Characterization of A High Quality and UV-Transparent PECVD Silicon Nitride Film for Non-Volatile Memory Applications

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ABSTRACT

A high quality and UV-transparent plasma enhanced chemical vapor deposition (PECVD) silicon nitride film is well developed to form passivation layer for non-volatile momery devices. The dependence of the film properties on process parameters has been studied by factorial designed experiments. The deposition rate, uniformity, stress, refractive index, wet etching rate, density, step coverage and UV-transmittance are the items used to evaluate the film properties. Rutherfold backside scattering (RBS) and hydrogen forward scattering (HFS) are used to measure the film composition and total hydrogen composition, respectively. Comparing to the tranditional PECVD nitride (PE-SiN) film known to have tensile stress and opacity to ultra-violet light (UV light), the developed PE-SiN film with very low compressive stress (< 1E9 dynes/cm*2) and excellent UV-transmittance (>70% for 1.6um-thick film) can be achieved. The developed film has higher density, lower hydrogen content and high N/Si inside film. Based on RBS/HFS, UV-transmittance and Fourier Transform Infrared Spectrum (FTIR) results, the material and optical properties of the developed PE-SiN film is well investigated. This developed PE-SiN film is successfully applied to EPROM devices, and very good electrical and reliability performances have been demonstrated.

Keywords : PE-SiN, UV-transmittance, EPROM

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2. INTRODUCTION

Silicon nitride films have been widely used in semiconductor device fabriaction for various purposes. For the application of passivation layer, the silicon nitride film is used to protect underlying device structures. PECVD approach is usually adopted to minimize backend thermal process. Amorphous silicon nitride (a-SiN:H) is one of the popular films for passivation. However, conventional PECVD silicon nitride film possesses relatively high internal stress. The excessive tensile or compressive stress easily causes cracking or peeling of the deposited film. Therefore, PECVD silicon nitride is often used together with PECVD silicon dioxide (PE-OX), TEOS (tetraethoxysilane) based silicon dioxide (PE-TEOS) or phosphorus doped silicon glass (PSG) to form passivation layer. On the other hand, the opacity to ultra-violet light (UV light) of conventional PE-SiN film also limits the application for non-volatile devices such as EPROM. PE-OX, PE-TEOS and PSG are the general passivation layers used for non-volatile memory devices such as EPROM/FLASH EPROM/EEPROM. However, these films can not effectively block the penetration of moisture and mobile ions. As a result of this, more reliability issues are induced by using these oxide-based films.

In this paper, one high quality and UV-transparent PECVD silicon nitride film is well developed. The film stress can be controlled below 1E9 dynes/cm*2 compressive. Dense film characteristics is identified by pin-hole test. Meanwhile, the UV-transmittance is comparable to that of PE-OX. The physical properties are detailedly characterized by means of factorial design experiments to understand the correlations between various process parameters (temperature, pressure, RF power, spacing and SiH4/NH3 flow ratio) and system responses (deposition rate, uniformity, stress, refractive index, wet etching rate, density, step coverage and UV-transmittance).[1] The film composition and total hydrogen concentration are measured by Rutherfold backside scattering (RBS) and hydrogen forward scattering (HFS), respectively. From the RBS/HFS, UV-transmittance and Fourier Transform Infrared Spectrum (FTIR) results, the optical properties of this developed PE-SiN film is investigated as well. Finally, the implementation of this PE-SiN film into EPROM devices is performed. Good electrical performance, device reliability and UV-erasability are demonstrated.

3. EXPERIMENT

The PE-SiN films described in this paper have been deposited in a parallel plate RF plasma enhanced CVD reactor at 400C and at a total pressure of 5 torr. The RF frequency is 13.56 MHz. A gas mixture of SiH4/NH3/N2 was used as reactant gas. Factorial design experiements are conducted to characterize the deposition process.

Film stress at room temperature was calculated from wafer curvature. The refractive index is measured with an ellipsometer. The step coverage was observed with SEM. For pin-hole decoration, KOH solution was used. Regarding UV-light transmission, the developed PE-SiN films were deposited on quartz wafers and measured in UV-2000 spectrometer. The UV-erasability was analyzed by monitoring the reduction of threshold voltage with erase time. For device reliability evaluation, high temperature baking and pressure cooking tests were performed.

4. RESULTS AND DISCUSSIONS

Table 1 shows the correlation between process parameters and output responses. The chamber pressure, RF power input, electrode spacing and SiH4/NH3 gas flow ratio are critical process parameters for deposition rate. The SiH4/NH3 gas flow ratio expresses significantly positive effect; deposition rate increases with SiH4/NH3 flow ratio. On the other hand, chamber pressure, RF power input and electrode all show negative effect on deposition rate. For uniformity response, the electrode spacing is the only significant factor. There are two influential factors observed for film stress. One is the SiH4/NH3 gas flow ratio which shows a positive effect. This indicates that as the ratio increases the stress tends to be tensile. The other factor, the RF power input, shows a negative effect on film stress. It is necessary to pay more attention that stress is extremely sensitive to RF power. As for refractive index, it can be affected by chamber pressure, electrode spacing and SiH4/NH3 gas flow ratio. As for film density, the dominated process parameter is RF power. Finally, the UV-transmittance is more related to chamber pressure and SiH4/NH3 gas flow ratio. The pressure has a significant positive effect to UV-transmittance; on the contrary, the SiH4/NH3 ratio shows a drastically negative effect.

For the application of passivation layer of non-volatile memory devices, the low compressive film stress and good UV-transmittance are required. As shown in figure 1, the dependence of film stress on RF power is characterized. Apparently, low compressive stress less than 1E9 dynes/cm*2 can be obtained by properly adjusting RF power input. It is obviously that the film stress is very sensitive to RF power. The proposed explanation is that the RF power input dominates the ion bombardment in plasma CVD system. More ion bombardment is achieved by raising power input. Denser film is therefore resulted and the stress tends to be compressive, due to the incorporation of bombarding ions in the film. For the change of every one watt in RF power, around 1E8 dynes/cm*2 stress shift is observed.

The optical properties of developed PE-SiN film was investigated by correlating the UV-transmission with refractive index, film density and film composition. As shown in figure 3, the UV-transmittance degrades with increasing refractive index. For refractive index higher than 1.93, the UV-transmission of PE-SiN film decreases drastically. This is the reason why tranditional PE-SiN with refractive index around 2.00 shows UV-opacity. The UV-transmittance was also correlated to film density. As shown in figure 3, denser film achieves higher transmission performance. The increase of UV-transmittance with the N/Si ratio is expressed in figure 4. This is because that a-SiN:H films with lower N/Si ratio have the microstructure closer to that of a-Si:H. The energy band gap is so narrow that it absorbs most of the incident UV-light. On the contrary, films with higher N/Si ratio have microstructure closer to that of high energy β-phase Si3N4 and hense possess better UV-transparency.[2,3,4] The denser film generally has tighter bonding, therefore results in larger energy band gap and good UV-tranparency.

From the analysis of hydrogen forward scattering (HFS), the hydrogen content of developed PE-SiN film is about 25% lower than that of tranditional PE-SiN film. From the FTIR spectra of the developed PE-SiN before and after a 30 minute annealing at 410C, we observed larger change in the N-H peak than that of the Si-H peak. Similar observation has also been reported.[5,6]

The device performance of EPROM processed with developed PE-SiN as passivation layer showed comparable result to that of EPROM with PE-OX passivation. To study the erasability of UV-light, a 1.6um-thick developed PE-SiN film was deposited on EPROM device wafers. One wafer with 0.7um PE-OX film was used as a reference. On initially programmed devices, the threshold voltage (Vt) was measured before and after a UV-light exposure (intensity of 70 mw/cm*2, wavelength of 254nm). The erasability was evaluated from the relationship between Vt and exposure time. The two curves of 1.6um developed PE-SiN and 0.7um PE-OX films are shown in figure 5. They are nearly overlap with each other, indicating comparable UV-transmittance between the two films. The charge retention tests on EPROM devices had also been conducted. The Vt drop of a programmed EPROM cell after a 26 hours, 250C oven baking is shown in figure 6. The Vt drop of device wafers with developed PE-SiN are smaller than those with PE-OX. The pressure cooking test was performed at 121C, 30 psia for 48 hours. The experimental results shown in figure 7 indicate that the use of developed PE-SiN as passivation layer can effectively block the attack of moisture.

5. CONCLUSIONS

A high quality and UV-transparent PECVD silicon nitride film has been developed and characterized as a passivation layer for non-volatile devices. Low compressive stress of PE-SiN film is easily controlled by adjusting RF power and good UV-transmittance is achieved by decreasing SiH4/NH3 gas flow ratio. The relationship of UV-transmission and refractive index, film density and film composition is characterized as well. With the implementation of the developed PE-SiN film into EPROM devices, good UV-erasability and charge retention results are demonstrated.

6. ACKNOWLEDGMENTS

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	Temperature	Pressure	RF power	Electrode spacing	SiH4/NH3 flow ratio
Deposition rate (A/min)	0	--	-	-	+++
Uniformity (%)	0	0	0	--	0
Stress (dynes/cm*2)	0	0	---	0	+
Refractive index	0	--	0	-	+
BOE etching rate (A/min)	0	+	0	0	0
Density (g/cm*3)	0	0	+++	0	-
Step coverage (%)	0	+	0	0	0
UV-transmittance (%)	0	+++	+	0	---

Table 1 : The relationship between process parameters and system responses
+ : positive effect - : negative effect 0 : nearly no effect
(The number of symbol represents the degree of sensitivity)

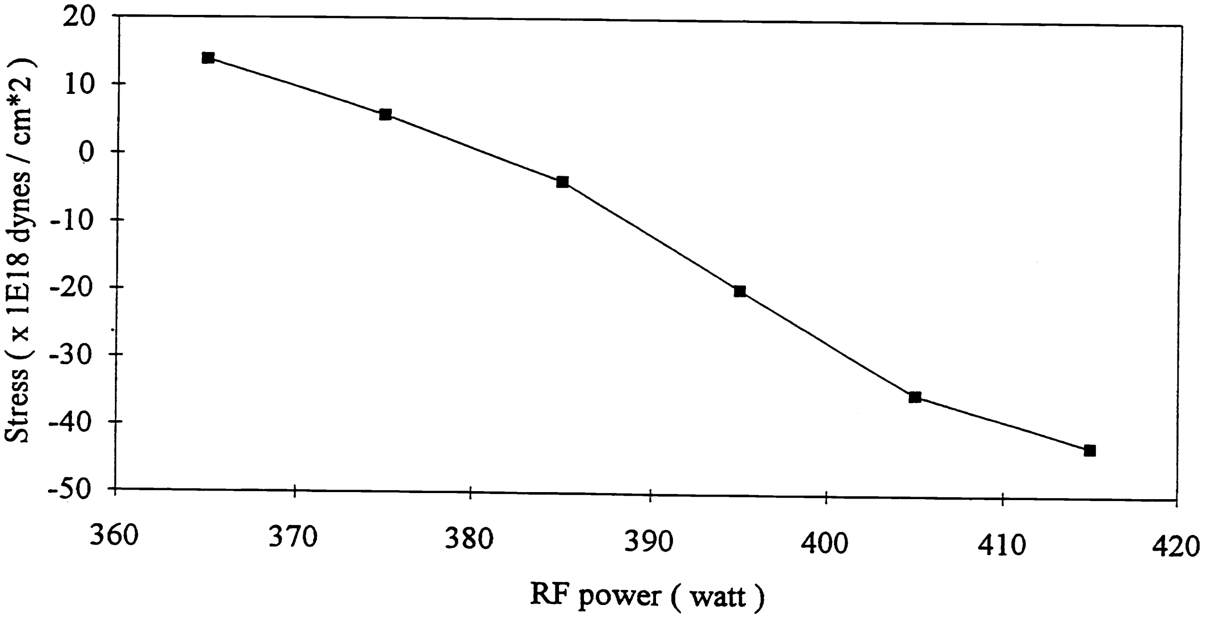

Figure 1 : The dependence of film stress on RF power. The deposited PE-SiN thickness is 10000A.

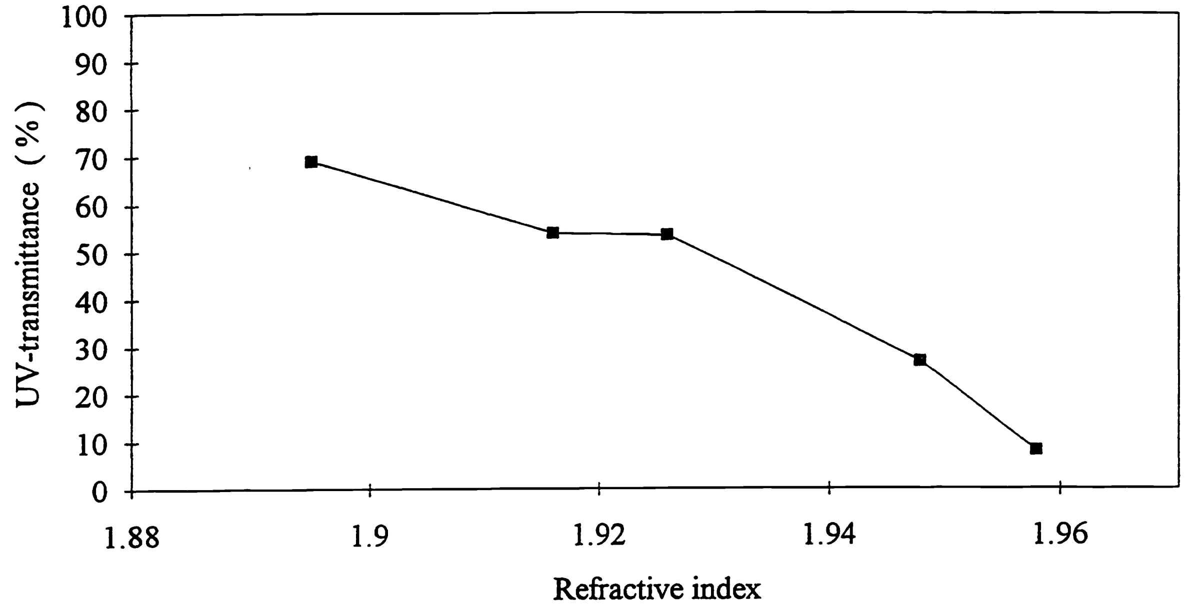

Figure 2 : The correlation of UV-transmittance and refractive index. The deposited PE-SiN thickness is 16000A.

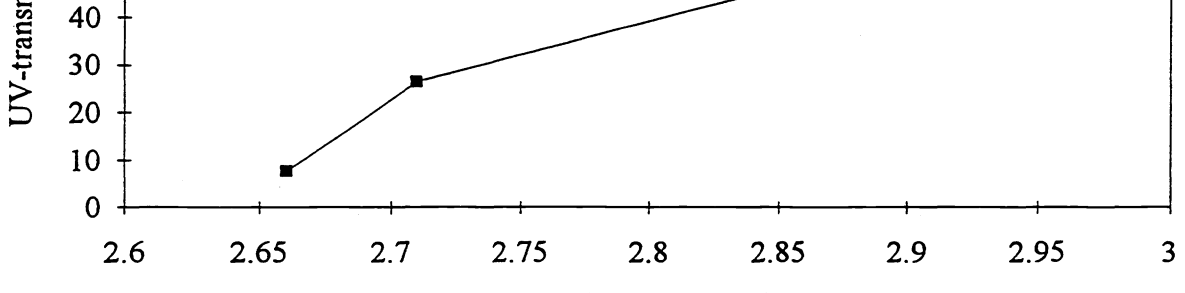

Figure 3 : The relationship between UV-transmittance and film density. The deposited thickness is 16000A.

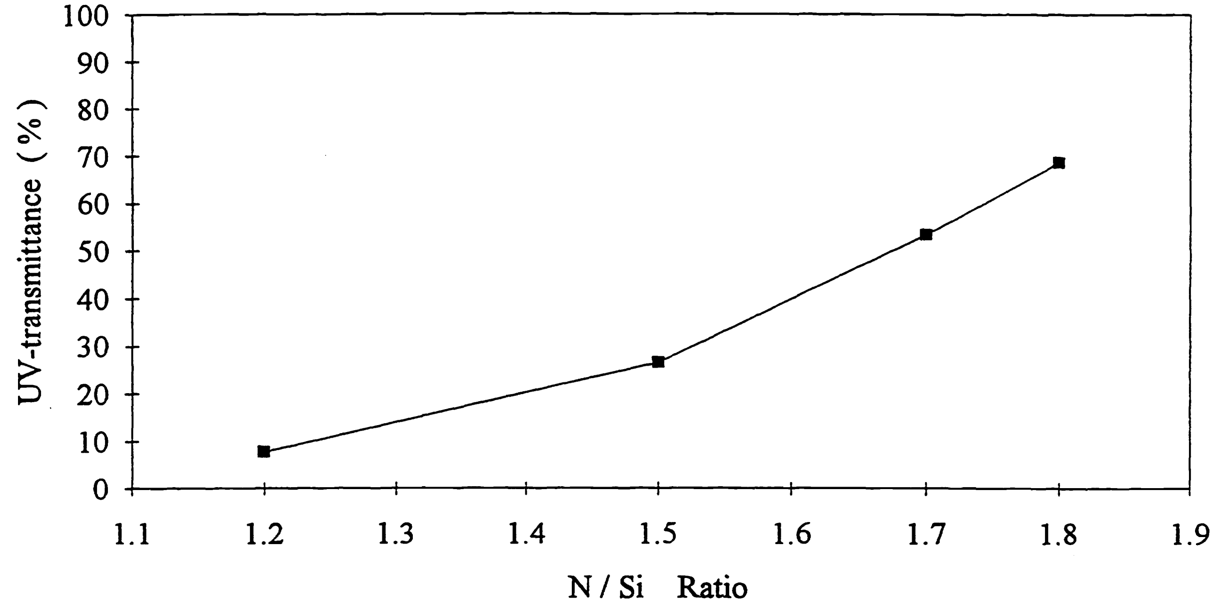

Figure 4 : The relationship of UV-transmittance versus film composition (N/Si ratio). The deposited PE-SiN thickness is 16000A.

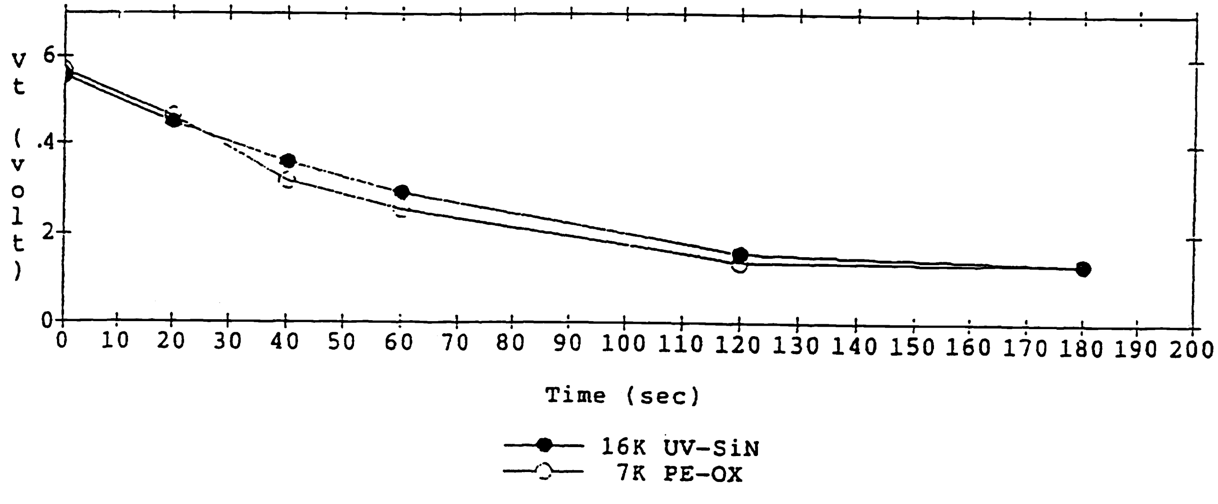

Figure 5 : The UV-erasability of developed PE-SiN (16000A) and PE-OX (7000A) was evaluated by monitoring the reduction of threshold voltage (Vt) with erase time.

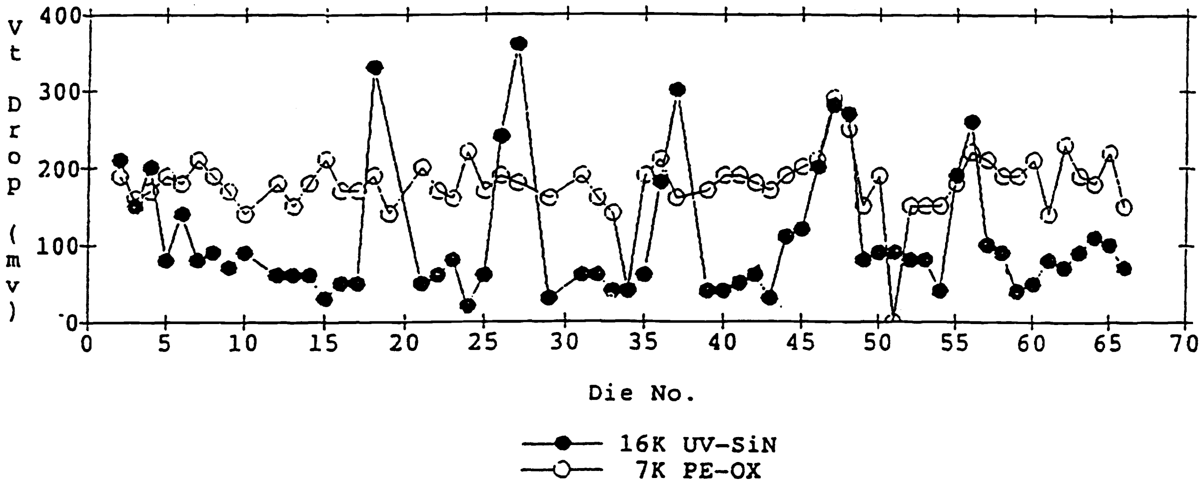

Figure 6 : Charge retention test by measuring the Vt drop of a programmed EPROM cell after 250C oven baking for 26 hours.

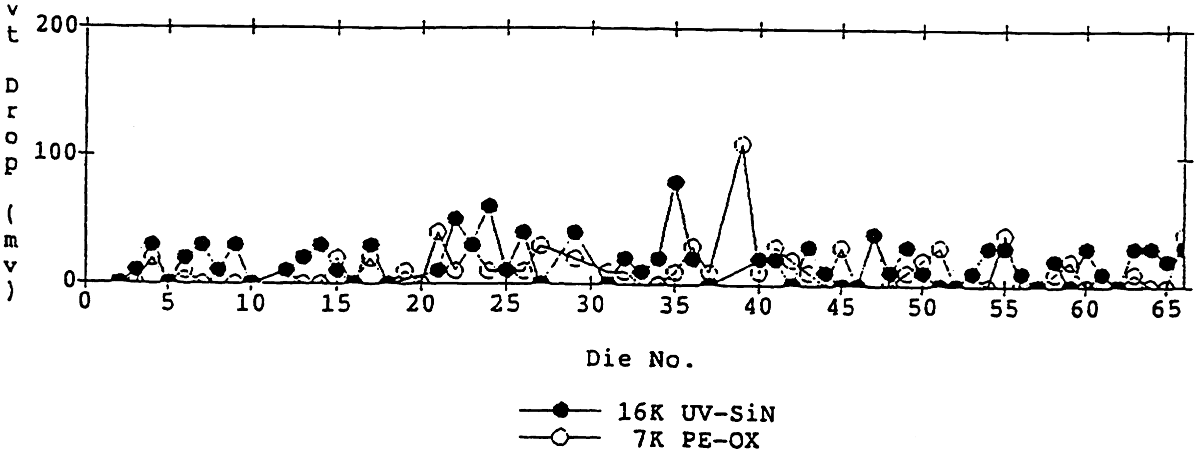

Figure 7 : Charge retention test by measuring the Vt drop after 121C, 30 psia pressure cooking for 48 hours.