Current-voltage-time characteristics of the reactive Ar/N_2 high power impulse magnetron sputtering discharge

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1. Introduction

High power impulse magnetron sputtering (HiPIMS) is an emerging ionized physical vapour deposition technique (IPVD) [1].

By pulsing the sputtering target with high power (~1 kW/cm^2), short duration pulses, a high ionization of the sputtered species is obtained, without significant target heating.

HiPIMS has been shown to have several advantages over conventional dc magnetron sputtering (dcMS) including increased film density, lower roughness, increased reactivity at low temperatures and better step coverage [1].

The aim of this study is examine the current-voltage-time (I-V-t) characteristics of the reactive Ar/N_2 HiPIMS discharge with a Ti target and compare them to the non-reactive case.

We study the effect of pulse repetition frequency and discharge voltage on the I-V-t characteristics.

2. Experimental setup

UHV chamber (base pressure 4×10^{-6} Pa) with circular, planar, balanced magnetron.

3 inch diameter titanium target.

Ar or Ar/N_2(5%) mixture with a constant total pressure of 0.6 Pa.

Square voltage pulse, 400 μs long.

Pulse repetition frequency varied in the range 10–80 Hz

Ion flux at substrate determined by measuring the current from the negatively biased substrate to ground (Fig. 1).

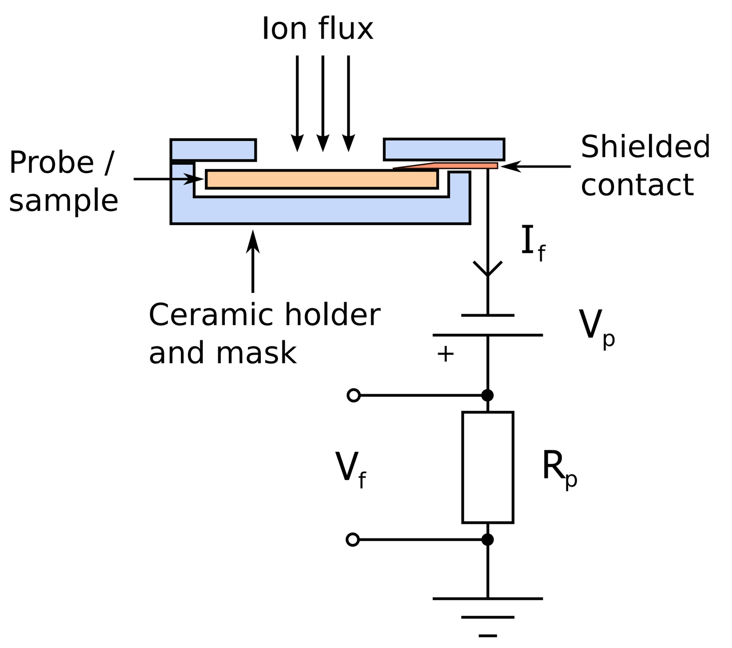

Fig. 1. Schematic of the ion flux

3. The Ar discharge

For low voltages (up to 600 V) the current waveforms can be described by three distinct regions:

I. Plasma initiation and a current maximum → gas compression
II. A decay to a minimum → rarefaction
III. A steady state regime that remains as long as the discharge voltage level is maintained → sustained self-sputtering

At higher voltages (650 V and above) the plateau current increases rapidly and the waveform becomes unstable.

At highest voltages self-sputtering runaway occurs (pulse is cut short to maintain stability).

Consistent with results of Anders et al. [2].

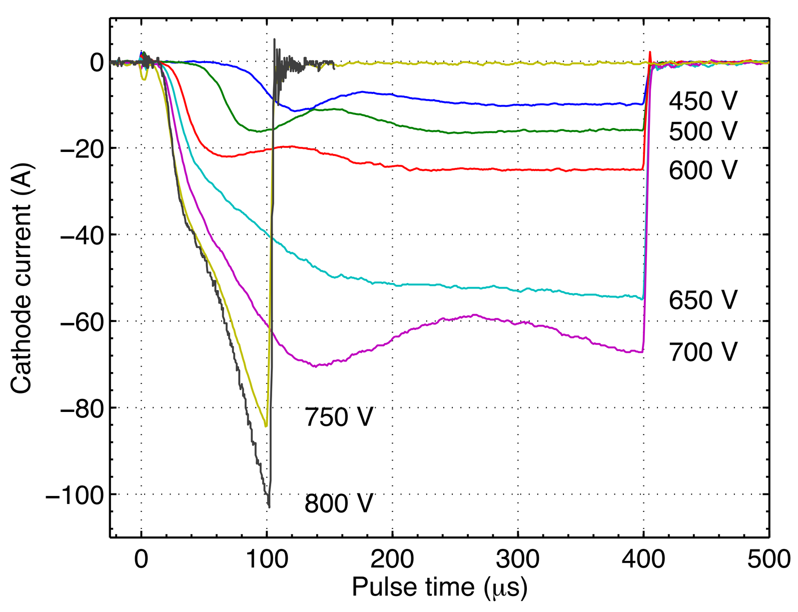

Fig. 2. The discharge current in an Ar discharge for a range of discharge voltages.

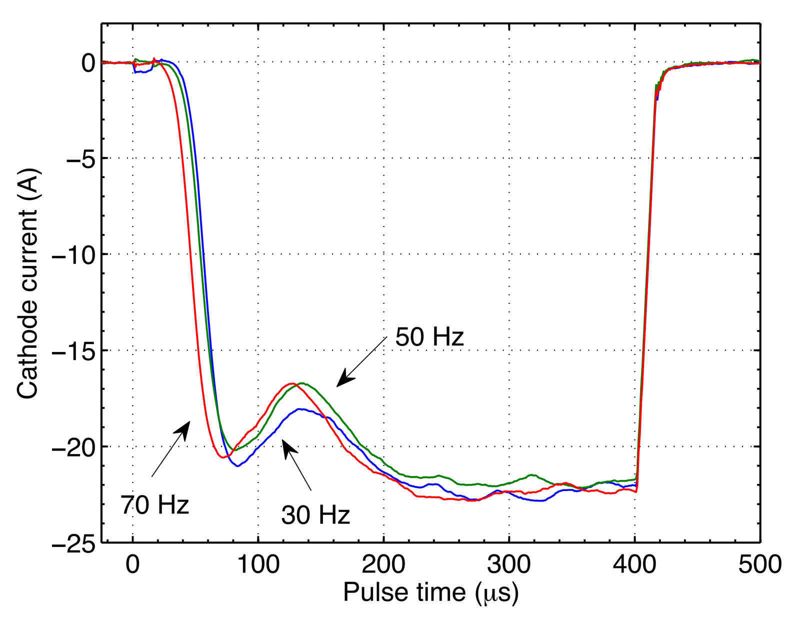

Fig. 3. The discharge current in an Ar discharge for a range of pulse repetition frequencies.

The current waveform is not affected by the pulse repetition frequency in the Ar discharge (Fig. 3).

This means that the average power can be varied independently of the peak power and without changing the discharge properties

4. The Ar/N_2 discharge

The current waveforms in the reactive Ar/N_2 discharge (Fig. 4) show the same general features as in the non-reactive Ar discharge.

Self-sputtering runaway occurs at lower voltages.

The discharge current is highly dependent on pulse repetition frequency in the Ar/N_2 discharge (Fig. 5).

Current increases as frequency is lowered due to target nitridation.

The self-sputtering phase outgrows the initial current peak.

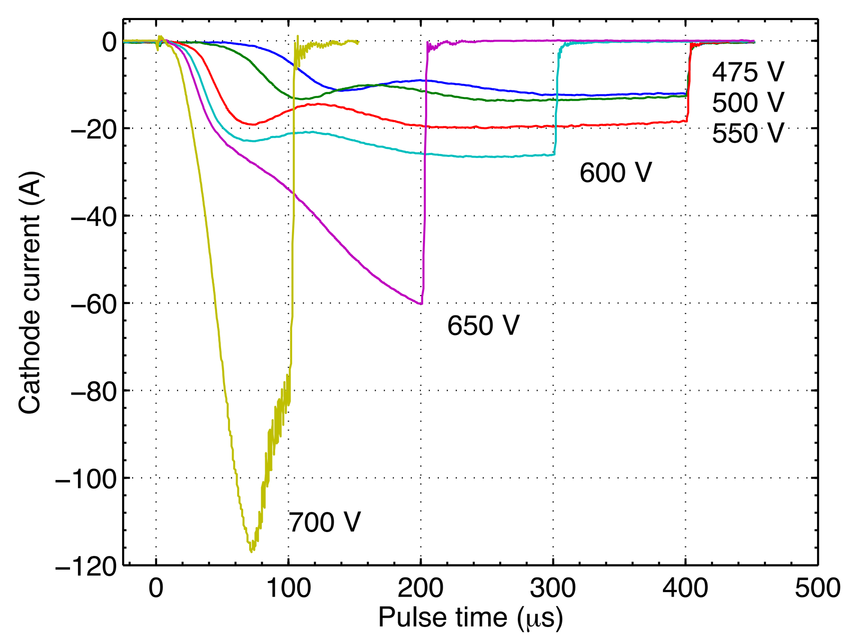

Fig. 4. Cathode current for a range of dicharge voltages in an Ar/N_2 discharge

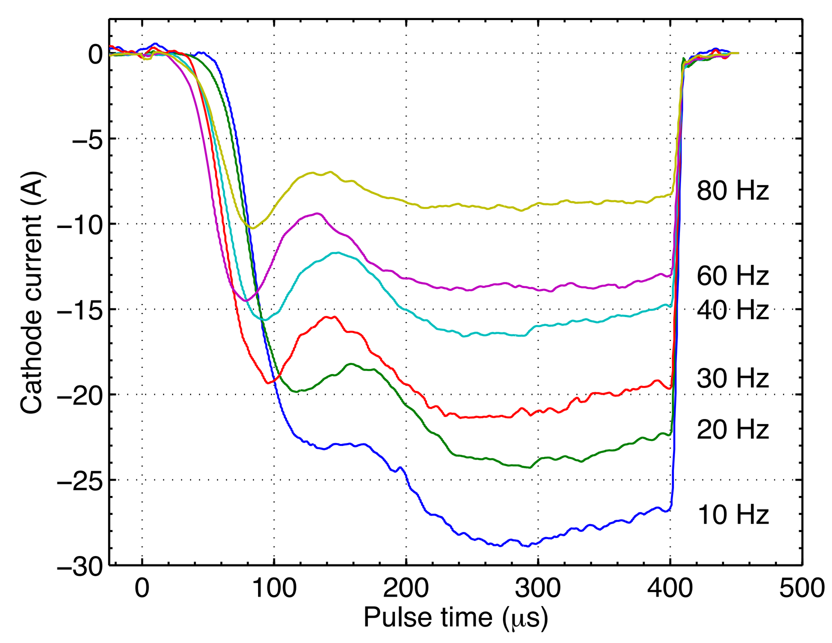

Fig. 5. Cathode current for a range of pulse repetition frequencies in an Ar/N_2 discharge

The target current depends on the energy loss per ion-electron pair created and secondary electron emission yield according to:

$$I_{\rm d} \propto \frac{1}{\mathcal{E}_{\rm c}}(1+\gamma_{\rm SE})$$

An increase in discharge current can therefore be due to:

(1) A decrease in the energy loss per ion-electron pair created $\mathcal{E}_c$ or

(2) An increase in the secondary electron emission yield γ_{SE}

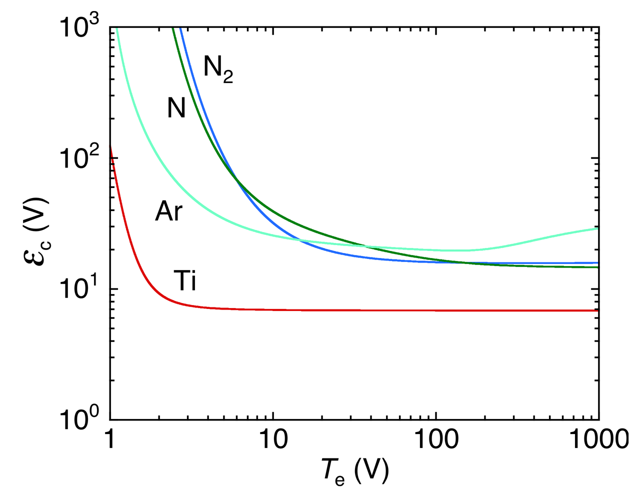

Fig. 6. The energy loss per ion-electron pair created.

(1) can be ruled out as $\mathcal{E}_c$ increases with the addition of nitrogen to the discharge as $\mathcal{E}_c$ is higher for N and N_2 than for Ar and Ti (Fig. 6).

γ_{SE} increases during the self-sputtering phase with target nitridation

Ti and N ions are dominant whereas Ar is depleated from the target area during self-sputtering.

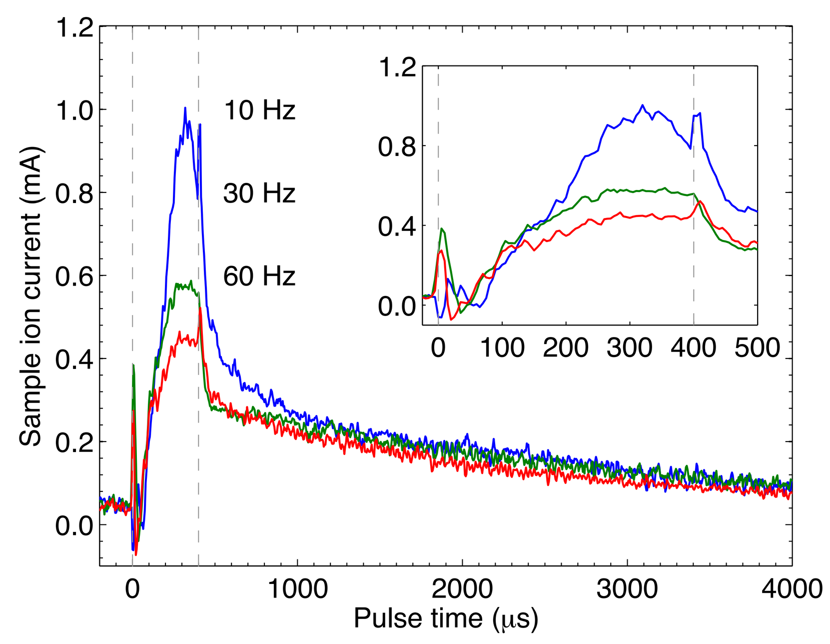

Fig. 7. The time evolution of the ion flux at the substrate.

The ion flux at the substrate rises shortly after the rise in the cathode current and reaches a maximum at approximately 300 μs into the pulse (Fig. 7)

The frequency dependence of the ion flux mirrors that of the cathode current

The observed increase in secondary electron emission yield with target nitridation should therefore be followed by an increase in deposition rate

5. Conclusions

The reactive Ar/N_2 HiPIMS discharge is highly frequency dependent, unlike the non-reactive discharge.

The discharge current increases with decreasing frequency due to target nitridation.

The increase in current is a result of the increased secondary electron emission yield of the nitride target during the self-sputtering phase.

The increase in current is reflected in an increase in the ion flux arriving at the substrate.

References

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2. A. Anders, J. Andersson, A. Ehiasarian, J. Appl. Phys. **102**, 113303 (2007).

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