JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 10, No. 8, August 2008, p. 2020 - 2023

The influence of an auxiliary discharge on the ablation plasma produced by a pulsed electron beam

M. NISTOR, F. GHERENDI, N. B. MANDACHE*
National Institute for Lasers, Plasma and Radiation Physics, Plasma Physics and Nuclear Fusion Laboratory, L 22, P.O. Box MG-36, 77125 Magurele-Bucharest, Romania

In this work we studied the effect of a pulsed auxiliary discharge on the plasma plume produced by ablation of a zinc oxide target using a pulsed electron beam generated by a channel-spark discharge. For an auxiliary discharge current peak of 400 A, a four times increase of the ion signal was measured using ion probes, revealing an increase of the ionisation degree of the ablation plasma. The estimated ion density was 5 x 10^{12} cm^{-3}. An ion energy increase from 19 eV to 24 eV in the presence of the auxiliary discharge was calculated using the time of flight method for the ion signal peak.

(Received March 1, 2008; accepted June 30, 2008)

Keywords: Pulsed electron deposition, Ablation plasma, Auxiliary discharge, Ion probes

1. Introduction

As an alternative to pulsed laser deposition, pulsed electron deposition (PED) made with electron beams produced in channel-spark discharges were studied since several years [1]. Like in pulsed laser deposition, the pulsed electron beam interaction with a target leads to the melting of a thin layer at the target surface, vaporisation and formation of plasma plume. This plasma plume propagates normally to the target into the background gas towards the substrate where a thin film is formed on the surface. Each of these stages has an important role in the growth of high quality thin films. In a previous work we used optical emission spectroscopy and fast imaging as diagnostics to characterize the plasma plume produced by a pulsed electron beam [2]. These measurements proved that the composition of the emissive species in the plasma plume of hydroxyapatite is similar with that obtained with nanosecond pulsed laser deposition. In particular the electron beam ablation induces higher ionization of the plume and the background gas than in the case of pulsed laser deposition.

Combined techniques are used to obtain thin films with specific properties, required in different applications. Pulsed laser deposition used simultaneously with radio-frequency plasma beam was used in order to influence the direction of film growth [3].

In the case of an excimer laser induced plasma, a higher degree of ionisation and higher energies of species were obtained by pumping additional energy with a second CO_2 laser. Oxide thin films practically particulates-free were grown with this dual laser beam technique [4].

In this article we used an auxiliary discharge to pump more energy into the plasma plume produced by the pulsed electron beam interaction with a zinc oxide target. Ion probes measurements were used to characterize the ablated species in the presence of the auxiliary discharge. The effect of the auxiliary discharge on the surface morphology of ZnO thin films was also investigated by scanning electron microscopy (SEM).

2. Experimental set-up

The pulsed electron beam was produced in a channel-spark discharge [5]. The capillary tube (5 mm diameter and 110 mm length), in which the channel spark discharge generates the electron beam, was mounted at 45° to the target, as shown in figure 1.

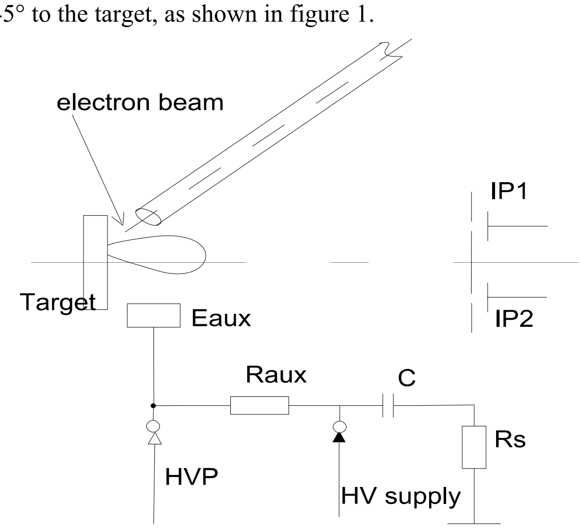

Fig.1 Experimental set-up

An auxiliary electrode (E_{aux}) was placed laterally near the target, opposite to the capillary tube. Two ion probes (IP1 and IP2) were placed at 45 mm distance to the target, 6 mm symmetrical from the axis. The auxiliary discharge circuit consisted of a capacitor C (80nF) connected to the electrode E_{aux} through a resistor (R_{aux}).

The auxiliary discharge current was measured by a 0.3Ω shunt (R_{shunt}) and the potential on the electrode E_{aux} by a Tektronix P6015 high-voltage probe (HVP). In these experiments the electron beam fluence was about 2.5 J/cm^2.

3. Experimental results

The discharge voltage applied to the electron beam source U_d is shown in Fig. 2 (bottom trace). The pulsed electron beam is generated during the discharge voltage fall (time 0 in figure 2). The electron beam produces the ablation plume plasma at the interaction with the target.

The duration of the electron beam is approximately 100 ns and the fluence is 1-3 J/cm^2, depending on the applied voltage. The working gas was argon at a pressure of 10^{-2} mbar. The typical discharge voltage was -15kV and the repetition rate was 1Hz.

The auxiliary discharge was triggered by the beam electrons scattered on the target surface and secondary electrons emitted from the target. The current and voltage waveforms of the auxiliary discharge in the case of R_{aux}=24 Ω are presented in figure 2 (top and middle waveforms, respectively).

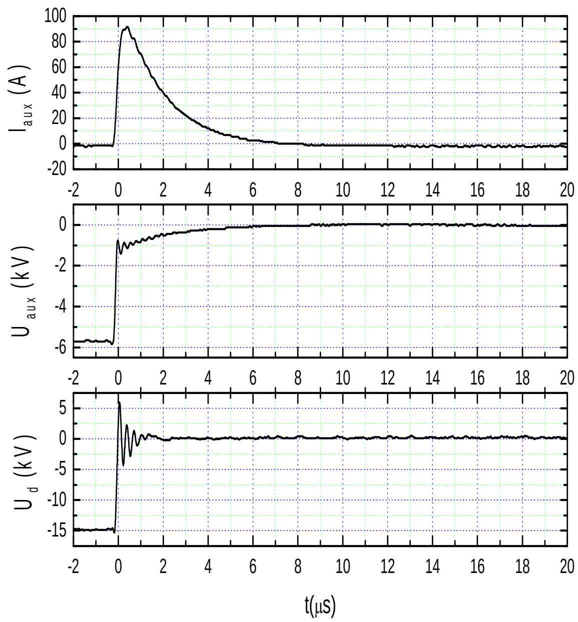

Fig.2. Oscillograms of the auxiliary discharge current (top) and voltage (middle); the electron beam source voltage (bottom).

During the development of the ablation plasma in front of the target, the auxiliary discharge voltage falls to less than 1 kV and the current rises to its maximum value of ~90 A. Most of the auxiliary energy is pumped in the first ~ 4μs, as seen in the upper trace in fig. 2.

Typical ion signals recorded by the two ion probes, with and without auxiliary discharge are shown in figures 3 and 4. For both probes the signals were averaged over 16 electron beam pulses. The ion probes were biased at -24 V.

The negative signal at the beginning of the ion probe signal is due to the high energy electrons (a few keV) from the beam scattered on the target which reach the ion probe. One can note a significant increase of the ion probes signals in the presence of the auxiliary discharge. This proves that an important energy is pumped by the auxiliary discharge into the plasma plume.

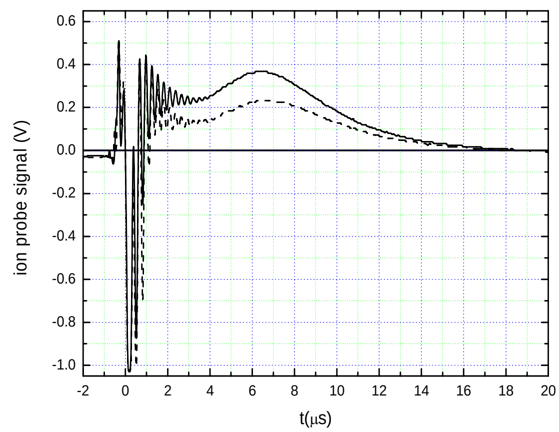

Fig.3 Ion probe IP1 signals with (solid line) and without (dashed line) auxiliary discharge

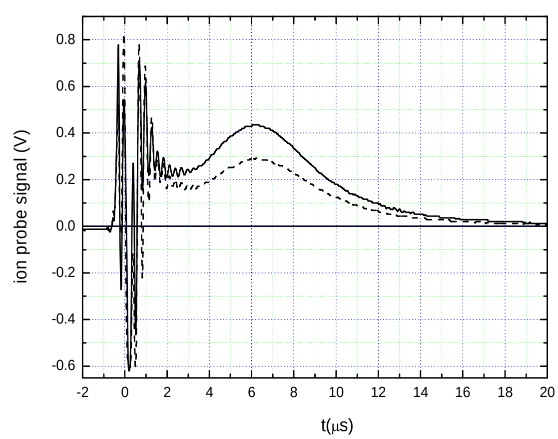

Fig.4 Ion probe IP2 signals with (solid line) and without (dashed line) auxiliary discharge.

To pump more energy into the plasma plume, only the 0.3 Ω shunt resistance was used in the auxiliary discharge circuit (fig. 1). The current and voltage waveforms of the auxiliary discharge are presented in figure 5.

One can note that the auxiliary discharge voltage and current present damped oscillations with T/2 = 0.8μs. The current rises to a value of 400 A in the first quarter of period (350 ns).

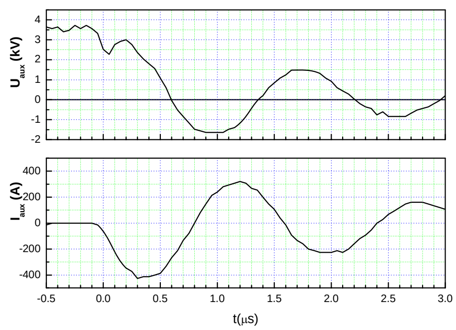

Fig.5: Oscillograms of the auxiliary discharge voltage (top) and current (bottom); U_{aux}=+4kV, R_{aux}=0.3Ω

The effects on the ion probe signals are more significant at such higher currents. The ion signal recorded by IP2 has increased four times (fig. 6).

Another effect revealed in fig. 6 is the displacement of the time corresponding to the maximum of the ion signal towards a lower value, from 9μs without auxiliary discharge to 8μs in its presence. This means higher velocities for the ions in the presence of the auxiliary discharge.

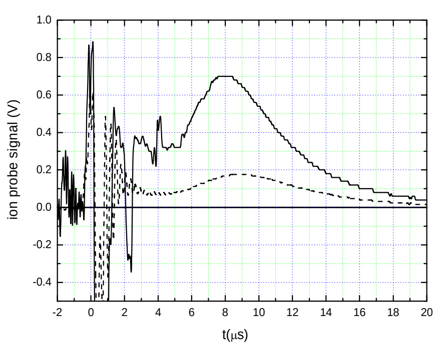

Fig.6. Ion probe IP2 signals with (solid line) and without (dashed line) auxiliary discharge for a maximum current of 400 A.

The ion energies were calculated using the time of flight method. The time zero for the ion flight from the target to the ion probe location is given by the first negative signal of the high energy electrons scattered on the target. The time of flight of these electrons from the target to the ion probe is negligible compared to the ion time of flight, due to the much larger mass and lower energies of ions.

The second negative peak in figure 6 (at approximately 2μs) can be correlated with the second negative alternance of the auxiliary discharge current (figure 5).

The energy of zinc ions, corresponding to the maxima of the ion probe signals (figure 6), increases from 19 eV in the case of plume plasma without auxiliary discharge to 24 eV in the presence of the auxiliary discharge.

The estimated maximum ion density at 45 mm distance from the target is 5 x 10^{12} cm^{-3} in the presence of the auxiliary discharge.

For testing the effects of the auxiliary discharge on the morphology of a thin film, a ZnO film was grown on a Si substrate placed between the two ion probes.

The SEM image of the ZnO thin film grown on Si substrate at room temperature is shown in figure 7.

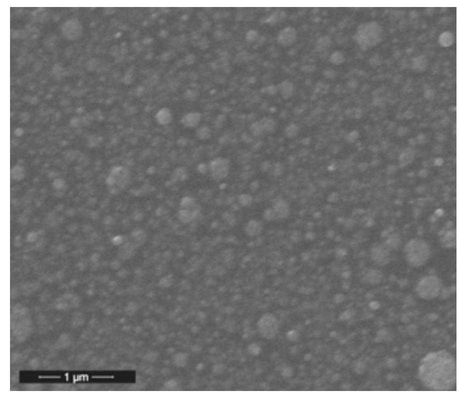

Fig. 7. SEM image of a ZnO thin film (scale bar 1 μm) obtained in the presence of the auxiliary discharge

The film presents a surface morphology characterized by the presence of small particulates with diameters in the range of hundreds of nanometres.

In an experiment without auxiliary discharge we studied the influence of the beam energy on the ZnO thin film surface morphology (Fig.8).

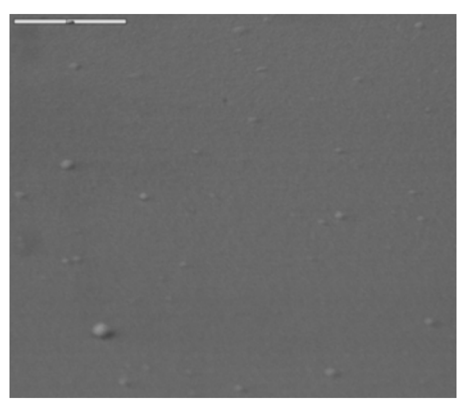

Fig. 8. SEM image of a ZnO thin film (scale bar 1 μm) obtained without the auxiliary discharge

Only few particulates are present on the surface of the ZnO thin film grown at room temperature on a Si substrate. The number of particulates increases with the beam energy.

4. Conclusions

We have studied the effects of an auxiliary discharge on the ablation plasma produced by the interaction of pulsed electron beam with a zinc oxide target.

The energy pumped into the plasma plume determined a significant increase of the ionization degree of the ablation plasma evidenced by the increase of ion probe signal. This effect becomes more important with the increase of the auxiliary discharge current. For 400 A peak current the ion probe signal increased four times. The estimated maximum ion density at 45 mm distance from the target is 5×10^{12} cm^{-3}.

The time shift of the ion signal maximum at higher auxiliary discharge currents shows an increase of the mean ion energy from 19 to 24 eV.

The auxiliary discharge seems to favour the growth of particulates having diameters in the range of hundreds of nanometers, as revealed by the SEM image. The same effect was observed without auxiliary discharge but increasing the electron beam energy.

Acknowledgements

This work was supported by projects of the Romanian Ministry of Education and Research: CEEX 3172/2005 and PN06360302/2006.

References

[1] G. Müller, M. Konijnenberg, G. Krafft, C. Schultheiss, Science and Technology of Thin Film, World Scientific Publ. Co. PET. LTD, 89 (1995).

[2] M. Nistor, F. Gherendi, M. Magureanu, N. B. Mandache, J. Optoelectron. Adv. Mater. **7,** 979 (2005).

[3] G. Dinescu, C. Ruset, M. Dinescu, Plasma Process. Polym., **4**, 282 (2007).

[4] P. Mukherjee, S. Chen, J.B. Cuff, P Sakthivel, S. Witanachchi, J. Appl. Phys. **91**, 1828 (2005).

[5] M. Nistor, N.B. Mandache, J. Optoelectron. Adv. Mater. **7**, 1619 (2005).

*Corresponding author: mandache@infim.ro