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A plasma diagnostic study of bipolar high-power pulsed magnetron sputtering discharges for improved thin film deposition process

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Abstract

Nowadays, thin films have become ubiquitous in our life, so that hardly can we find any field of activity where they are not present. Among the large variety of deposition methods allowing for the synthesis of thin films, plasma-based technologies offer remarkable advantages. Considering the growing demand for thin films in the near future, new process developments are expected to meet it. This is the context of technological innovation in which the bipolar high power impulse magnetron sputtering (bipolar HiPIMS or BPH) technique has recently emerged. In BPH regime, the negative (plasma) pulse, necessary for sputtering and ionizing the metal atoms, is followed by a positive voltage one (U_+) allowing for the control of the ion energy flux during the synthesis of thin films. Even though recent works have demonstrated the advantages of BPH, the full understanding of the physics behind this new kind of plasma is still required to establish the correlation between this new physics and the film properties. Based on these considerations, this thesis work aims to better understand the BPH technique with particular emphasis on the plasma diagnostics and thin film properties considering potential industrial applications.

From plasma diagnostics (substrate current and energy-resolved mass spectrometry measurements) we have observed that different groups of positive ions are accelerated toward the substrate. Laser Induced Fluorescence (LIF) imaging analysis in the form of two-dimensional time-resolved ion density distributions confirms the two ion groups propagating away from the cathode as a result of ion acceleration during the positive pulse. Finally, we also have demonstrated that the modification of the magnetic field configuration enables additional ion energy control.

After having highlighted important phenomena involved in the physics of BPH discharges, Ti and TiO_2 films were deposited in a broad range of discharge conditions including direct current magnetron sputtering (DCMS), HiPIMS and BPH on conductive and insulating substrates. Our results show that in the case of conductive substrate (Si wafers) the substrate biasing effect obtained in DCMS can be reproduced in metallic regime by using BPH with similar U_+ values. On the other hand, in the case of TiO_2 films, a change in the grain orientation is observed as a function of U_+. In addition, we also have demonstrated, in agreement with modeling results, that the film's morphology, density, and surface roughness are significantly impacted by the discharges conditions which ultimately affects the optical properties of the deposited TiO_2 coatings. In addition, the films deposited on glass revealed that the increase of the energy flux at the substrate is mainly provoked by an intensification of the positive ion bombardment by increasing U_+. As a consequence, the film properties are strongly affected if sufficient level of ion bombardment is reached.

Altogether, the present work demonstrates that the BPH approach allows for a "simple" control of the ion fluxes bombarding the substrate by wisely designing the pulse configuration at the cathode. This makes the method flexible and adaptable to many types of process and substrates, including dielectric ones. We have also demonstrated that a fine tuning of this pulse configuration has to be performed in order to avoid side problems such as re-sputtering of the growing film or trapping of gaseous ions.