From Target to Substrate – About the Generation of Energetic Ions in HiPIMS Discharges

A. von Keudell, C. Maszl, W. Breilmann, J. Held, V. Schulz-von der Gathen, A. Hecimovic
Institute for Experimental Physics II, Ruhr University Bochum, 44780 Bochum, Germany

Abstract

The dynamic of high power pulsed magnetron plasmas is analysed using various diagnostics ranging from optical emission spectroscopy, probe diagnostics to mass spectrometry. It shown that structure formation in these plasmas is driven by the Simon-Hoh instability leading to the appearance of rotating spokes along the racetrack of the magnetrons. The plasma parameters in these rotating ionization zones are measured using time resolved optical and mass spectrometry. It is shown that the energy distribution of the ions reaching the substrate are directly connected to the appearance of the spokes. The underlying mechanisms are discussed to explain the good performance of HiPIMS plasmas for material synthesis

Introduction

High power impulse magnetron sputtering (HiPIMS) plasmas are characterized by a high degree of ionization and a very energetic metal growth flux leading to superior material properties. Power densities at the target of several $kWcm^{-2}$ are realized by using short pulses of 10 to 200 µs and duty cycles of a few percent only.

Many studies focus on unraveling the dynamic of a HiPIMS plasma. The intense sputter wind in a HiPIMS pulse causes gas rarefaction after a time span of 10...30µs after the onset of the plasma pulse. At target power densities above 1 kW cm^{-2}, localized ionization zones, so-called spokes, are observed which rotate along the plasma torus with a typical velocity of 10 km s^{-1}. It is assumed that the localized ionization zones correspond to regions of high electrical potential, and are, therefore, the source of an energetic group of ions of typically few tens of eV in the growth flux on the substrate. The spoke pattern depends on target material, plasma gas, power density and pressure. By adding a reactive gas such as oxygen or nitrogen to a HiPIMS plasma specific oxides and nitrides can be deposited on the substrate.

The analysis of the plasma parameters of this dynamic plasma pulses is very demanding because two time scales need to be taken into account: the first is the pulsing of the discharge with a duty cycle of a percent of less, the second is the dynamic of the plasma evolution during each pulse itself, where the current is rising from zero to over 100 A for a 2” target and the spokes form dynamically. Therefore, an elaborate triggering scheme is developed, to trigger the optical diagnostic as well as the mass spectrometer to the presence of the ionization zone in the direct line of sight to the diagnostic.

By using Stark broadening of hydrogen lines, the electron density inside the spokes can be determined to 10^{14} cm^{-3}. By inserting probes into the magneton target, the modulation of the target current by the traveling ionization zones of 30% could be determined. The synchronized mass spectra show that the energetic ions are uniquely connected to the presence of the spokes. This can be explained by the occurrence of a Simon-Hoh instability which modulates the electrical potential in the plasma and thereby the energy of the ejected ions.

Acknowledgments

This work is supported by the German Science Foundation within the framework SFB TR 87.

[1] W. Breilmann, C. Maszl, A. Hecimovic, A. von Keudell, J. Phys. D (accepted) (2017)
[2] A. von Keudell, A. Hecimovic, C. Maszl, Contrib. Plasma Phys. **1**, 9 (2016)
[3] A Hecimovic, C Maszl, V Schulz-von der Gathen, M Böke and A von Keudell, Plasma Sources Science and Technology **25**, 035001 (2016)
[4] A. Hecimovic, V. Schulz-von der Gathen, M. Böke, A. von Keudell, Plasma Sources Science & Technology **24**, 045005 (2015)
[5] W Breilmann, A Eitrich, C Maszl, A Hecimovic, V Layes, J Benedikt, A. von Keudell, J. Phys. D **48**, 295202 (2015)