A HIGH-VOLTAGE PULSE GENERATOR FOR PLASMA ION IMMERSION IMPLANTATION APPLICATIONS

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Abstract

The design and construction of high-voltage pulse generator for applications in treatment of metal and polymer materials by Plasma Ion Immersion Implantation (PIII) are described.The generator was built in a circuit category of Pulse Forming Network (PFN), consisting of ten LC sections with L = 300 µH , C = 2.5 nF and an air core high-voltage pulse transformer. The instrument was designed to produce an adjustable, several amperes, flat 70 kV pulse for over 15 µs with pulse repetition frequency (PRF) from 50 to 500 Hz. The generator is fed with sinewave, constant high current source, and a 10 kV, 2A switching power supply. The voltage and current pulse shapes of PIII reactor using this pulse source are presented.

Introduction

Plasma Immersion Ion Implantation (PIII) technique was developed during the late 80's for surface treatment of nonplanar components in contrast with the traditional method of implantation using ion accelerators. There are two basic limitations of the ion implantation technique based on accelerators: line -of -sight and high cost of equipment and processing. PIII technique overcomes these limitations by extracting directly the ions of interest from the plasma where the samples to be irradiated are immersed. The application of negative high-voltage pulses to a target immersed in plasma and the subsequent sheath expansion in the presence of high voltage allows three dimensional implantation in the samples. Preliminary results of INPE PIII research have shown successful N implantation in Al samples, but indicated the necessity of better plasma optimisation and confirmed the need for higher PRF and negative high-voltage pulse generation.

The need for high-voltage pulse generator (adjustable from 0 to 70 kV, pulse duration more than 15 µs), with high PRF were the motivation of the design of the present pulse generator and its construction. Our efforts have been concentrated on three important objectives:

(i) Design of a line-type pulse generator (pulse duration of 15 µs, adjustable pulse voltage in the range 0 - 70 kV for nonlinear loads such as PIII reactor.

(ii) Design of high-voltage pulse transformer between pulser and load (PIII reactor).

(iii) Design of high-voltage adjustable sine-wave constant current switching power supply (0 - 10 kV/ 2A) for line-type high-voltage pulse generator.

Pulse Generator

The line-type pulser is commonly known as a pulse forming network (PFN), as it has a lumped constant transmission line which serves not only as source of electrical energy during the pulse occurrence but also as pulse-shaping element. The PFN in this generator consists basically of inductors and capacitors set in a specific configuration in order to provide the desired pulse shape. Fig.1 shows the electrical diagram of the pulser circuit. In this scheme, the PFN capacitors are charged from DC power

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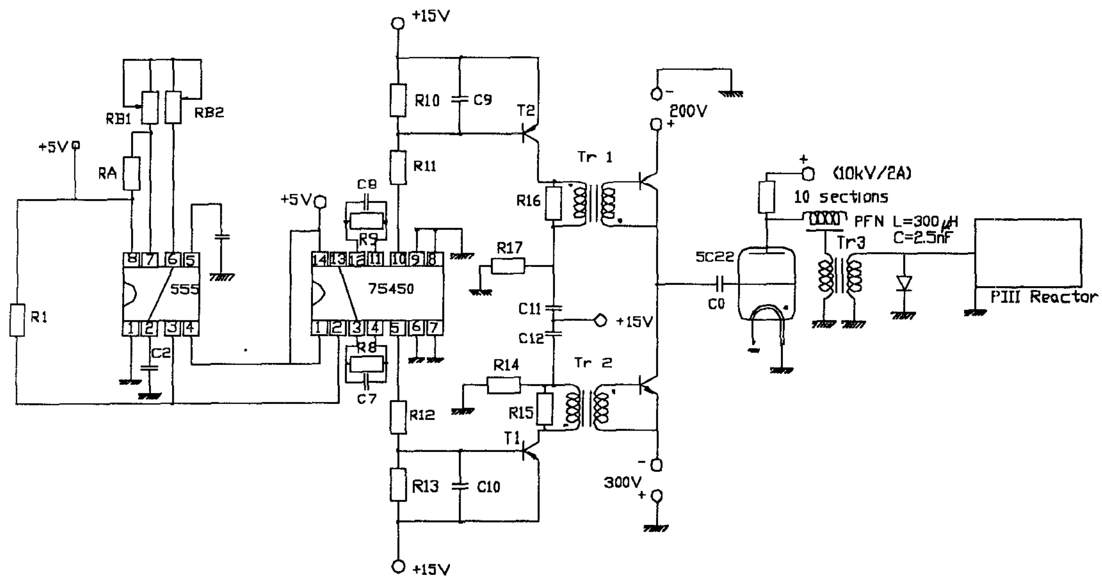

Fig.1 Circuit of the high-voltage pulse generator based on thyratron 5C22.

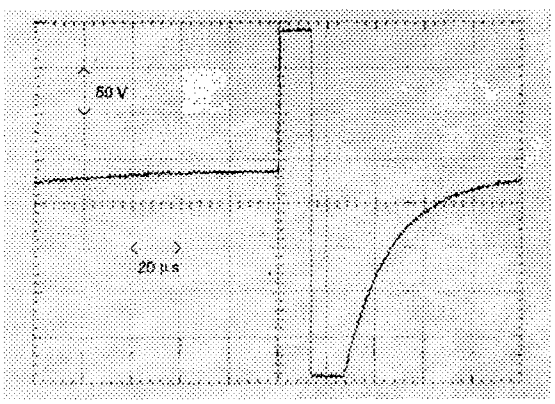

Fig.2 Grid voltage waveform for start-stop pulse of the thyratron 5C22

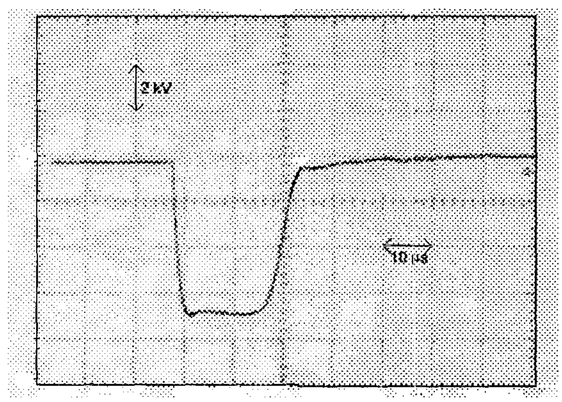

Fig.3 Pulse voltage waveform on input of the high-voltage pulse transformer Tr_3 from Fig.1.

supply (10 kV,2 A). The charging operation is completed when the equilibrium voltage on the network is nearly equal to the power supply voltage V_o. The energy stored in the capacitive elements is discharged on the load upon closing a fast switch tube (thyratron 5 C 22).

The PFN output impedance Z_o can be determined as $Z_o=(L/C)^{1/2}$, where L and C are the inductance and capacitance values of each cell, respectively. If the load is matched to the PFN output impedance, a rectangular voltage pulse with time duration $\delta = 2N(LC)^{1/2}$ and amplitude $V = 0.5 V_o$ occurs across the load after closing the thyratron, where N is the number of LC cells in PFN and V_0 is the PFN charging voltage [1]. The triggering of the thyratron 5C22 is driven by positive voltage pulse of 150 V and a negative cutoff voltage pulse of 250 V in consecutive order to the thyratron grid.

By means of the integrated timer 555, a tunable oscillator generates rectangular pulses, which are applied to the input of the circuit 75450. Two independent pulse sequences, alternatively changing in time, are obtained and drive the fast transistor switches T_3,T_4 by driver transistors T_1,T_2 and pulse transformers Tr_1,Tr_2 respectively. The capacitor C_o is included to isolate the switch circuit from thyratron high voltage.

The instrument testings have shown a high stability in the high-voltage pulse amplitude during continuous operation (more than 1 hour). The shape of a grid pulse and output high-voltage pulse across the primary winding of the air core high-voltage pulse transformer are shown in Fig. 2 and 3, respectively.

High-voltage pulse transformer

Utilizing results from Refs. (1) and (2), an air-core high-voltage transformer was built in a spiral-strip configuration. With this transformer construction, the voltage gain is largely a function of the radial thickness of the secondary winding because the turns directly overlay each other. The winding stack, therefore, has a pure radial voltage gradient between the high-voltage inner turns and low voltage outer turns. However, because of high winding density, spiral-strip windings must be ordinarily immersed in oil to dislodge air from the secondary windings and improve the insulation. In our transformer construction, the primary and secondary windings consist of 120 and 1800 turns, the magnetizing and leakage inductances of the primary winding are 800 μH and 125μH, respectively. The shape of the transformer output high-voltage pulse across the resistance load of 2.5 kΩ is shown in Fig.5.

High-voltage power supply

A practical circuit diagram of a high-voltage, tunable (0 - 10 kV, 2A), sine-wave, constant current source switching power supply, designed by using results from Ref. (3), is shown in Fig.4. It consists of:

(i) A generator of equidistant rectangular pulses, based on the timer 555. It is possible to tune the frequency of the generator by the potentiometer R_{B1}(fine) and R_{B2}(coarse) (Fig.4,a)

(ii) Two independent, but alternatively changed in time, pulse sources, based on the circuit 75450, the driver transistors T_1, T_2 and pulse transformers Tr_1, Tr_2 direct the transistor switches T_3, T_6 and T_4, T_5 { Motorola IGBT E.M.S. (Energy Management Series) modules MG 300 A2U100/120 or MG 100 BZ100}, respectively (Fig.4,a).

(iii) A resonant circuit L_1C_{13} and high-voltage transfer transformer Tr_3, which is between the transistor switches T_3, T_6 and T_4 ,T_5. The diodes D_3 - D_6 are used as preventive measure against over voltage (Fig.4,b). Tr_3 is wound on high-frequency toroidal ferrite core with rectangular crosscection equal to $4.5.10^{-4}$ m^2 and mean length of the magnetic path equal to 0.38 m. The primary and secondary windings consist of 50 and 2500 turns, respectively.

(iv) An error amplifier based on the circuit 311 is used for tuning the high voltage output from 0 to 10 kV using the potentiometer R_6 (Fig.4, a).

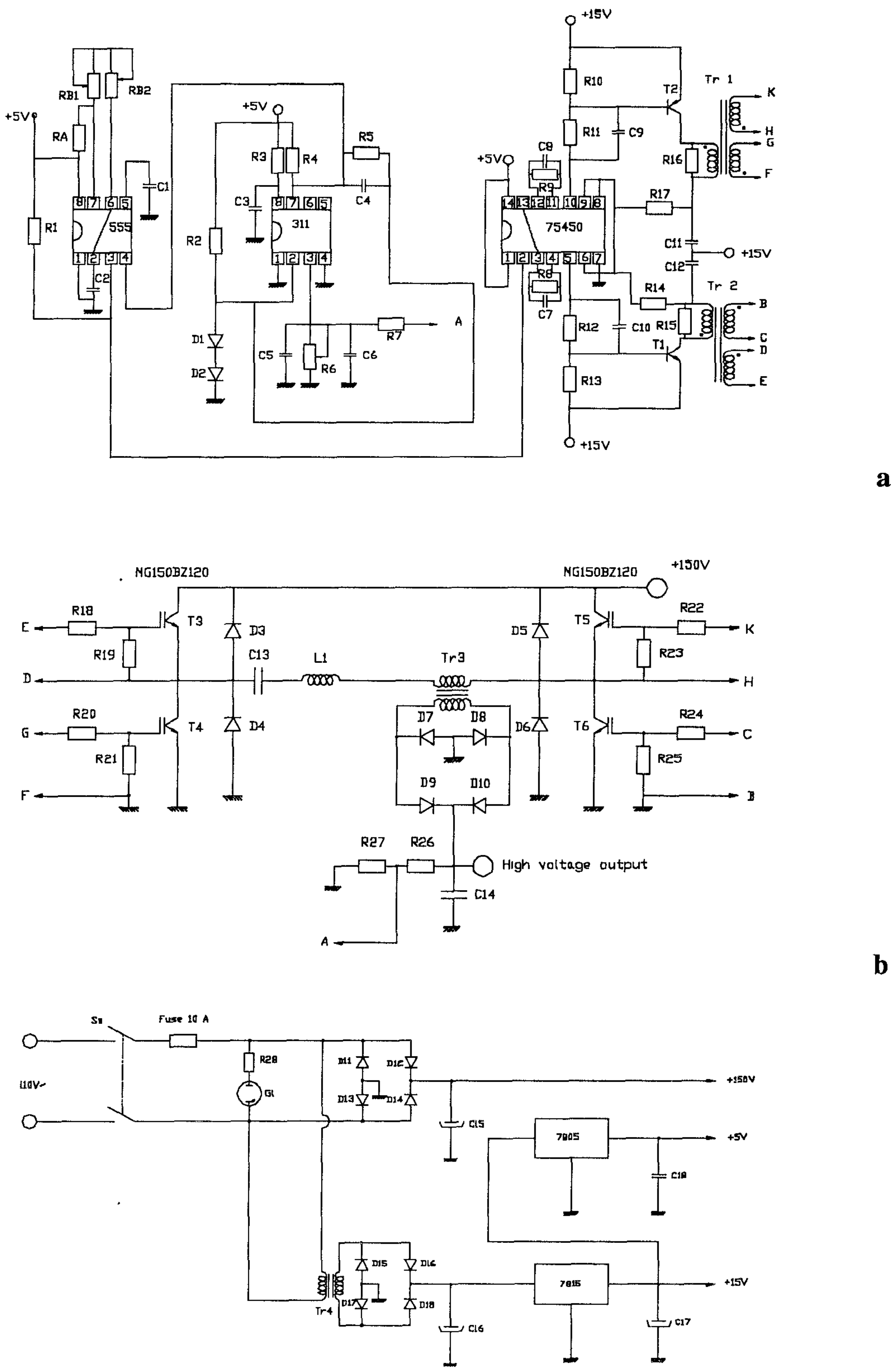

Fig. 4 - Circuit of the high-voltage tunable switching power supply.

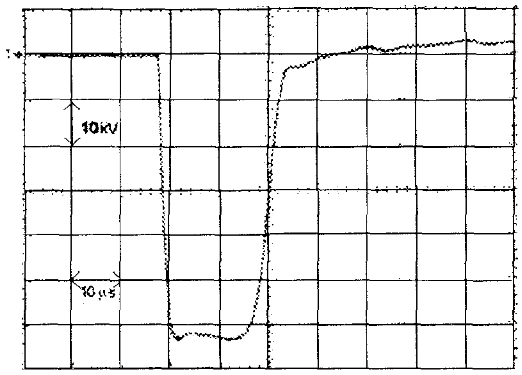

Figure 5. Pulse voltage waveform of the transformer output across the resistance load of 2.5 kΩ.

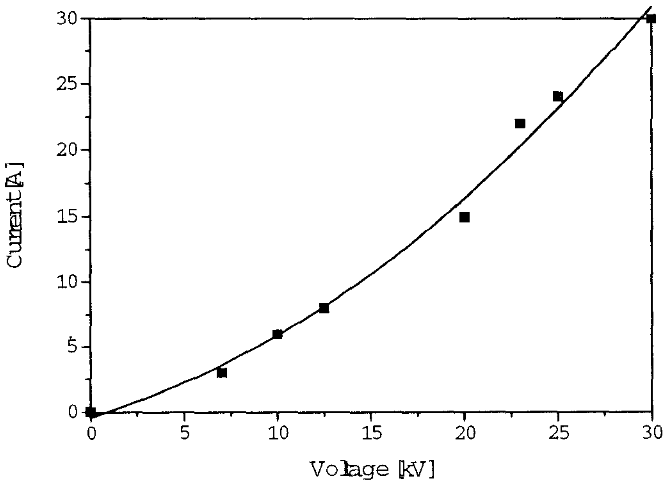

Figure 6. Output voltage-current characteristic of the PIII reactor driven by the pulser.

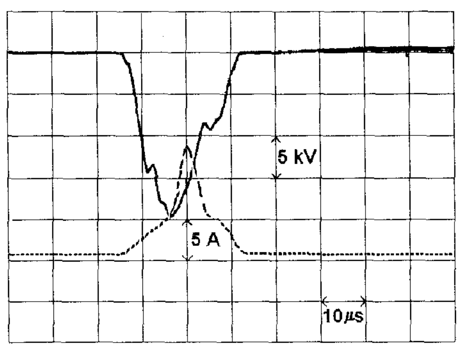

Figure 7. Pulse voltage (continuous line) and current (dashed line) waveforms during the operation of the PIII reactor.

(v) An auxiliary power supply with three independent voltages: 150 V, 15 V and 5 V (Fig.4, c).

The high voltage transfer transformer Tr_3, diode rectifiers D_7 - D_{10} and charging capacitor C_{14} are assembled in additional block, immersed in transformer oil.

Summary

The performance test of the high-voltage pulse generator was conducted using a PIII reactor with a cylindrical volume (0.3 m diameter and 0.5 m length). Plasma generation was produced by a 2.35 GHz, 600W magnetron in DC working regime.The output voltage-current dependence of the high-voltage pulser using this PIII reactor is shown in fig.6, and typical voltage and current shapes during the operation are shon in fig.7. PRF up to 500 Hz was achived at the maximum charging voltage of 10 kV during the PFN operation.

Further increase of the output amplitude of the generator above 30 kV results in appearence of arcs between the high-voltage electrode of the PIII reactor and the walls, which are grounded. This event is shown in the presure interval from 10^{-3} to 10^{-2} Torr of the working gas, where the conditions of plasma implantation are optimal.The maximal amplitude (aprox.70 kV) of the output pulse voltage was obtained in working presure of 10^{-5} Torr, but unfortunately, the current was negligibly small, due to the low plasma density.

In conclusion, It was possible to construct a high-voltage pulser for PIII applications which is capable of working with voltages up to 30 kV.Operation at higher voltages necessitates a PIII reactor with a larger volume and electronic current feedback of the pulser in case of electrical breakdown.

The pulser has experienced no electrical or mechanical failures during its operation, for a long time.

An efficiency of 90 % was obtained for charging voltages higher than 8 kV, due to the negligibly small switching losses in the power supply. The major losses appear to come from the resistivity and the leakage inductance of the high-voltage transfer transformer Tr_3 (Fig.4, b).

Acknowledgment

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Reference:

1. G.N. Glasoe, J.V. Lebacqz : Pulse Generators, Mc Graw-Hill Book Company, N.Y., 1948.
2. W. James Sarjeant, R.E. Dollinger: High-Power Electronics; TAB Books Inc., 1989, p.276.
3. I.V. Chaltakov: J.Physics E; Sci.Instruments; (21), p.663, 1988.