mm (L4). The choke L3 turns number - 5, the choke L4 has 1 volumetric turn.

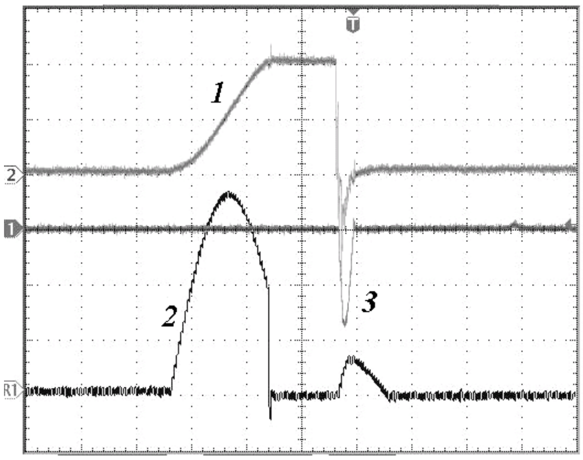

Fig. 2. Charging voltage of C2 (1) (400 V/div), charging current of L1 (2) (20 A/div) and recuperation current of L5 (3) (50 A/ div). Time – 200 μs/ div

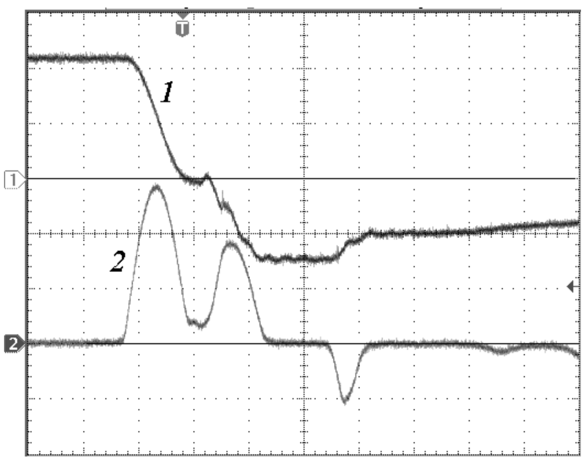

Fig. 3. Voltage capacitance C2 (1) (400 V/ div), the current of one thyristor VS (2) (200 A/ div). Time – 4 μs/ div

The cooling of the IGBT-module, the power thyristors and the core chokes of magnetic compression is made by water. The premagnetization of all nonlinearly magnetic components (L2.1…L2.12, TV1, L3, L4) is made by the direct current in 17 A in one turn.

The pulse cycle begins from the arrival of the control pulse on the IGBT-module VT (τ = 500 μs) from the control unit, then the charge of the capacitances C2 begins through the charging choke L1, the diode VD3 and isolating diodes VD4.1…VD4.12. Capacitances C2 voltage level is measured by the divider and comes in the control unit. Stabilization of C2 voltage in the 0.6ч1 U_{max} level is made by the stabilization scheme turning off control pulse at the achieving of the required voltage level. The rest energy in L1 is recovered in C1 through the secondary winding of L1 and the diode VD2. To decrease the emergency overvoltage in the thyristors VS1 and VT, the varistors were connected in parallel (are not shown on the scheme).

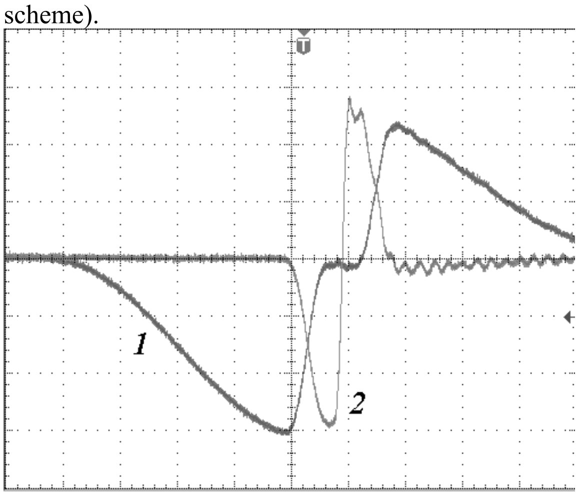

Fig. 4. Voltages of C3 (1) (2 kV/ div) and C4 (2) (2 kV/ div). Time – 1 us/ div

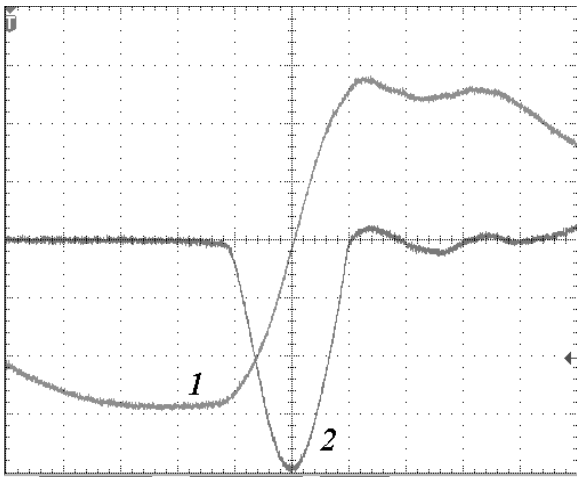

Fig. 5. Voltage of C4 (1) (2 kV/ div) and current through the load (2) (10 kA/ div). Time – 100 ns/ div

The control module has a protection circuit on the charge current (on the level ~ 100 A) and charging voltage (on the level 1100 V). After ending of the charging C2 capacitances, the start pulses from the control module come on the thyristors VS1.2…VS1.12 and the energy from the C2 capacitances comes in the C2 capacity through the set-up transformer. The chokes L2 delay commutation in 2 μs, protecting thyristors from the starting losses. The thyristors overall current peak is ~ 7.5 kA, duration –

4 μs. The pulse on the level ~ 6 kV is compressed by nonlinear chokes L3 and L4. The time charging of C4 is about 0.6 μs, the discharging time on the load is ~ 0.2 μs. The load current achieves the amount of 40 kA during the short circuit operation. C2 capacitance is recharged up to ~5 kV of positive polarity. The choke L4 is "closed" (non-saturated) for this polarity and choke L3 is opened. Therefore in loading the single polarity pulse is formed.

Then the process of recuperation of unabsorbed in load energy begins. C4 capacity is discharged in the C3 capacitance which is charged up to +4.4 kV. Through transformer TV1 energy goes to C2 capacitance and charging it up to -550 V. The negative voltage in C2 closes the thyristors VS1. Because of the large current fall speed through the thyristors at the moment of its closing, the peak voltage amplitude on the thyristor anode reaches 1.5 kV. To decrease this thyristor anode peak voltage the circuits VD6, C5 were set. The negative voltage in C2 and C5 is imposed on the transformer TV2 and rest energy after the end-of-cycle returns through the choke L5 and the diode VD7 in to the filter capacitor C1 in a time ~50 μs. The recuperative circuit allows to return 3 J out of 10 J cumulated in C2, into the primary circuit. The peak pulse generator frequency is 500 Hz. Now it is limited to L2, TV2, and L5 heating.

Fig. 2 shows the voltage of the charge capacitance C2 waveforms, charging current of choke L1 and recuperative current through L5. One can see the abrupt current fall at the moment of IGBT-module switching off after the reaching of the fixed level in C2 voltage.

Fig. 3 shows the voltage capacitance C2 waveforms and one of the thyristor VS current. Second half-wave is C2 recharging by undissipated energy; negative half-wave is thyristor closedown. Fig. 4 shows capacitance C3 and C4 voltage (process of magnetic compression). Negative pulses is voltages charging, positive pulses – recharge and reflection to the beginning. Fig. 5 shows the C4 voltage waveforms and the current through short-circuited load. The current is as a single-polarity pulse. The circuit inductance C4 – L4 calculated from current wave form is ~ 9 nH.

3. Conclusion

The thyristor-magnetic generator of high current nanosecond pulses (40 kA, 200 ns, 500 Hz) has been developed for a low-pressure gas discharge pumping. The reliable operation of 12 parallel thyristor in current pulse duration of 4 μs and amplitude of 7 kA was reached according to the high-level symmetry of a discharge circuits. Proprietary design of the recuperation scheme of reflected energy from unmatched load allows to save 30 % of a source power.

References

[1] V. M. Borisov, A. Yu Vinokhodov et. al., Journal of Academy of Sciences. Physical series. Vol. 68, № 4, pp. 503 - 508, 2004.

[2] Yu. D. Korolev, O.B. Frants, V. G. Geyman, et al,. *in Proc. of SPIE,* Zvenigorod, vol. 5401. pp. 16 – 21, 2003.