

PLASMA GENERATING IN PULSED INDUCTIVE DISCHARGE FOR DEPOSITION OF THIN FILMS WITH SELF-ION BOMBARDMENT

A.I. Kuzmichev

National Technical University of Ukraine "Kiev Polytechnical Institute"

pr. Peremogy 37, KPI-2230, 252056 Kiev, Ukraine

There is a great interest in evaporative deposition systems with simultaneous self-ion bombardment for manufacturing high quality thin films for electronics, optics and mechanics. In these systems, ions are generated in different kinds of low pressure plasma discharges (e.g. RF inductive discharge) that are excited in the flow of deposited material vapor. Continuous discharges are often used but the pulsed mode of ones is attractive too [1,2]. It allows to improve the characteristics of thin films, increase the instantaneous plasma density with reducing the treatment temperature, stimulate chemical reactions on coated surfaces. The present work deals with the study of the pulsed RF inductive plasma discharge in the low pressure metal vapor.

The pulsed discharge was generated by the five-turn inductor placed above the crucible with evaporated material in a vacuum chamber. The e-beam (1-10 kW) was used for heating the evaporated metal, the metal vapor pressure inside the inductor was 10^{-2} - 10^{-4} Torr. The thyatron pulser (see Fig. 1) was used for impact-excitation of the free dying sine oscillations with frequency $f = 0.4$ - 4 MHz in the inductor L and capacitor C. The latter was connected in parallel with the inductor to create the oscillating contour. Also in Fig. 1, VL is the thyatron of TGI-1000/25 type, C_s - energy storage capacitor. The repetition frequency of thyatron firing was 1-20 kHz. Electrostatic probes were placed in several points in the vicinity of the inductor. Above the inductor there was the ion collector with the negative DC or RF (13.56 MHz) bias of 100-1000 V. It was used as the substrate holder too. An ionization of vapor occurs after energizing the inductor L above some critical level by discharging C_s through L-C and VL. Yet, the ionizing process has a delay that is several half-waves of the inductor current. Then the plasma discharge continues until oscillations in the inductor die down.

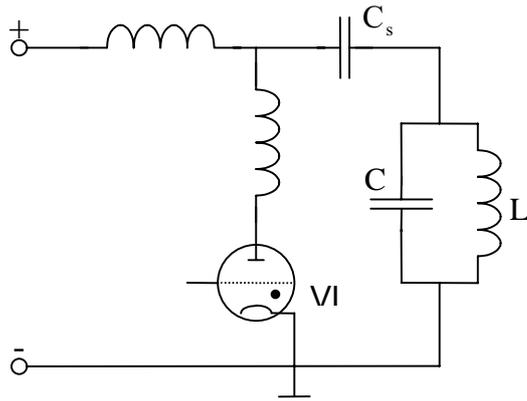


Fig.1. Schematic diagram of the thyatron pulser

The pulse mode of inductive discharge leads to the pulse modulation of the ion current in the collector or substrate circuit. There is a delay (some tens microseconds) in appearance of the ion collector current relatively the inductor excitation pulse as seen in Fig. 2 where t is time, j - collector ion current density and u - envelope of free dying sine oscillations of the inductor

voltage. It is a result of the finite time of plasma expansion outside the inductor. This delay as well the ion current pulse duration are greater for larger distances between the inductor and collector. Within the 15 cm distance from the crucible with the inductor current oscillation duration < 10 msec, the ion current density on the negative probe was $0.1-12 \text{ mA/cm}^2$ and the ion current pulse duration ~ 50 msec. The measurements made with help of the probe above the inductor have shown that the charge particles density of Al-vapor pulsed plasma was the order of 10^{10} cm^{-3} , the electron temperature ~ 15 eV, the velocity of plasma flying away the inductor $\sim (1-2) 10^6 \text{ cm/sec}$, plasma potential was 50-90 V with the 2 - 3 kV inductor voltage, $f = 0.88 \text{ MHz}$ and 2.5 kW e-beam power. The all-round study of such RF discharge allows to conclude that it is AC glow discharge in crossed fields and the inductor serves as a magnetic field source as well as a spreaded electrode.

The efficiency of energy transfer from the inductor to the plasma discharge depends on a charge particles concentration or plasma density inside the inductor. That is why it increases when following inductor current oscillations are laid on the tail of previous ones. In this case inside the inductor there is some rest concentration of charge particles already at the moment of applying the following pulse to the inductor and the discharge begins to develop again but without a delay in the first half-wave of the inductor current. Therefore, higher repetition frequencies of excitation pulses or the pulse packet regime are more suitable for plasma generation. In the former case the average power of RF discharge rises substantially and therefore the latter regime is more preferable. The pulse packet regime presents itself as the succession of groups of excitation pulses and each group or packet in its turn contains a few pulses. The pauses between pulses inside the packet are to be smaller than the deionization time of pulsed discharge plasma.

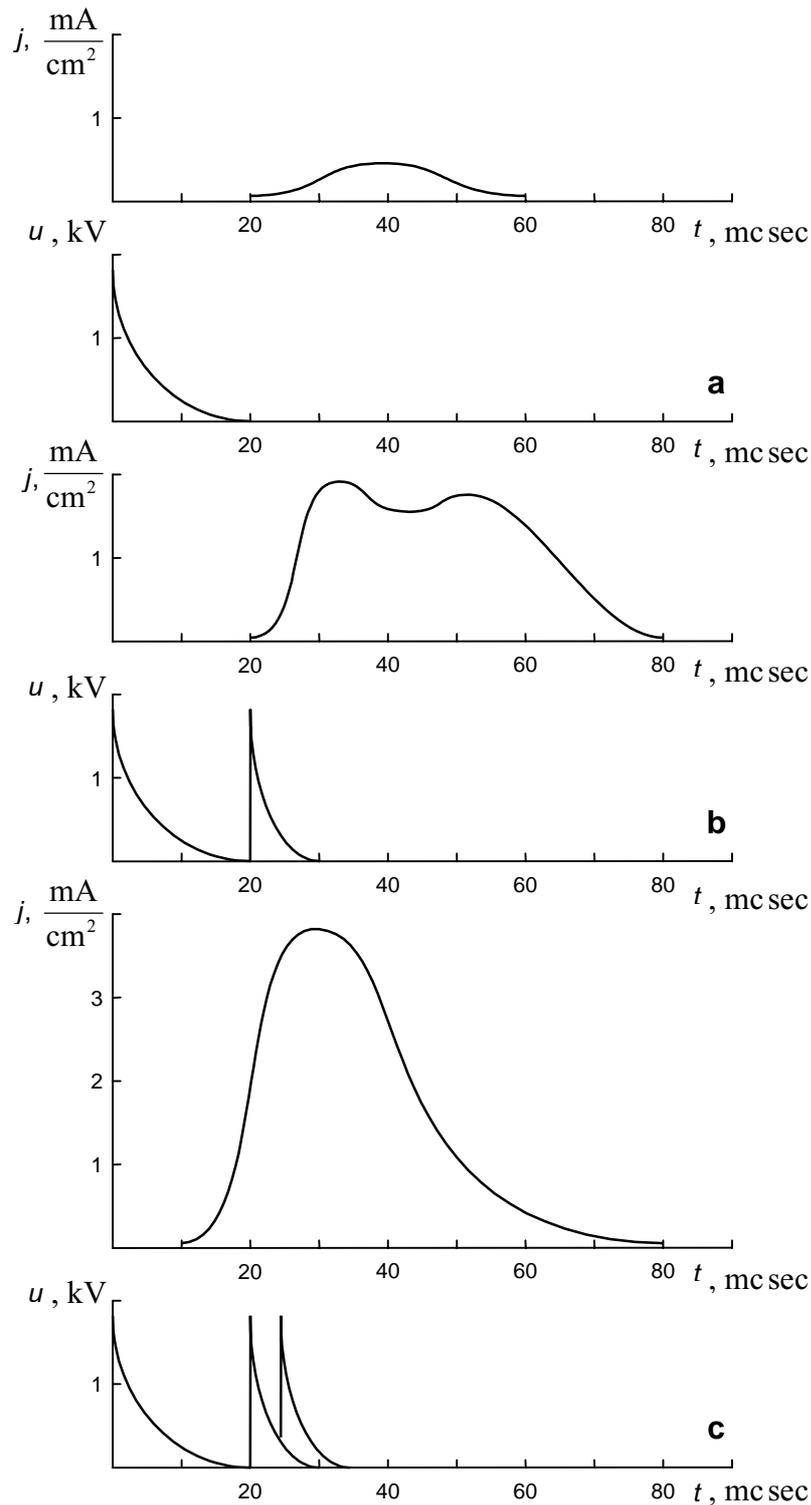


Fig. 2. Time diagrams of ion collector current density and inductor voltage. Al-vapor, $f = 0.88$ MHz.

The packet repetition frequency is chosen to obtain the required average power of RF discharge. Fig. 2 shows the time diagrams of collector ion current density j and envelope u of the free dying sine oscillations of the inductor voltage for packets containing one (a), two (b) and three (c) excitation pulses. Inside packets, the following pulses are laid on the tail of previous ones. As seen, the ion charge given to the collector during one pulse packet and divided by quantity of pulses inside packets is greater for two- and three-pulse packets. Increasing the quantity of pulses inside packets and the delays between them leads to varying the form and amplitude of ion current pulses. It is seen also, inductor current oscillations after the second and following excitation pulses die more quickly that

indicates more effective energy absorption by the plasma discharge during these pulses. Fig. 3 shows the influence of delays between excitation pulses inside packets on the ratio J/P . Here, J - the average collector ion current, P - the average power of the thyatron pulser, t_l - the

delay of the last pulses relatively the previous one inside packets, t_2 - the delay of the second pulse relatively the first one in three-pulse packets. The solid curves are for three-pulse packets, the dashes - for two-pulse ones, the dash - dots - for single ones. The ratio J/P characterizes the efficiency of vapor ionization in the pulsed discharge. As seen, using the pulse-packet regime allows to increase the J/P . There is a region of optimum pulse delays where the following excitation pulses are laid on the tail of previous ones inside packets and J/P is maximum.

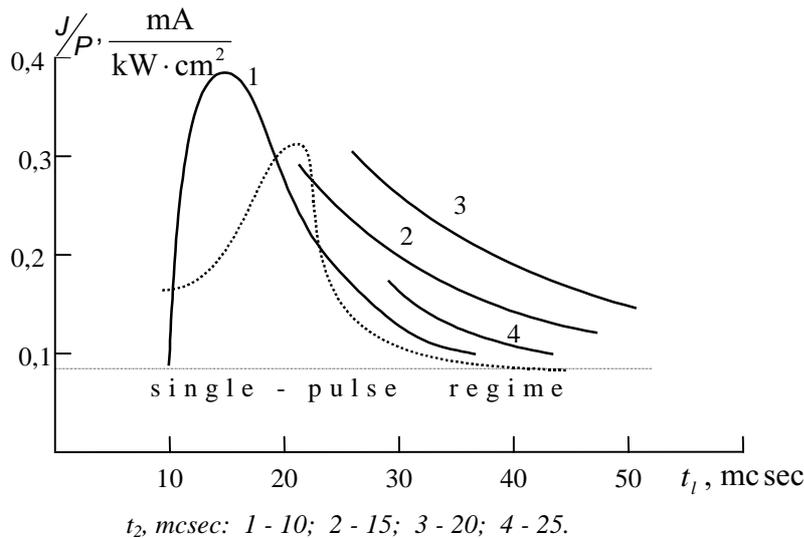


Fig. 3. Dependence of J/P on the delay of the last pulse in packet. Al-vapor, $f = 0.88$ MHz.

This system is used for deposition of metal thin films (Al, Ni, Cr, Cu, etc.) and their chemical combination with oxygen, nitrogen and carbon [1,3] on a surface of conducting or nonconducting substrates with self-ion bombardment. It is suitable especially for coating the temperature sensitive substrates. Other advantages consist

in the low plasma potential and weak interaction of the discharge plasma with chamber walls because the duration of the active discharge stage is smaller than the life time of charged particles in the space between the inductor and substrate. Due to high pulse power of inductor current oscillations, their frequency may be lower than in usual stationary low pressure RF discharges.

References

- [1] Belevsky V.P., Kuzmichev A.I. and Massalitin E.F.: Pulsed ion treatment and plating of thin films and coatings. Society "Znanie" of Ukraine, Kiev, 1991 (*in Russian*).
- [2] Schiller S., Kirchoff V., Goedicke K. and Schiller N.: FEP Annual Report, Dresden, 23 (1996).
- [3] Gusev I.V., Kuzmichev A.I. and Sidorenko S.B.: *Proc. 6-th Int. Symp. "Thin films in electronics"*, Herson, 46 (1995) (*in Russian*).