

Electrical characteristics of a hot-target HiPIMS discharge in reactive N₂/Ar environment

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Abstract. In this work, we study the effects introduced by adding reactive gas (nitrogen) to a magnetron discharge with a thermally insulated chromium target from the point of view of its electrical parameters. The dependences of the current-voltage characteristics and the shapes of the current and voltage pulses of a high-current pulsed magnetron discharge on the reaction gas flow are studied. The voltage and current waveforms exhibit a transition into unstable mode with increasing the reactive gas flow and pulse duration. In this mode, in power-regulation regime of the power supply, the pulses follow certain recurring patterns characterized by the current oscillations in a wide range from several to tens of amps.

Keywords: reactive magnetron sputtering, evaporation, HiPIMS, *I-V* characteristics, target poisoning, hot-target magnetron, chromium, nitrogen.

1. Introduction

A high-current pulsed magnetron discharge in a reactive (oxygen- or nitrogen-containing) medium with a thermally insulated target is a promising and currently little-studied type of gas discharge, which can be used to obtain high-quality oxide and nitride coatings at rates significantly higher than those in classical magnetron sputtering systems. To adequately describe the entire variety of processes occurring on a target in this regime, the numerical model of the thermal state of the target [1] and the nonstationary model of reactive film deposition in pulsed sputtering systems with a high discharge current density (more than 10 A/cm²) can be considered [2]. For the development of these models, it is necessary to experimentally study a high-current pulsed reactive magnetron discharge with target evaporation and to determine the dependences of its parameters on the flow of the reactive gas into the vacuum chamber.

In this work, we study the effects introduced by adding reactive gas (N₂) to a magnetron discharge with a thermally insulated chromium target from the point of view of its electrical parameters. The dependences of the current-voltage characteristics and the shapes of the current and voltage pulses of a high-current pulsed magnetron discharge on the reaction gas flow are studied.

2. Experimental setup

To form the discharge, an APEL-M-5HPP-1200 power supply with a maximum average power of 5 kW was used. A HiPIMS discharge was formed on thermally insulated Cr target in Ar and N₂ mixtures. All experiments were carried out for two values of the average discharge power, 500 W and 1000 W. These power levels were chosen based on the results of previous studies [1], where these values were shown to correspond to thermal conditions before and after the onset of active evaporation of the material with a predominance of target atoms. Thus, in the 500 W regime, the classical process of magnetron sputtering occurs, but with a heated target, which affects the rate of chemical reactions on its surface. In the 1000 W mode, in addition to the effect of a heated target, effects associated with chromium species evaporation is added that should improve the Cr_xN_y film deposition rate as well.

We analyzed the voltage and current waveforms recorded at various pulse duration of 50–500 μs, frequency of 1 kHz and for reactive gas flow rates 0–1.80 l/h. The experimental setup scheme is shown in Fig.1.

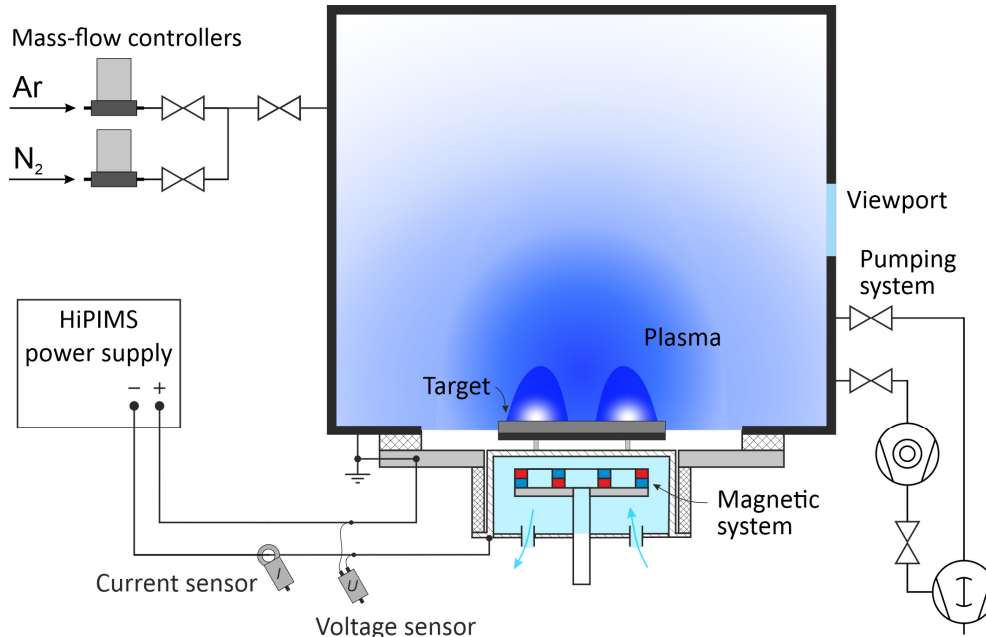
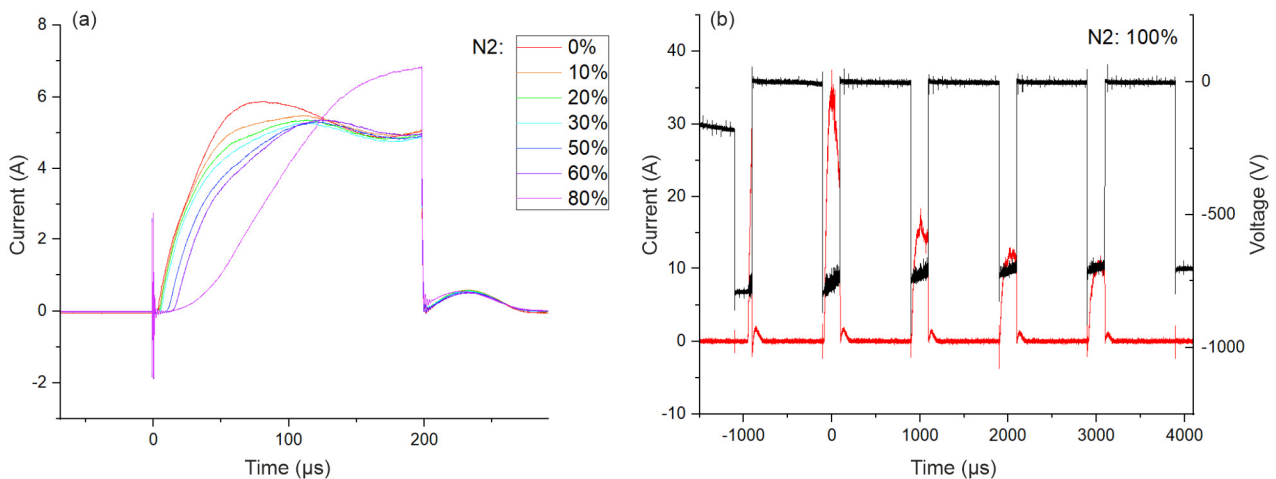


Fig.1. Experimental setup scheme.

3. Results and discussion

Two discharge power levels P were used in the experiments: 500 and 1000 W. The lower value corresponds to the situation of target sputtering without significant evaporated metal flux enhancement. The higher one enables intense chromium evaporation.

The waveforms of the discharge voltage and current are plotted and analyzed for various values of the fraction of nitrogen in the mixture (0–100%) and pulse duration 100–500 μs . For 500 W case, the dependences of the discharge current on the fraction of nitrogen in the mixtures with up to 80% N_2 content are shown in Fig.2a. It should be noted that for a discharge power 500 W, it is typical that at fractions of nitrogen more than 80%, an unstable mode of repetitive patterns of pulse series (< 10) of different current and voltage values is observed.

Fig.2. (a) Stable discharge operation waveforms ($P = 500$ W); (b) unstable discharge mode at 100% N_2 ($P = 500$ W).

The most important feature is the aforementioned observation of repetitive series of pulses with the discharge current and voltage magnitude being constant between series, but different within the series. Characteristics of neighboring discharge pulses become different from each other, but the

pulse structure is repeated in recurring patterns. The characteristic time of such oscillatory process is several pulse durations. Presumably, this happens when the pulse-off time approaches the time of target poisoning, provided there is a sufficient flow of reactive nitrogen atoms.

This effect might be partly related to the principle of operation of the discharge power source. Indeed, the experiments were carried out in the power stabilization mode. The characteristic stabilization time is about 1 ms, which again is in the order of several pulse-on times, and if the target cleaning from nitride cannot be finished within one pulse, the current increases greatly due to larger electron emission. After the overshoot, the power supply would try to reduce voltage in several steps, and eventually the target would become poisoned again, triggering the repetition of this pattern.

The measurement results for 1000 W mode are shown in Fig.3.

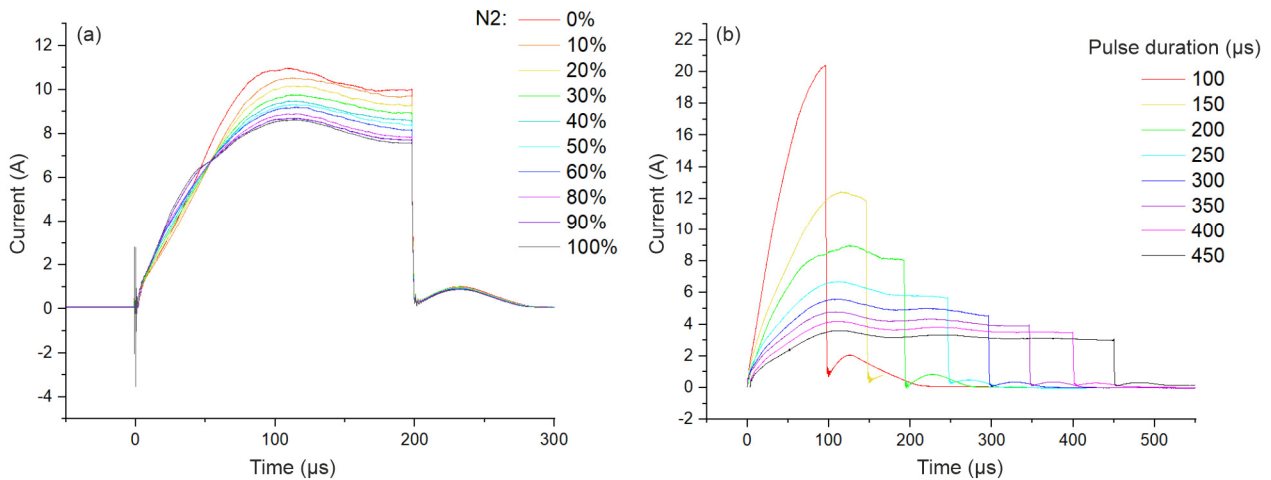


Fig.3. (a) Stable discharge operation waveforms for 1000 W power; (b) current waveforms for different pulse duration time values for 1000 W power.

At 1000 W, the discharge remains stable up to 100% nitrogen atmosphere. The peak current decreases with nitrogen flow increasing. Obviously, provided the average power is fixed, the peak current is inversely proportional to the pulse duration. The peak current and average pulse current values are summarized in Fig.4.

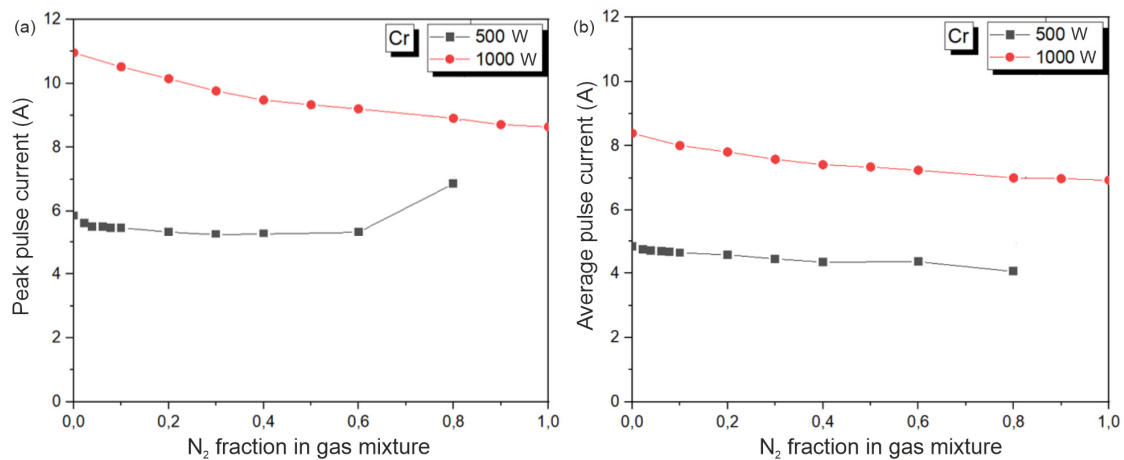


Fig.4. Discharge current vs. nitrogen fraction in gas mixture: (a) peak values, (b) average values within the pulse.

Finally, voltage-current characteristics for two discussed power modes were plotted together with constant power lines. They are shown in Fig.5.

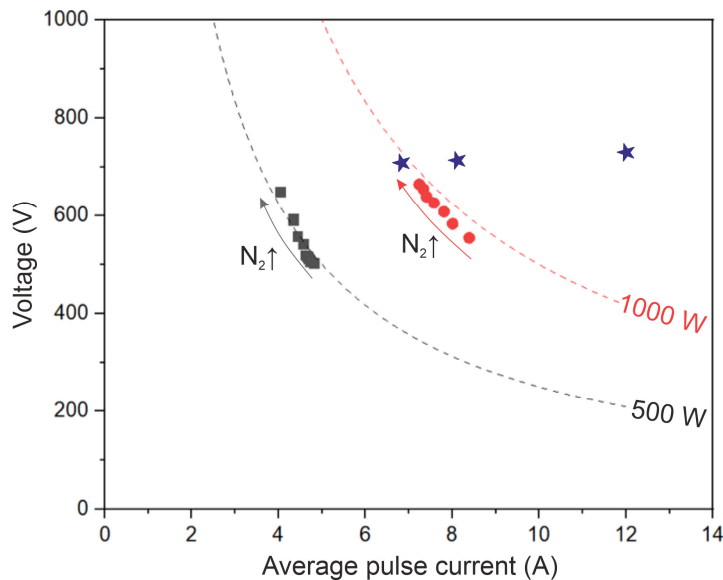


Fig.5. Overview of I - V curves for hot-target Cr HiPIMS discharge in Ar/N₂ mixtures. Purple stars denote unstable modes of operation at 500 W and 100% N₂.

For 500 W mode, the hot-target HiPIMS operation in pure nitrogen is unstable, and the points that should remain on the constant power line, tend to shift to much higher power values in 100% nitrogen case (purple stars). This must be taken into account in practical applications, where switching to constant current mode might solve the issue.

4. Conclusion

In the hot cathode HiPIMS, the operating range of discharge characteristics for stable deposition of chromium nitride is defined: for a power of 500 W at a pulse duration of 200 μ s with a nitrogen content in the range of 0–80%; for 1000 W with a pulse duration of 100–450 μ s at 100% nitrogen content. The dependence of the discharge current on the power and duration of the pulse and the nitrogen content in the gas mixture was revealed: the peak current decreases with an increase in the nitrogen supply, the peak current decreases with an increase in the pulse duration. The I - V characteristics of a pulsed discharge during deposition of chromium nitride in a nitrogen medium are obtained.

The voltage and current waveforms exhibit a transition into unstable mode with increasing the reactive gas flow and pulse duration. In this mode, in power-regulation regime of the power supply, the pulses follow certain recurring patterns characterized by the current oscillations in a wide range from several to tens of amps.

Acknowledgements

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5. References

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