N_2 Plasma Treatment Effects of Silicon Nitride Insulator Layer for Thin Film Transistor Applications

Jae Kyung Ko, Yong Seob Park, Joong Hyun Park, Do young Kim and Junsin Yi
School of Electrical and Computer Engineering, Sungkyunkwan University
300 Chunchun-dong, Jangan-gu, Suwon, Kyunggi-do, 440-746, Korea
K. Chakrabarty
Photon Semiconductor & Energy Company, 300 Chunchun-dong, Jangan-gu,
Suwon, Kyunggi-do, 440-746, Korea

Abstract

We investigated to decrease the leakage current of SiNx film by employing N_2 plasma treatment. The insulator layers were prepared by two step process; the N_2 plasma treatment and then PECVD SiNx deposition with SiH_4, N_2 gases. To prove the influence of the N_2 plasma treatment, the Si substrate was exposed to the plasma, which was generated in N_2 gas ambient. Without plasma treatment SiNx film grow at the rate of 7.03 nm/min, has a refractive index $n = 1.77$ and hydrogen content of 2.16×10^{22} cm^{-3} for N_2/SiH_4 gas flow ratio of 20. The obtained films were analyzed in terms of deposition rates, refractive index, hydrogen concentration, and electrical properties. By employing N_2 plasma treatment, interface traps such as mobile charges and injected charges were removed, hysteresis of capacitance-voltage (C-V) disappeared. We observed plasma treated sample were decreased the leakage current density reduces by 2 orders with respect to the sample having no plasma treatment.

1. Introduction

Silicon nitride (SiNx) thin film have been used extensively in the semiconductor industry for over two decades, an application of particular recent importance being as the insulator in hydrogen amorphous silicon (a-Si:H) thin film transistor [1]. To further improve device performance, device stability, as well as long-term reliability, gate dielectric material becomes one of the most critical issues. Also, plasma treatment has been adopted as surface treatment, etch and deposition processes in many industrial applications [2]. Plasma treatment has proven to be very efficient for the enhancement of adhesion, and advances in this area have recently been reviewed [3]. The principal reason for this is that the plasma-surface interactions controlled by the energetic ions, photons and free radicals present in the plasma, act in synergy [4]. Such interactions lead to (1) surface cleaning (removal of both contaminants and weak boundary layers), (2) the grafting of chemical groups (functionalization) capable of reacting to form strong bonds to subsequently deposited layers, (3) surface ablation (microetching), leading to an increase in surface microroughness that serves to enlarge the surface contact area, and (4) an increase in mechanical stability of the near-surface region through cross-linking [5].

In case of N_2 plasma treatment, SiNx film improved to electrical properties after plasma treatment. Further, it presents the advantage of being one of the precursor gases in the deposition of SiNx film [6]. The present work, we have investigated the properties of SiNx film for various gas flow ratio of N_2/SiH_4 and resulting from N_2 plasma treatment.

2. Experimetal

Before being introduced in the reactor, the used silicon substrate (4", (100), p-type, 25.5-42.5Ω cm). A silicon substrate was cleaned by RCA method to remove substrate contamination [7]. Just before being transferred to the vacuum deposition chamber, substrate were etched in $HF:H_2O$ (1:10) for 10 second. The SiNx film was deposited in planar coil plasma enhanced chemical vapor deposited (PECVD) reactor. To study the influence of the N_2 plasma treatment, the Si substrate was exposed to the plasma, which was generated in N_2 gas ambient. Substrate temperature during the N_2 plasma treatment was kept at 300 ℃ and the applied rf power of 400 W. Treatment time was 3 minute at the fixed pressure of 49mTorr. N_2 gas flow was 30sccm. After the N_2 plasma treatment, the insulator deposition was carried out. At the condition using pure nitrogen and a helium dilution of silane gas. We also studied of 30mTorr working pressure, 300℃ substrate temperature, 3-50 nitrogen-to-silane gas flow ratio, 200W PECVD rf power (13.56 MHz). The thickness of SiNx film was kept unchanged at 400Å. After the insulator deposition, aluminum top electrodes (about 1000Å) were deposited by thermal evaporation. The thickness and the refractive index of the films were measured by ellipsometry and chemical bonds were determined using FT-IR measurement [8]. MIS structures were characterised by high Frequency (1MHz) capacitance-voltage (C-V) characteristics study with Boonton 7200 and the current-voltage curves (I-V) with a Keithley 617, Fluke 5100B system.

3. Results and discussions

The SiNx film shows IR spectral features at frequencies characteristic of the local bonding of the Si, N, and H atoms. The nature of the chemical bonding groups was analyzed using FTIR spectroscopy. Figure 1 shows that FTIR transmission spectra from 450 to 4000 cm^{-1} for films prepared at N_2/SiH_4 gas flow ratios of 5, 10, 20 and 50 at 300 °C. The calculations were made for the absorbance at the absorption peak position and molecular extinction coefficients 5.7×10^{-20} cm^2 for Si-H and 4.8×10^{-20} cm^2 for N-H [9]. Figure 1 shows that the hydrogen content of Si-H bond is decreasing as gas ratios increasing. On the contrary, hydrogen content of N-H bond is increasing. Additional re-bonding of silicon to nitrogen is expected as hydrogen is evolved from the film at these conditions. The reduction of bonded hydrogen and Si-H bond healing are responsible for the improved electrical and passivation properties of SiNx film.

Figure 2 shows the hydrogen concentration in the as-deposited films is in the form of Si-H and N-H bonds. It was observed that all of the detectable hydrogen in the SiNx film was bonded to nitrogen and detected as N-H groups for the nitrogen-to-silane gas flow ratio at the 10~50 range. It was observed that the hydrogen content is about 2.0×10^{22} cm^{-3} for SiNx film deposited at nitrogen-to-silane gas flow ratio more than 5 as shown was observed in Figure 2. The hydrogen content of about 2.14×10^{22} cm^{-3} for the gas flow ratio equal to 50. For the sample made of using gas flow ratio of 20 and at the substrate temperature of 300℃, the Si-H bonding concentration was detected as 2.47×10^{21} cm^{-3} and that of N-H bonding as 1.91×10^{22} cm^{-3}. To optimize the properties of SiNx film, the gas flow ratio of 20 was selected.

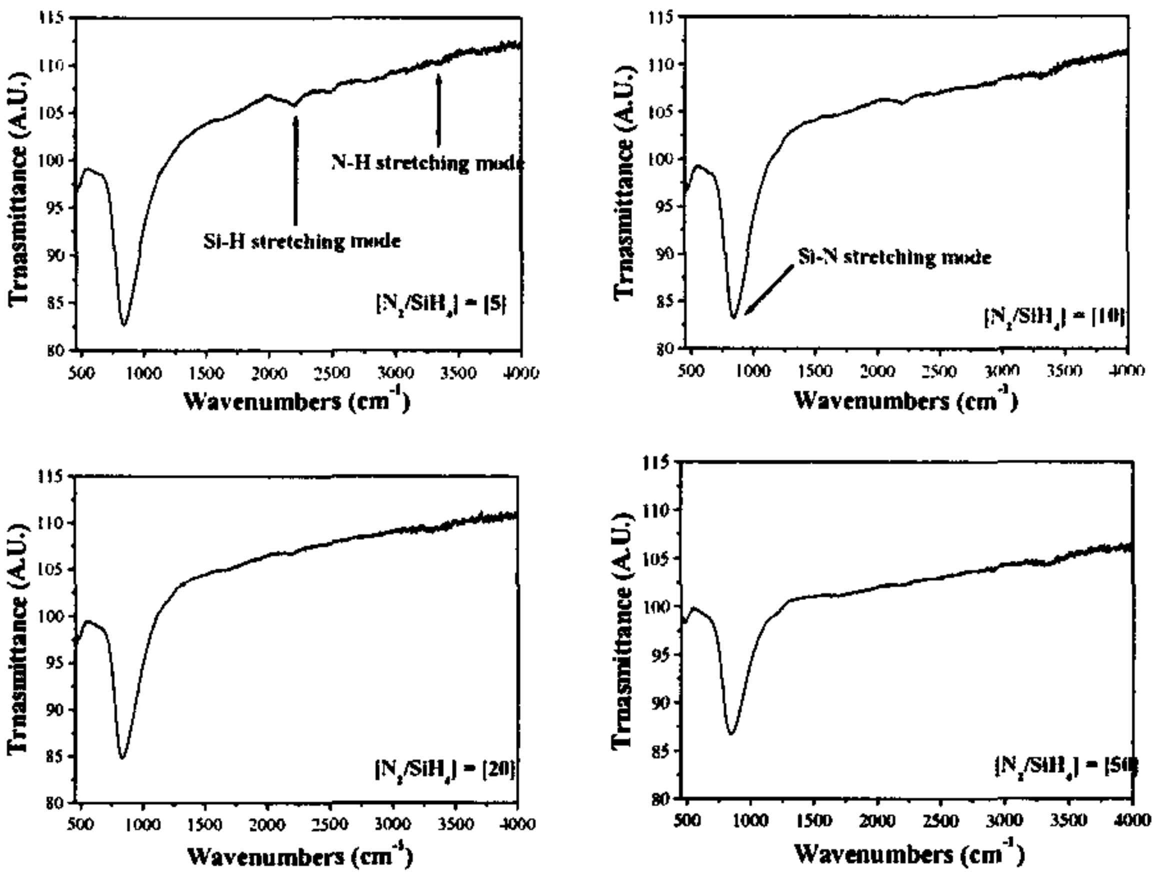

Figure 1. FT-IR transmission spectra of SiNx films that is deposited in various N_2/SiH_4 gas flow ratios, 200W source power, 30mTorr discharges at 300℃

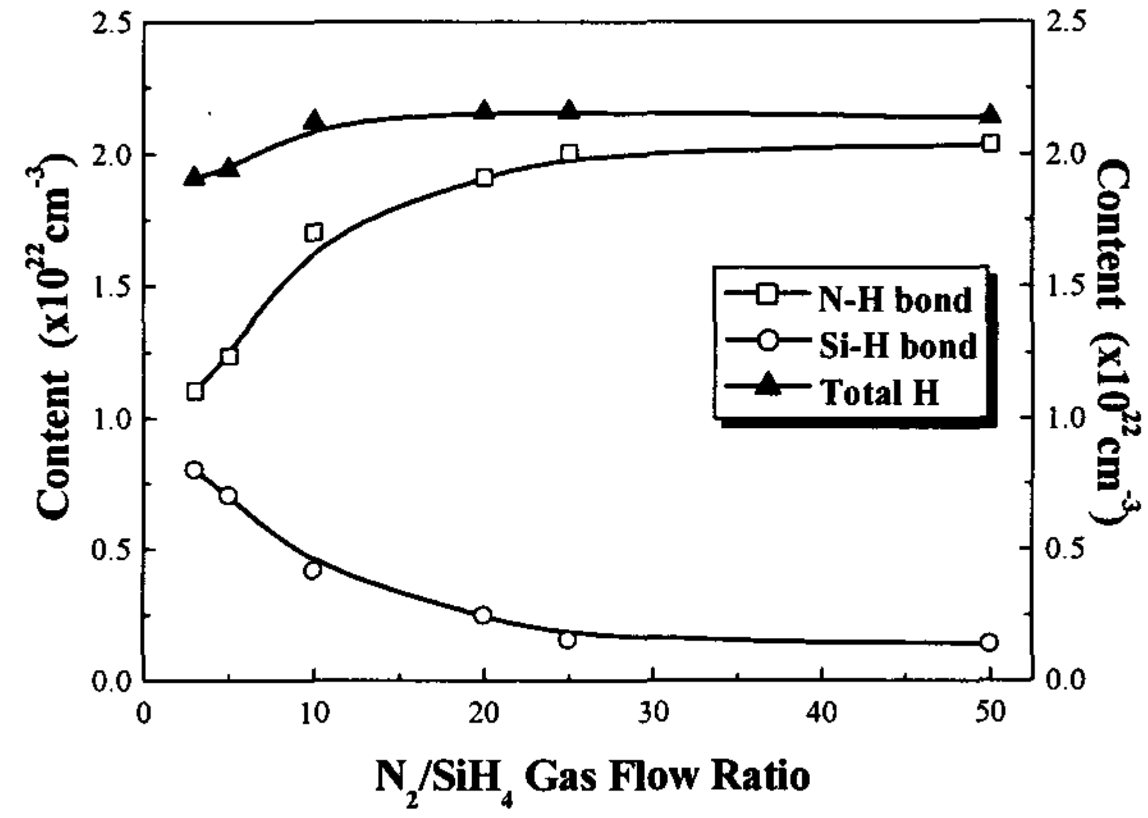

Figure 2. hydrogen concentration for the SiNx films prepared by different N_2/SiH_4 gas flow ratio

Figure 3 shows deposition rate and the refractive index of SiNx film as a function of N_2/SiH_4 gas flow ratio and existence and nonexistence of N_2 plasma treatment. The N_2 plasma treatment reduces the deposition rate and increases the refractive index from its original value of SiNx film without plasma treatment. The deposition rate is 11.1 nm/min no N_2 plasma treatment at the gas flow ratio of 5. After N_2 plasma treatment, deposition rate reduces 9.3nm/min. The refractive index increases about 0.2 magnitudes after plasma treatment than before plasma treatment.

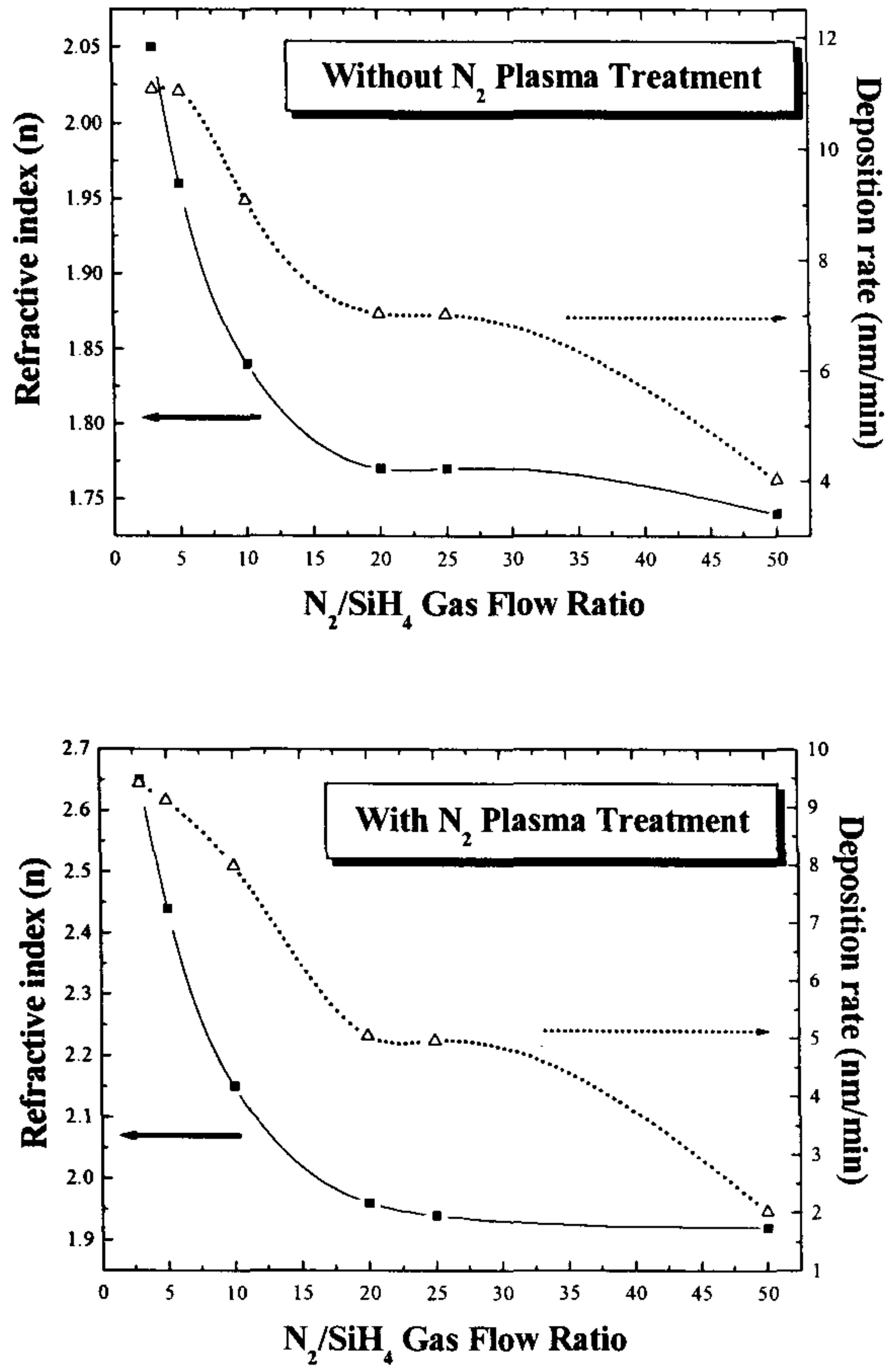

Figure 3. Refractive index and deposition rate as existence and nonexistence of N_2 plasma treatment

Figure 4 shows the capacitance-voltage (C-V) curve of Al/SiNx/Si with and without N_2 plasma treatment. The main difference between the two curves is in the amount of hysteresis observed in their transfer characteristics. As can be seen from Figure 4, the direction of hysterisis was clockwise, which is contributed by the mobile charge. It can be attributed that by employing N_2 plasma treatment, interface traps such as mobile charges and injected charges were removed, which helps to show a very narrow hysteresis of C-V curve, and shift the flat band voltage towards negative voltage. These results indicate that N_2 plasma treatment induces a small number of slow interface states, which produce an important hysteresis phenomenon. These phenomenons are probably related to the nitridation induced by this plasma treatment [6]. The reduction of mobile charge (naturally positive) improves the insulating property of SiNx film.

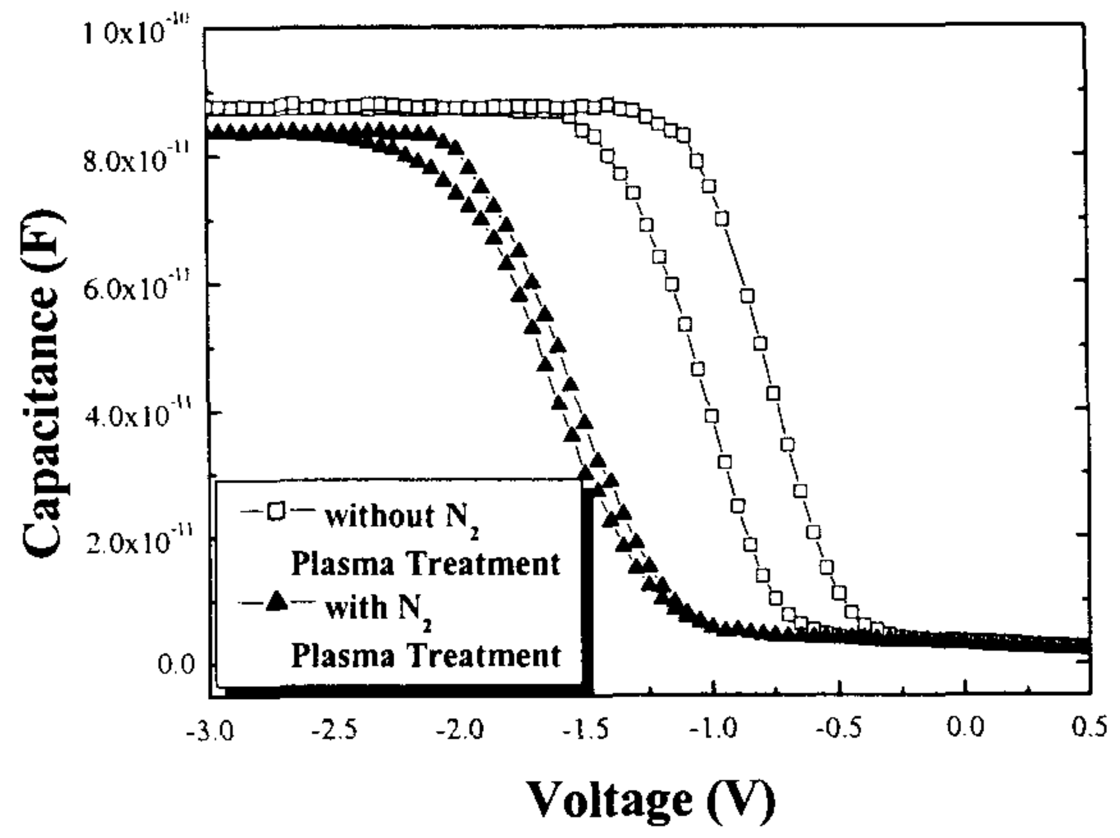

Figure 4. Caparison of the CV characteristics for SiNx films with N_2 plasma treatment and without N_2 plasma treatment

Figure 5 corresponds to the leakage current density of the SiNx film prepared by different N_2/SiH_4 gas flow ratio. At the electric field of -0.6 MV/cm is the leakage current density of 7.29×10^{-6}A/cm^2 for the gas flow ratio was observed 5. An increase in the gas flow ratio from 20 to 50 causes as increase in the leakage current density from 5.45×10^{-8}A/cm^2 to 2.34×10^{-7}A/cm^2. Addition of N_2 reduces peak intensity of Si-H bond and increases peak intensity of N-H bond. These results were reduced leakage current density for addition of N_2. But, in case of the gas flow ratio of 50, the electrical properties of a insulator layer becomes poor, because of the presence of excess a nitrogen in the films.

Figure 6 shows the effect of N_2 plasma treatment process on the I-V characteristics of the SiNx film. For N_2 plasma treated sample were decreased the leakage current density reduces by 2 orders with respect to the sample having no N_2 plasma treatment. The decrease in the leakage current density has two possible causes. One is the plasma treatment play a cleaning role of a silicon substrate. The N_2 plasma treatment can also remove impurities, left on the surface after the conventional wet etching. The other is related to the nitridation induced by N_2 plasma treatment. As we know from C-V curve, reduction of the interface defects like mobile and injected change decrease the leakage current density.

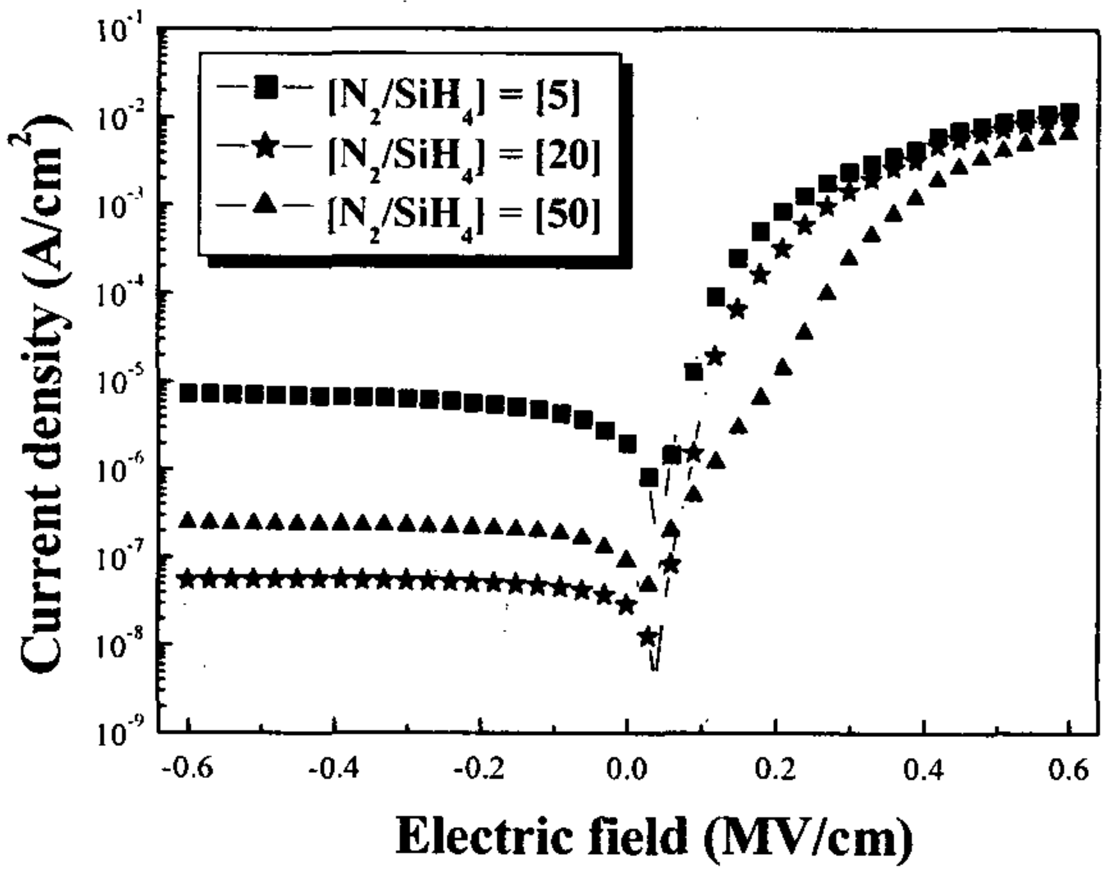

Figure 5. Fig. 5. I-V characteristics of SiNx films without N_2 plasma treatment

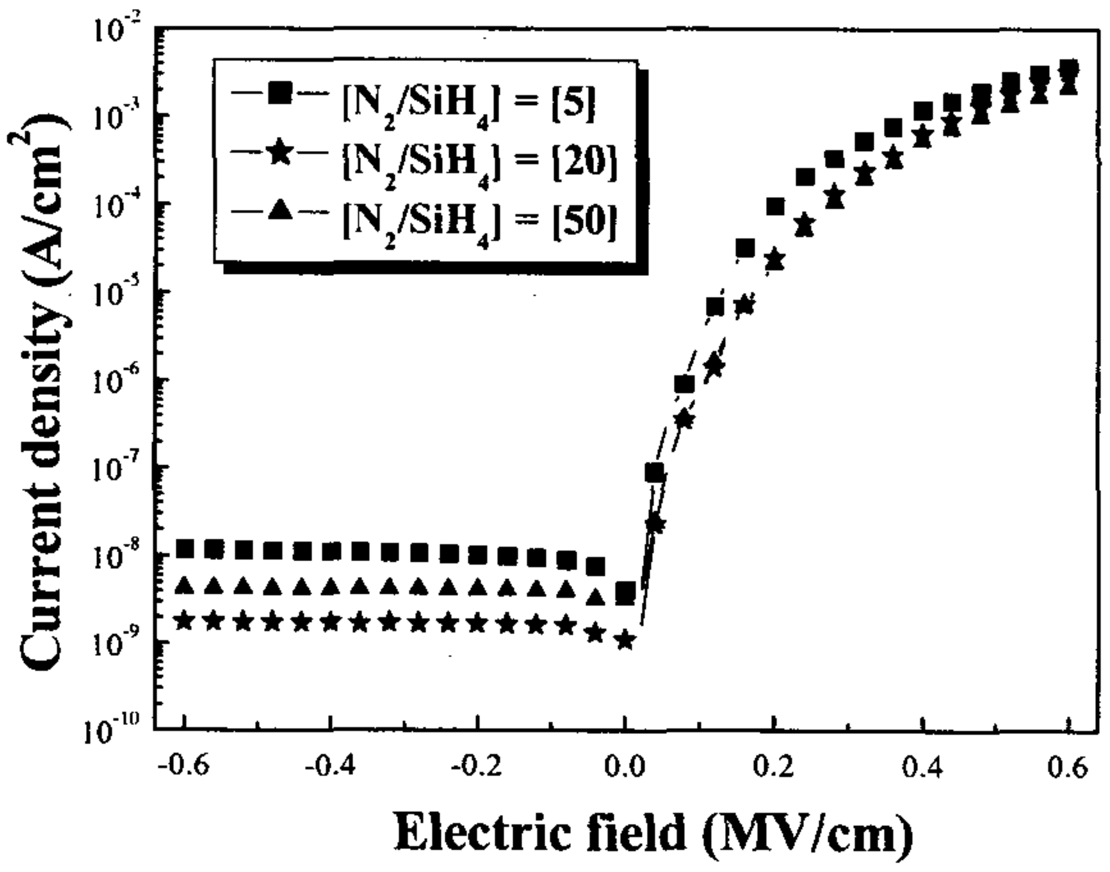

Figure 6. I-V characteristics of SiNx films with N_2 plasma treatment

4. Conculsions

From the present work it can be concluded that, it is possible to get a good quality SiNx film at low temperature by PECVD. Our research gave evidence that by proper choosing the nitrogen-to-silane gas flow ratio, H-atom release from the growing SiNx film may be obtained at as low temperature as 300 °C. It can be adapted to TFT that need a low temperature processing. Also, it is proved that N_2 plasma treatment removed a mobile and injected charges existing in SiNx layer and interface. It means that the electrical and physical properties were improved. So the hysteresis of C-V curve was reduced to a negligible value almost all and a leakage current was decreased. Therefore, the process of N_2 plasma treatment can be used for low temperature deposition of SiNx film and to maintain to a good quality of SiNx films.

5. References

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