High power impulse magnetron sputtering from a chromium target

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Abstract

High power impulse magnetron sputtering (HiPIMS) discharges with a chromium target are studied experimentally and by applying the ionization region model (IRM). For a given pulse length the deposition rate decreases and the ionized flux fraction increases with increased discharge current density ranging between 0.4 – 1.0 A/cm^2. The measured chromium ionized flux fraction ranges between 10 – 50 %. It is highest for the highest peak discharge current density, and the shortest pulse length studied. The deposition rate is maximum for a pulse length of 50 μs and decreases when shortening the pulses down to 25 μs or lengthening the pulse up to 200 μs. The IRM results indicate that the singly charged chromium ion is the dominant ion in the ionization region. The discharge consequently operates in metal recycling mode. The back-attraction probability of the sputtered species decreases with decreasing pulse length, and with increasing peak discharge current density.

Introduction

Magnetron sputtering is a versatile and widely applied physical vapor deposition technique where the film-forming material is sputtered from a cathode target by ion bombardment [1]

Chromium Cr([Ar]3d^{5}4s^1) is a transition metal of Group VI, which in thin film form is known for its high corrosion resistance and high hardness and are popular as decorative surfaces, due to their mirrorlike surface finishing

High power impulse magnetron sputter (HiPIMS) deposition has been demonstrated to deliver chromium thin films with higher mass density than dc magnetron-sputtered deposited films, however, the deposition rate is lower [2]

Here, the effect of shortening the pulse length on the deposition rate and the ionized flux fraction is explored for a HiPIMS discharge, with argon as the working gas and a chromium target, through experiments and using the ionization region model (IRM)

Results and discussion

The experiments were performed in a cylindrical stainless steel vacuum chamber (44 cm in diameter and 75 cm in height) with a 150 mm diameter chromium target and argon as the working gas at 0.3 Pa [3]

The average sputtering power delivered to the target was kept at 1.5 kW by adjusting the pulse repetition frequency between 50 – 2100 Hz – the pulse length was varied in the range between 25 and 200 μs, for peak discharge current density $J_{D,peak}$ of 0.4 A/cm^2, 0.7 A/cm^2, and 1.0 A/cm^2

It can be seen in Figure 1 (a) that for any given pulse length investigated we observe a decrease of the deposition rate when the peak discharge current density is increased

The measured ionized flux fraction is shown in Figure 1 (b) as a function of pulse length – and an increase in the ionized flux fraction with increasing $J_{D,peak}$ is observed as well as an increase with decreasing pulse length

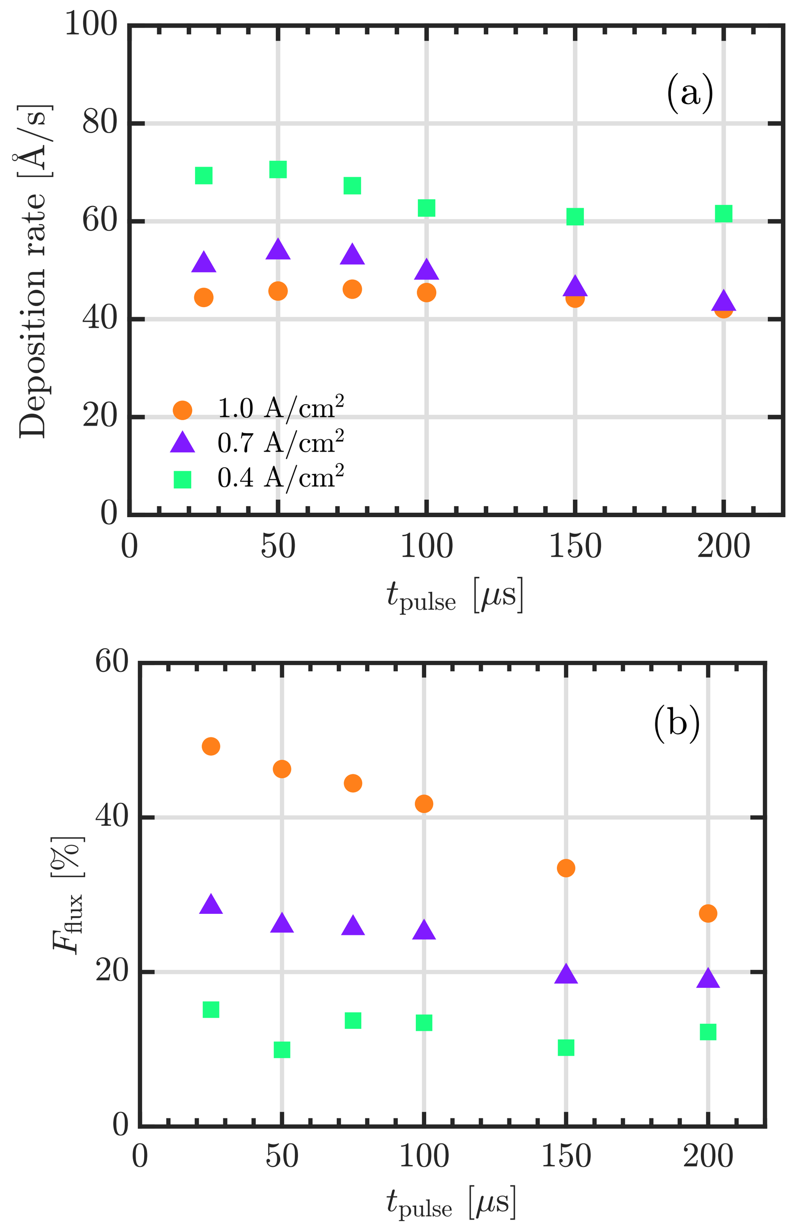

Figure 1: (a) The experimentally determined deposition rate and (b) the ionized flux fraction versus the pulse length for peak discharge current density of 0.4 A/cm^2, 0.7 A/cm^2, and 1.0 A/cm^2, for argon working gas pressure of 0.3 Pa.

The connection between the external control parameters, such as working gas pressure, pulse power density, the magnetic field strength, and the pulse configuration, and the two flux parameters, the deposition rate and the ionized flux fraction, is typically studied using the two internal discharge parameters, the probability of ionization of the target atom α_t and the probability of back-attraction of the target ion β_t

The ionization probability α_t increases with increased peak discharge current density and it increases at first and then decreases as the pulse length is increased

Figure 2 (b) shows the back-attraction probability of the sputtered species versus pulse length. We see that the back-attraction probability β_t increases with increasing pulse length and decreases with increased peak discharge current density

The fraction $\zeta = J_{Ar^+}/J_{D,i}$ of the total ion current at the target surface that is due to Ar$^+$ ions is shown in Figure 3

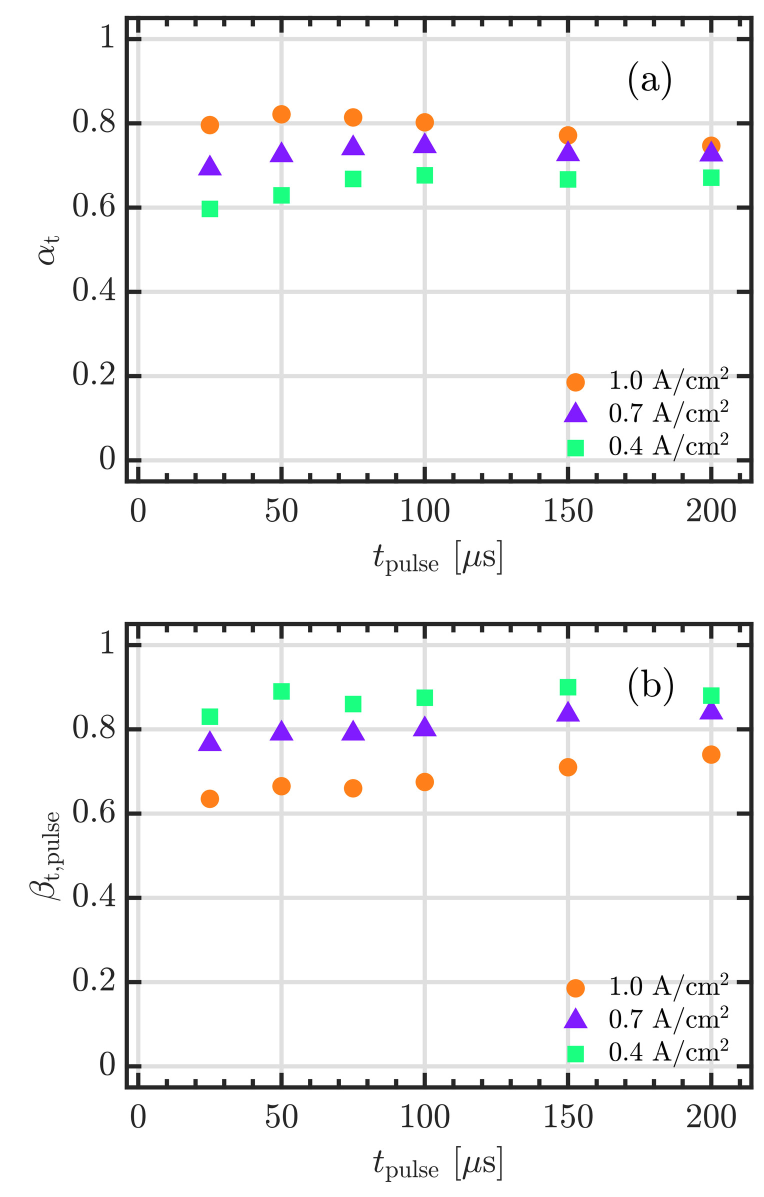

Figure 2: (a) The ionization probability α_t and (b) the back-attraction probability $\beta_{t,pulse}$ determined by the IRM versus the pulse length.

This fraction increases with decreasing pulse length and decreasing discharge current density – this confirms that the discharges are dominated by Cr$^+$ ions

In an early study using the IRM two routes of electron energization were quantified: sheath energization by secondary emitted electrons accelerated across the cathode sheath, and Ohmic $\mathbf{J}_e \cdot \mathbf{E}$ heating of electrons that carry the current in an extended presheath or the ionization region [4]

The share of the electron power absorption that is due to Ohmic heating is shown versus pulse length for the different current densities in Figure 4

The contribution of Ohmic heating is very high, in the range 84 – 96 %, and it increases with increasing pulse length and increasing peak discharge current density

Conclusions

For a given pulse length the deposition rate decreases and the ionized flux fraction increases with increased discharge current density

The ionization probability of the sputtered species increases with increased peak current discharge density and the back-attraction probability decreases with decreasing pulse length and with increasing peak discharge current density

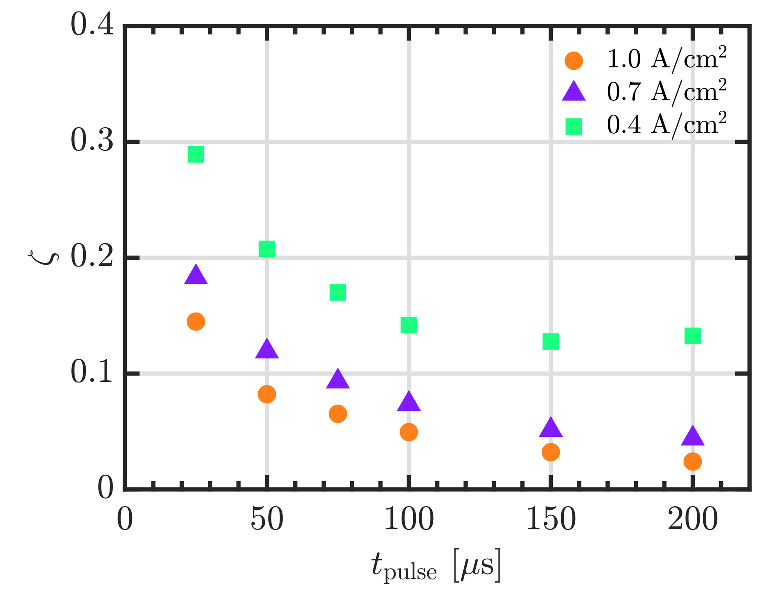

Figure 3: The fraction of Ar$^+$ ions in the total ion current onto the target ζ versus the pulse length for peak discharge current density of 0.4 A/cm^2, 0.7 A/cm^2, and 1.0 A/cm^2.

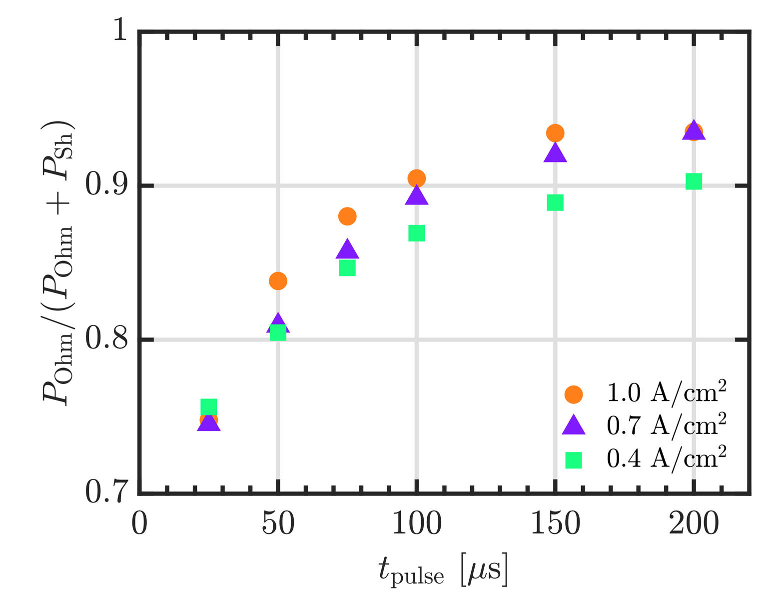

Figure 4: Share of electron power absorption due to Ohmic heating of the electrons versus t_{pulse} for different current densities.

References

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