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Impact excitation of MF magnetron discharge for PVD processes

Anatoly Kuzmichev[a,*], Oleg Bevza[a], Hartmut Steffen[b], Rainer Hippler[b]

[a]National Technical University of Ukraine "Kiev Polytechnical Institute", pr. Pobedy 37 KPI-2230, Kiev 03056, Ukraine
[b]Institute of Physics, Ernst-Moritz-Arndt-University of Greifswald, Domstrasse 10a, Greifswald 17489, Germany

Abstract

A system for impact excitation of the MF magnetron discharge is presented. A thyratron pulser excited a ringing circuit, which, in turn, supplied power to the pulsed MF discharge. The discharge current oscillation frequency was 1.76 MHz, the impact excitation frequency was up to 8 kHz. The discharge operated at voltages of several kilovolts and current amplitudes up to a hundred amperes without sparking and arcing on the Ti electrodes in inert and reactive gas and generated large-volume plasma. The proposed power supply combines the advantages of the MF bipolar discharge mode and the conventional pulse modulation.

Keywords: Medium frequency; Pulsed MF magnetron discharge; Impact excitation

1. Inroduction

The abilities of magnetron sputtering systems are defined mainly by discharge modes and power supply features. A good example is pulse sputtering since it has overcome many limitations of conventional DC sputtering. Near-rectangular pulses or medium frequency (MF) sinusoidal voltage can supply the pulsed magnetron discharge [1–7]. This paper deals with the combined pulse and MF approaches to magnetron discharge excitation. Earlier, the impact method of MF plasma generation was successfully applied to self-ion enhanced EB PVD with ionization of metal vapour [8].

2. Base modes of magnetron discharge modulation

The pulsed discharges of various types (polarities) are favourable for sputtering of conductive materials in non-reactive and reactive gases. They are employed mainly for reducing the temperature and for arc suppression [1–8]. Recently, the pulse packet modulation was proposed (Fig. 1a,b) in order to improve the arc handling in reactive PVD

*Corresponding author. Fax: +38 044 2419645.
E-mail address: A.Kuzmichev@edd.ntu-kpi.kiev.ua (A. Kuzmichev).

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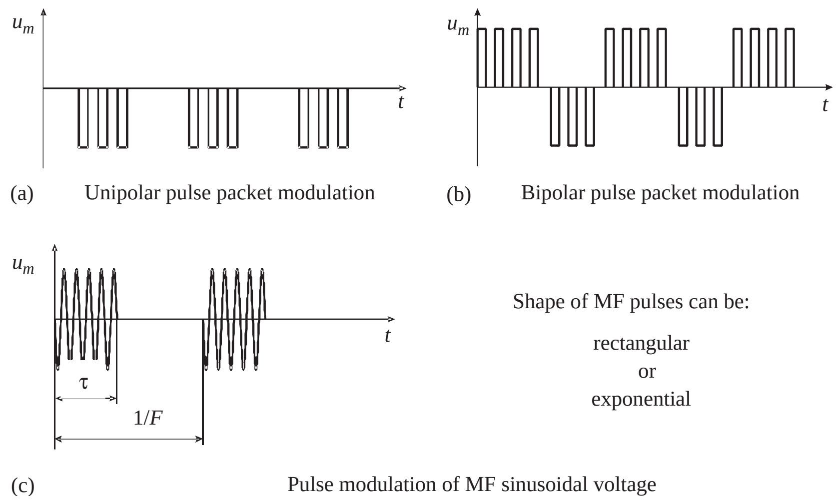

Fig. 1. (a–c). Discharge voltage diagrams for various pulse modulations.

processes and the control of deposited layer properties [9,10]. By analogy with the packet mode the modulation of sinusoidal voltage can be implemented as shown in Fig. 1c, where τ is the duration of sinusoidal pulse train, F is the modulation frequency.

The discharge pulsing results in the increase of the mean electron energy and densities of ions and excited reactive species [5,11,12]. Transient plasma processes during discharge reignition at pulse fronts are responsible for this effect. The pulse fronts are accompanied by circuit oscillations and the transient target voltage usually is much higher than the normal discharge voltage. In such conditions, the ion pulses and short beam-like spikes of electrons with energy up to 100 eV are generated at the substrate, the motion of near-electrode charged sheaths occurs and stochastic electron heating takes place [5,11–13]. The effect of bipolar mode must be stronger as the bipolar variation is two-fold unipolar amplitude. It is confirmed by the investigations of modulation modes effects on film properties [6,14]. The effect must be stronger at higher pulse rates and smaller pulse duration since the repetition frequency of transient plasma processes is higher. Hence, short bipolar pulse and pulse packet modes are more favourable.

Since the duration of these processes is a few microseconds, a good way of producing high-energy electrons and reactive species is the MF voltage with half-period of 1–2 μs. The sinusoid can be considered as a permanent series of bipolar fronts. The MF voltage amplitude should be much higher than the normal discharge voltage for enhancing the effect (2–4 kV against 0.5 kV for DC discharge). To avoid overheating, the mode shown in Fig. 1c should be used. Such an approach is developed in this work.

3. Magnetron system with the MF power supply from the ringing circuit

Magnetron M (T—target, A—anode) together with substrate S is in chamber C (Fig. 2). A ringing circuit L1–C1, connected to the magnetron, is proposed to be used for the generation of MF sinusoidal voltage and impact excitation of the discharge. The circuit is excited, in turn, with the pulser, containing hydrogen thyratron VL, energy storing capacitor C2, discharging inductor L2 and charging choke L3, connected to the DC source E1. The DC source E2 allows the ignition of a low-current (~30 mA) starting-up discharge between the pulses; R is the ballast resistor. C3 is the capacitor separating DC and MF parts.

C2 is positively charged from E1 through L3 until a trigger pulse is applied to the thyratron control grid (Fig. 3a). Then the thyratron is closed