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Diagnostics and Monitoring of Thermal and Plasma Enhanced Atomic Layer Deposition of Titanium Nitride

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Atomic Layer Deposition (ALD) is a rapidly evolving technique allowing one to produce films for optoelectronic, microelectronic and other nanotechnology applications with unprecedented quality and precision. Further development and optimization of the ALD processes requires novel approaches and diagnostic tools for the process control and monitoring. In the present work, we study the deposition process of TiN films obtained from $TiCl_4$ as a precursor for Ti, and NH_3 vapor or $Ar/N_2/H_2$ plasma as a reducing agent in thermal and plasma-enhanced (PE) ALD modes. High sampling rate in-situ spectroscopic ellipsometry was used to provide the insight into the TiN growth kinetics, specifically the thickness and the optical and electrical properties. Chemical reactions were assessed by optical emission spectroscopy directly in the reaction zone as well as in the downstream pumping line. In the latter case we used a remote plasma spectroscopy concept in which secondary plasma was generated within the sensor head, and its emission was analyzed by a spectrometer. We found that the high-voltage Penning-type discharge gives rise to an intensity enhancement of the N_2^+ first negative band head at 391.4 nm, making it possible to follow the relatively small changes in the downstream concentration of nitrogen in relation to its consumption by the ALD reaction. In addition, mass spectrometry measurements were performed to obtain complementary information about the reaction dynamics.
Films obtained in both configurations are compared for their stoichiometry, concentration of contaminants (oxygen and chlorine), resistivity, and growth rate per cycle. Based on the results, we discuss the capabilities and limitations of the different diagnostics techniques in thermal ALD and PEALD configurations. Appropriate use of such techniques allows for rapid optimization of the ALD process, better reproducibility, and improved properties of the deposited films.

Keywords
PEALD
titanium nitride
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optical emission spectroscopy