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Characterization of Dielectric Silicon Nitride Thin Films Deposited by Radio Frequency Plasma-Enhanced and Electron Cyclotron Resonance Chemical Vapor Deposition

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ABSTRACT

The silicon-nitride (SiNx) thin films have been deposited by radio frequency plasma enhanced chemical vapor deposition (RF-PECVD) at 250°C and Electron cyclotron resonance chemical vapor deposition (ECR-CVD) at 280°C techniques using ammonia (NH3) and silane (SiH4) as reactant gases. The films deposited by both the techniques were compared by atomic force microscopy (AFM), Fourier transform infrared spectroscopy (FTIR), UV-Visible spectroscopy and Ellipsometry. We have achieved refractive index ~2.06, high optical band gap ~4.15 eV and small surface roughness about 0.40 nm with the thickness of 640 Å on the film deposited by RF-PECVD technique at 250°C, which is good for most of the optical devices. The SiNx thin films deposited by RF-PECVD technique at 250°C have been used in the passivation of metal–semiconductor field effect transistor (MESFET) due to their excellent barrier property to moisture, metal-ions and oxygen.

KEYWORDS: Atomic force microscopy; thin film; refractive index; band gap; passivation; MESFET

Introduction

The silicon nitride films with high refractive index and high optical band gap have a wide range of applications in microelectronic and optoelectronic devices [1]. In recent years, special attention has been devoted to the use of silicon nitride in semiconductor device technology due to their excellent adhesion to Si and GaAs. The silicon nitride thin films have also been used in interlayer isolation, device passivation and mechanical protection [2]. For the proper functioning of the device, thickness and refractive index of the film plays the critical role. Among the different techniques used to produce the SiN_x thin films, the most important technique is radio frequency plasma enhanced chemical vapor deposition (RF-PECVD) method, due to the growing interest in thin film deposition at low temperatures which minimizes the interface defects [3]. The Electron cyclotron resonance plasma enhanced chemical vapor deposition (ECR-CVD) has also been used for the deposition of silicon nitride thin films [4]. These techniques offer low-cost and high yield fabrication of thin films.

In this work, we focused on the low temperature deposition of silicon nitride thin films by RF-PECVD and ECR-CVD techniques at 250°C and 280°C, respectively. The films deposited by both the technique showed attractive optical and physical properties. Our aim was to deposit the high refractive index and thin films small surface roughness films at low substrate temperature. The deposited thin films have been used in the passivation of MESFET and I-V measurements were performed to evaluate the efficiency of the deposited films in the device passivation.

Experimental:

The silicon nitride films were deposited on p-type single crystal of Si (100) wafers. For the low cost, low temperature and good stoichiometric SiN_x thin films, the chemical vapor deposition methods have been employed. We have deposited the SiN_x thin films by Radio frequency plasma enhanced chemical vapor deposition (RF-PECVD) and Electron spin resonance chemical vapor deposition (ECR-CVD) techniques. Silane (SiH_4) and ammonia (NH_3) have been used as silicon and nitrogen precursor, respectively. The conditions of silicon nitride films deposited by RF-PECVD and ECR-CVD techniques are given in the table 1 and 2, respectively.

Table 1 RF-PECVD Conditions

Parameters	values
Substrate Temperature (°C)	250
Gas flow ratio: SiH4/NH3/N2	37.5/2.875/250
Final vacuum (Torr)	1.2×10-8
Radio frequency (RF) Power (W)	20

Table 2 ECR-CVD Conditions

Parameters	values
Substrate Temperature (°C)	280
Gas flow ratio: $SiH_4/NH_3/Ar$	30/7.5/30
Final vacuum (Torr)	5.9×10^{-8}
Radio frequency (RF) Power (W)	200

The deposited SiN_x thin films have been characterized by atomic force microscopy (AFM) for the surface morphology and roughness measurements. The Fourier Transform Infrared (FTIR) spectroscopy measurements were carried out to find the various chemical bonds in silicon nitride films. The UV-Visible analysis was performed to obtain the optical band gap of the films by using Tauc's relation. The Ellipsometeric measurements have been carried out to find the refractive index and thickness of the films. Finally, the deposited films were used in the Passivation of MESFET and, I-V characteristics of the MESFET before and after passivation have been compared.

Results and Discussions:

In order to understand the topography of deposited thin films, atomic force microscopy (AFM) studies were carried out. Fig. 1 (a) and (b) show two dimensional AFM images of the films deposited by RF-PECVD method at 250°C and ECR-CVD method at 280°C, respectively. The three dimensional AFM images of the films deposited by RF-PECVD technique at 250°C and ECR-CVD technique at 280°C has shown in the fig. 1 (c) and (d), respectively. The scanned area in each case is 1x1 μm^2. The surface roughness of silicon nitride thin films is listed in the table 3. The AFM measurements showed that the films deposited by ECR-CVD at 280°C have larger grain size and surface roughness than deposited by RF-PECVD at 250°C. The reduced surface roughness for RF-PECVD method is attributed to larger SiH_4/NH_3 flow ratio.

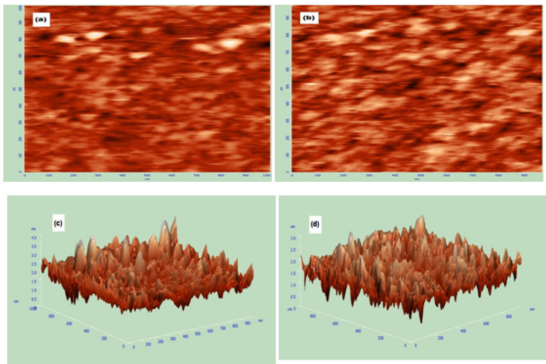

Fig. 1. AFM 2-D images of the films deposited by (a) RF-PECVD at 250° and (b) ECR-CVD at 280°C. AFM 3-D images of the films deposited by (c) RF-PECVD at 250°C and (d) ECR-CVD at 280°C.

Table 3: Roughness and Band gap of the SiNx thin films

Sample	rms surface roughness (nm)	Band gap (E_g)
RF-PECVD (250°C)	0.40	4.15 eV
ECR-CVD (280°C)	0.50	3.98 eV

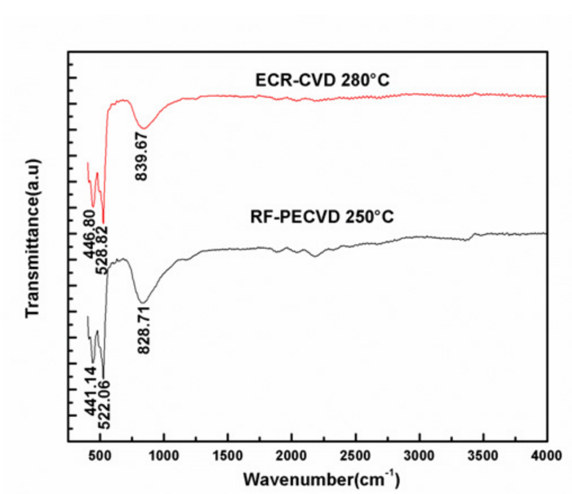

Fig. 2. FTIR spectra of SiN_x thin films deposited by RF-PECVD and ECR-CVD methods.

The FTIR spectra have been used to determine the chemical bonding among the various elements present in silicon nitride thin films. Fig. 2 shows the FTIR spectra of silicon nitride films, in the range of 400–4000 cm^{-1}, deposited by RF-PECVD at 250°C and ECR-CVD at 280°C. The absorption peaks observed at 825-840 cm^{-1}, in both the films, refer to the stretching vibration mode of the Si–N bond [5-6]. The small absorption band observed near 520 cm^{-1} may be attributed to the Si-N breathing mode. In addition to above peaks, we observed the Si-N wagging mode near 440 cm^{-1} and N-H stretching mode around 3360 cm^{-1}[7]. However, the positions of the corresponding absorption peaks of the films deposited by ECR-CVD technique found at slightly higher wave number. It may be due to high radio frequency (RF) power used in ECR-CVD technique.

The optical band gap (E_g) of the deposited films has been calculated from UV-Visible spectra using Tauc's relation [8],

$(\alpha h\nu)^{1/2}=A(h\nu-E\_g)$..................(1)

Where α is absorption coefficient, *A* is a constant, and *hν* is photon energy. The plot of and is shown in the fig. 3. The band gap (E_g) has been calculated by the extrapolation of linear portion of the curve between and. The values of the band gap (E_g) for both the films are listed in table 3. The film deposited by ECR-CVD at 280°C showed a lower band gap of 3.98 eV. On the other hand, film deposited by RF-PECVD at 250°C found to have larger band gap of 4.15 eV which clearly indicates the higher content of the nitrogen in the film. The calculated values of the band gap are well matched with the reports [9-10].

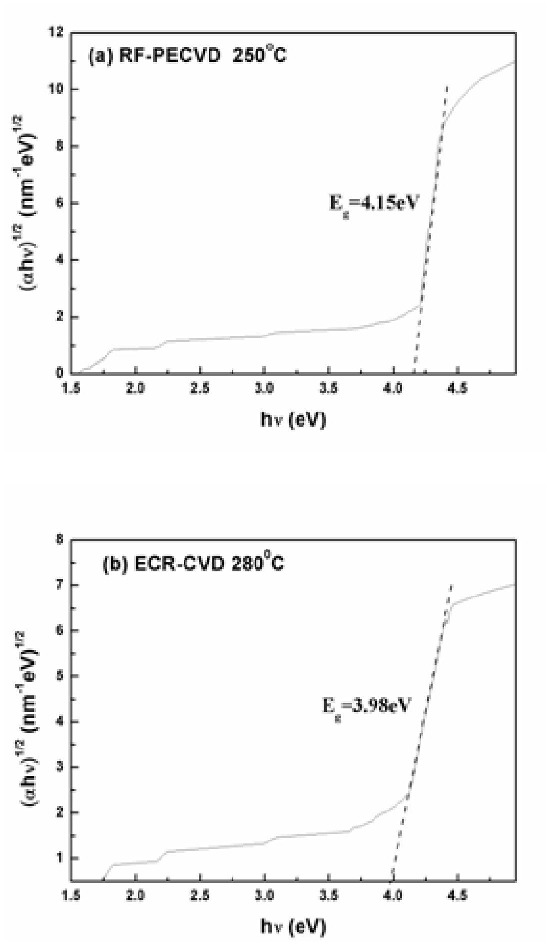

Fig. 3. UV–Visible analysis of SiNx thin films deposited by (a) RF-PECVD at 250°C and (b) ECR-CVD at 280°C.

Ellipsometric measurements have been carried out to calculate the refractive index, thickness and deposition rate of silicon nitride thin films deposited by using ECR-CVD and RF-PECVD techniques. The refractive indices of the films deposited by RF-PECVD at 250°C and ECR-CVD 280°C are found to be 2.06 and 1.95, respectively. The refractive index of the film deposited by RF-PECVD is higher than ECR-CVD technique. The values of refractive index obtained in this work have an excellent agreement with those reported in the literature [11]. The higher SiH_4/NH_3 flow ratio is the reason for higher refractive index for RF-PECVD method. The deposition rate of the film has been calculated from the ratio of film thickness to total deposition time. The deposition rate of the films deposited by RF-PECVD at 250°C and ECR-CVD 280°C are found to be 98 Å/min and 112 Å/min, respectively. The high deposition rate for ECR-CVD is due to large RF power used for the deposition [12-13].

From the results of various characterization techniques, it can be said that silicon nitride thin films deposited by RF-PECVD at 250°C are better for the passivation of MESFET. Fig. 4 (a) and (b) show the I-V characteristics of MESFET without and with passivation layer, respectively. Fig. 4 (c) shows the variation of transconductance (g_m) with the applied gate voltage (V_g) in the saturation region. The drain current (I_{ds}) varies almost linearly with gate voltage (V_g) over a wide range of applied bias. The slope of drain current vs gate voltage is transconductance. The transconductance increases after passivation at higher gate bias voltage. The results clearly show that the SiN_x thin films deposited by RF-

PECVD at 250°C have been used in the MESFET passivation successfully.

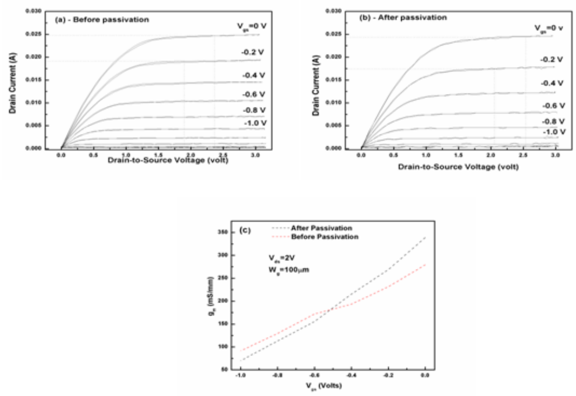

Fig. 4 The variation of drain current with drain to source voltage in MESFET (a) before passivation, (b) after passivation and (c) variation of transconductance with gate-to-source voltage.

Conclusions:

In this paper, we have deposited silicon nitride thin films by RF-PECVD at 250°C and ECR-CVD at 280°C methods. The films show deposited by both the methods show attractive physical and optical properties. However, the films deposited by RF-PECVD method at 250°C exhibit low surface roughness, high refractive index and high optical band gap. Moreover, the SiNx films by RF-PECVD has been deposited at low temperature and low radio frequency (RF) power which makes them suitable for a number of substrate materials. The films deposited by RF-PECVD method have been successfully used in the passivation of MESFET. The I-V measurements of MESFET confirm that the SiNx films deposited by RF-PECVD method have good passivation results.

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