Optimization of Magnetized PEALD Processes with Impedans Langmuir Probe and Semion RFEA

Published in Journal of Nanotechnology

Reference
You Jin Ji. et al, Plasma enhanced atomic layer deposition of silicon nitride using magnetized very high frequency plasma. Nanotechnology 35 275701 (2024)
HTTPS://DOI.ORG/10.1088/1361-6528/AD3740

Introduction

Impedans' Langmuir probes and retarding field ion energy analyzers (RFEAs) are versatile diagnostic tools widely used in plasma-assisted deposition and etching processes. The Langmuir probe provides real-time data on critical plasma parameters, such as electron density, electron temperature, plasma potential, and the electron energy distribution function (EEFDF). Meanwhile, the Semion RFEA offers live measurements of ion energy and flux at plasma-immersed electrodes. These insights enable precise process control and optimization by correlating plasma parameters with key performance metrics, such as deposition rate and surface morphology.

A recent study published in the Journal of Nanotechnology demonstrated the application of Impedans' Langmuir probe and Semion RFEA in the deposition of silicon nitride (SiNx) films using the plasma-enhanced atomic layer deposition (PEALD) process. Langmuir probe and Semion RFEA measurements were instrumental in understanding the role of plasma species under varying experimental conditions, leading to improvements in deposition rates.

Experimental setup

Figure 1(a) illustrates a schematic of the VHF (162 MHz) CCP-PEALD system, featuring magnetic coils encircling the chamber. The floating multi-tile electrodes for VHF power delivery consist of four pairs of rectangular-shaped tiles (two tiles per pair). The 162 MHz RF power is equally supplied to the multi-tile electrodes through the inductively coupled power splitter. For magnetized PEALD, an external magnetic field of 100 G was applied during the N2 plasma discharge

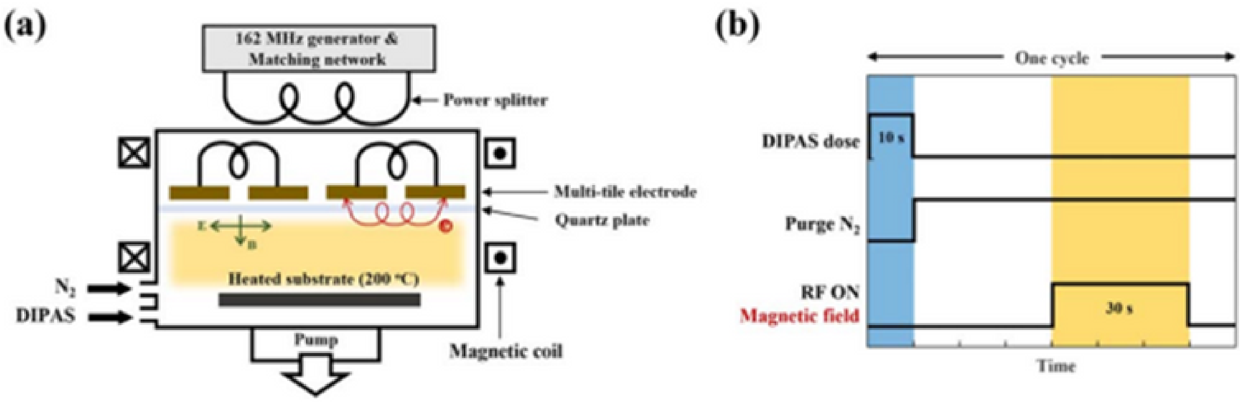

Figure 1 (a) Schematic of VHF (162 MHz) CCP- PEALD process chamber equipped with magnetic coils for axial magnetic field. (b) One cycle of SiNx PEALD process.

A low-doped p-type Si wafer was used as the substrate, and PEALD SiNx (10 nm) thin films were deposited as the insulator layer. The SiNx PEALD process steps are shown in figure 1(b). The process was conducted at a substrate temperature of 200 °C, while the chamber wall was heated to 100 °C.

Results

Plasma characteristics such as ion density (ni), plasma potential (Vp), and floating potential (Vf) of the N2 plasma were measured by using a Langmuir probe (ALP-150, Impedans) at varying operation pressure (0.3 - 1 Torr) and external magnetic field intensity (0–100 G) at 1 Torr.

First, the electron densities without external magnetic fields were measured, and the results are shown in figure 2(a). As the pressure increases from 0.3 to 1 Torr, the electron density gradually increases and high density of plasma about 9.5×10^{9} cm^{-3} is obtained at an N2 pressure of 1 Torr.

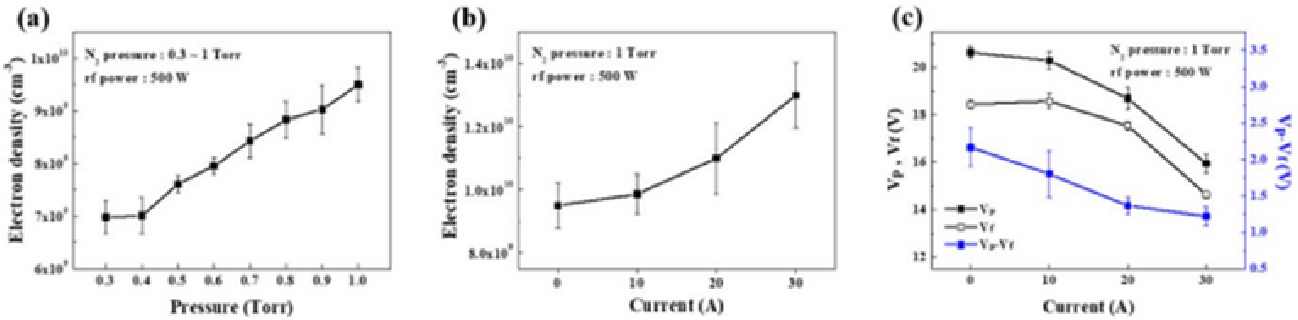

Figure 2 Characterization of N2 plasma using VHF (162 MHz) floating multi-tile electrode with external magnetic fields. (a) Electron density as a function of N2 pressures (0.3 - 1 Torr) without external magnetic fields, and (b) as a function of currents (0 - 30 A) flowing through the coil to apply external magnetic fields at an N2 pressure of 1 Torr. (c) Plasma potential (Vp), floating potential (Vf) and the difference between plasma potential and floating potential (Vp−Vf) for different current (0 - 30 A) at an N2 pressure of 1 Torr. Plasma RF power was fixed at 500 W for (a)–(c).

While keeping the N2 pressure at 1 Torr, plasma parameters were measured according to the current through the coil, and the results are shown in figures 2(b) and (c). With increasing current from 0 to 30 A (equivalent to 0–100 G), electron density increases, and an electron density of 1.3×10^{10} cm^{-3} is obtained at 100 G, as shown in figure 2(b). The plasma potential (Vp), floating potential (Vf) and the difference between plasma potential and floating potential (Vp−Vf) measured as a function of applied current under the same conditions in figure 2(b) are presented in figure 2(c). As shown in figure 2(c), Vp, Vf, and Vp−Vf decrease with increasing external magnetic field. The Vp−Vf is a measure of the ion energy bombarding the substrate.

The decrease of ion energy reaching the substrate with increasing an external magnetic field is consistent with the results of ion energy measured using an ion energy analyzer at lower pressure ranges (100 - 200 mTorr) as shown in figure 3. Ion energy distribution with applied coil current (0-30 A) was measured under different N2 pressure and RF power conditions. Increasing the operating pressure from 100 to 200 mTorr led to a decrease in ion energy, while raising the RF power from 300 to 500 W resulted in increased ion energy. However, in all conditions, the ion energy decreased with an increase in coil current

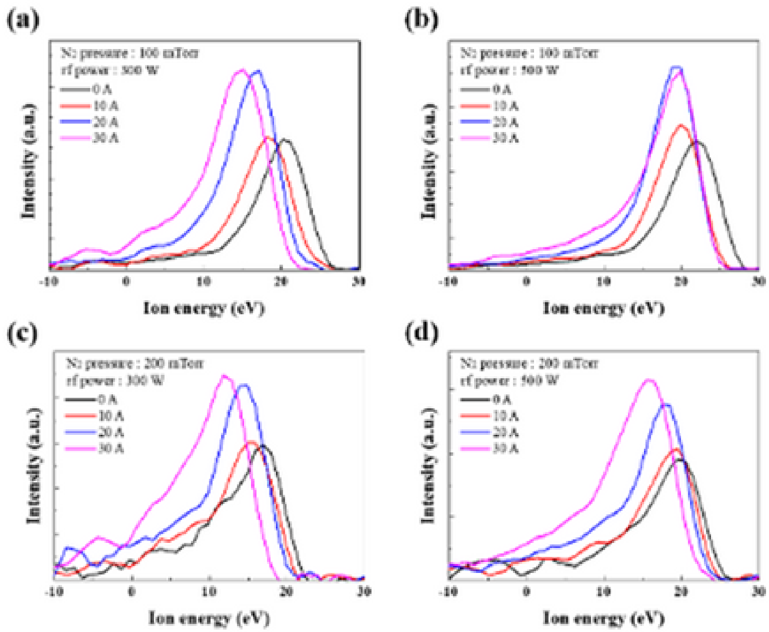

Figure 3 Ion energy distribution with applied current to the Helmholtz coil was measured using Semion ion energy analyzer under various N2 pressure (100 and 200 mTorr) and RF power (300 and 500 W) conditions.

Summary

The magnetized PEALD (Plasma-Enhanced Atomic Layer Deposition) process for SiNx film deposition was studied at a low substrate temperature of 200 °C. Plasma characteristics, such as ion energy and plasma density, were examined under varying external magnetic field strengths (0 to 100 G) and nitrogen (N_2) pressure. Increasing the magnetic field intensity resulted in higher plasma density, reduced ion energy, and increased radical density.

Plasma parameters including ion energy distribution, were measured using Impedans' Langmuir probe and Semion RFEA. These measurements provide valuable insights into the influence of magnetic fields on the deposition process. The findings demonstrate that controlling the magnetic field intensity allows precise regulation of deposition rates during the magnetized plasma process.