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Dynamic transition in the discharge current between gas-dominant discharge and self-sputtering in high-power impulse magnetron sputtering

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ABSTRACT

An unstable stage is observed from the discharge current during the transition from gas-dominant discharge to the self-sputtering dominant regime in high-power impulse magnetron sputtering (HiPIMS). The phenomenon and the formation mechanism are time dependent and there is a dynamic transition between the two stable stages. The threshold of the high stable discharge is investigated at different pressure and hybrid DC discharge. According to the derivation of the discharge current, the temperature in the discharge is found to play a major role in the dynamic transition at moderate voltage.

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1. Introduction

In high-power impulse magnetron sputtering (HiPIMS), unipolar pulses with a low duty cycle and up to 10 kW/cm^2 momentary power density [1,2] produce a larger plasma density [3] to boost the ionization efficiency of the sputtered species [4]. By controlling the energy and impact angle of the ionized materials to the substrate, HiPIMS provides greater flexibility in microstructure engineering and better film quality than conventional direct-current (DC) magnetron sputtering (MS) [5–7]. During deposition, a stable discharge current is a key factor. The typical current waveform during pulsing in HiPIMS shows three distinct regime: [8] (I) Plasma initiation and a current maximum, (II) a transition in which the current decays to a lower-current steady-state regime, and (III) a regime in which the discharge voltage is stable. With regard to materials such as Cr [9], the HiPIMS curve is characterized by two power law fits, $I_D \propto U_D^n$ [10], in I_D and U_D are the time-dependent discharge current and voltage measured at the cathode, and simultaneously measured at the peak current [11]. The two fits intersect at a kink for a certain current density marking the transition from the DC-like discharge to a self-sputtering dominant regime with higher discharge impedance [12,13].

However, they have been inferred from stable waveform data which are usually averaged on the oscilloscope. In fact, careful examination of the instantaneous curves reveals an unstable transition between the two stages and in this work, the unstable discharge phenomenon and formation mechanism are investigated.

2. Experimental

The experiments were performed in a turbo-molecular pumped vacuum chamber with a diameter of 40 cm and height of 40 cm and the base pressure is 3×10^{-3} Pa. The working gas (99.9997% pure Ar) is introduced through a leak valve. The magnetron cathode was a Cr target (ϕ50 mm × 6 mm) and powered by a hybrid pulsed power supply developed in our laboratory. The discharge pulse width and frequency were 200 μs and 100 Hz, respectively and the working pressure was kept at 0.5 Pa. A digital oscilloscope was used to record all the instantaneous discharge current curves without any fitting and the average currents were derived by the integration division by the pulse width.

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