Micron 44 (2013) 339–346

Contents lists available at SciVerse ScienceDirect

Micron

journal homepage: www.elsevier.com/locate/micron

PECVD based silicon oxynitride thin films for nano photonic on chip interconnects applications

Satinder K. Sharma [a,b,*], Sumit Barthwal [c], Vikram Singh [d], Anuj Kumar [e], Prabhat K. Dwivedi [f], B. Prasad [g], Dinesh Kumar [g]

[a] School of Computing and Electrical Engineering, Indian Institute of Technology (IIT), Mandi 175001, Himachal Pradesh, India
[b] Electronics and Microelectronics Division, Indian Institute of Information Technology (IIIT), Allahabad 211011, Uttar Pradesh, India
[c] Department of Bio and Nano Chemistry, School of Mechanical Systems Engineering, Kookmin University, Seoul, South Korea
[d] School of Basic Sciences, Indian Institute of Technology (IIT), Mandi 175001, Himachal Pradesh, India
[e] Centre for Energy Studies, Photovoltaic Lab, Indian Institute of Technology (IIT) – Delhi, Hauz Khas, New Delhi 110016, India
[f] DST Unit on Nanosciences, Chemical Engineering Department, Indian Institute of Technology (IIT) Kanpur, 208016, India
[g] Electronic Science Department, Kurukshetra University, Kurukshetra 136119, India

ARTICLE INFO

Article history:
Received 1 April 2012
Received in revised form 23 August 2012
Accepted 23 August 2012

Keywords:
PECVD
Silicon oxynitride
AFM
Micro RAMAN
PL and FTIR

ABSTRACT

Thin silicon oxynitride (SiO_xN_y) films were deposited by low temperature (~300 °C) plasma enhanced chemical vapour deposition (PECVD), using SiH_4, N_2O, NH_3 precursor of the flow rate 25, 100, 30 sccm and subjected to the post deposition annealing (PDA) treatment at 400 °C and 600 °C for nano optical/photonics on chip interconnects applications. AFM result reveals the variation of roughness from 60.9 Å to 23.4 Å after PDA treatment with respect to the as-deposited films, favourable surface topography for integrated waveguide applications. A model of decrease in island height with the effect of PDA treatment is proposed in support of AFM results. Raman spectroscopy and FTIR measurements are performed in order to define the change in crystallite and chemical bonding of as-deposited as well as PDA treated samples. These outcomes endorsed to the densification of SiO_xN_y thin films, due to decrease in Si—N and Si—O bonds strain, as well the O—H, N—H bonds with in oxynitride network. The increase in refractive index and PL intensity of as deposited SiO_xN_y thin films to the PDA treated films at 400 °C and 600 °C are observed. The significant shift of PL spectra peak positions indicate the change in cluster size as the result of PDA treatment, which influence the optical properties of thin films. It might be due to out diffusion of hydrogen containing species from silicon oxynitride films after PDA treatment. In this way, the structural and optical, feasibility of SiO_xN_y films are demonstrated in order to obtain high quality thin films for nano optical/photonics on chip interconnects applications.

1. Introduction

Recently, in the prospect of developing on-chip interconnects for nano optical/photonics technology to attain the higher performance and low power consumption has captured the attention of process engineers and scientific community towards its application for microelectronics, nanoelectronics, optoelectronics and biomedical applications (Melloni et al., 2003; David et al., 2001; Bona et al., 2003). Thus, the scaling of application oriented technology, interconnect concerns begin to play a major roles to a greater extent in the nano metric regime realm. Thus, the miniaturization of device feature sizes in nano metric regime, the higher clock frequencies, and complexity in processing all are negative factors to the extent of switching charges on metallic interconnect. Therefore, as the technology approaches to 45 nm node, traditional copper wire interconnect faces various reliability and performance related issues such as on/off chip communication bandwidth, clock frequency bottleneck, large power dissipation and serious cross-talk noise. Consequently, to the present supercomputing era, various alternatives interconnect materials (Chang et al., 2008; Saraswat et al., 2008; Srivastava et al., 2005) have been explored as an appropriate candidate for aforementioned bottlenecks. Among these issues, nano optical/photonic interconnect paradigm prompts frenzied investigations and is judged as a potential quantum leap towards next generation on-chip interconnect for nano technology (Biberman et al., 2009; Lee et al., 2009). It could result in considerable benefits, including shorter interconnects delays, higher bandwidth and smaller power consumption, in the signal transmission for the ultra large scale integration (ULSI) technology. Thus, the amorphous silicon based thin films might be a superior selection for the use of nano optical/photonics on chip interconnects (Netti et al., 2000). Currently, silicon oxynitride (SiO_xN_y) based nano

* Corresponding author. Fax: +91 512 259 0104; mobile: +91 9936336682.
E-mail address: satinder08@gmail.com (S.K. Sharma).

0968-4328/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.micron.2012.08.006

metric regime thin films has been considered as a possible interconnect material due to its several advantages, among these one of them is a low absorption loses in the wide spectral region, over silicon dioxide and silicon nitride for optical/photonics on chip integrated device applications. While, in case of CMOS technology, it serves as a gate oxide with extended scalability; improved device reliability and other performance related critical issues (Green et al., 2001; Hung et al., 2002; Hajji et al., 1999; Torrison et al., 2003; Togo et al., 2002). Additionally, for the nano optical/photonics on chip interconnects applications, tuneable refractive index made the nano metric regime silicon oxynitride films as a favoured choice of material (Hung et al., 2002) for next generation. Compared to the conventional silica materials, silicon oxynitride thin films offer much larger refractive index for the core of optical waveguide and allow to lowering minimum bending radius for waveguide designs. Furthermore, the high transparency and the index of refraction for silicon based oxynitride thin layer can easily be adjusted over the wide range between 1.45 (SiO_2) and 2.0 (Si_3N_4). The major advantages of the application of oxynitride as a interconnect thin layers in the nano optical/photonics integrated on chip technology is the compatibility of the material with the standard silicon technology, high temperature stability and easily to grow or deposited on the substrate that allows fabrication of wave guide with desire characteristic and compactness (Rand and Standley, 1972; Mattsson, 1995). Silicon oxynitride (SiO_xN_y) interconnect thin film can be formed by growing on the surface of silicon or by chemical deposition or by ion implantation process. Growth refers to thermal nitridation or oxynitridation of Si and deposition refers to low-pressure chemical vapour deposition (LPCVD), electron cyclotron resonance PECVD (ECR-PECVD) and plasma-enhanced CVD (PECVD). All these various deposition methods the quality of deposit depends upon processing temperature. Low pressure chemical vapour deposition methods typically require high temperatures in the region of >400 °C whereas the use of plasma enhanced chemical vapour deposition PECVD) typically requires deposition temperatures of <400 °C. Additionally, these above said techniques different species are used as gas precursors, but in particular, NH_3 and N_2O are the most widely employed gases for the silicon oxynitride nano metric regime thin film deposition (Hernandez et al., 1997; Orfert and Richter, 1999; Vogt and Hauptmann, 1995; Husein et al., 2000). The PECVD is a low temperature process (150–350 °C) and does not degrade the performance of the integrated optical/photonics on chip interconnects devices (Chang and Sze, 1996; Vossen and Kern, 1991).

In the present work, we have explored the processing effect on the surface topography, structural, optical and chemical properties of the thin oxynitride films deposited by low temperature PECVD technique and the effect of PDA treatment subsequent issues for the use in nano optical/photonics on chip interconnects device applications.

2. Experimental

P-type silicon wafers cleaned with the standard RCA cleaning technique were used for deposition of silicon oxynitride interconnect thin films. Moreover, PECVD based low temperature depositions are typically attained by using plasma in which the gases react in a glow discharge. This discharge ionizes the gases, creating active species that react at the RCA cleaned wafer surface. Thus, after drying in the nitrogen ambient, wafers were loaded into the parallel-plate PECVD (Plasmalab 8510C) reactor as shown in Fig. 1.

These parallel plates create a glow discharge and the gases flow radically through the discharge. The radio frequency generated through the electrodes having diameter 240 mm and distance

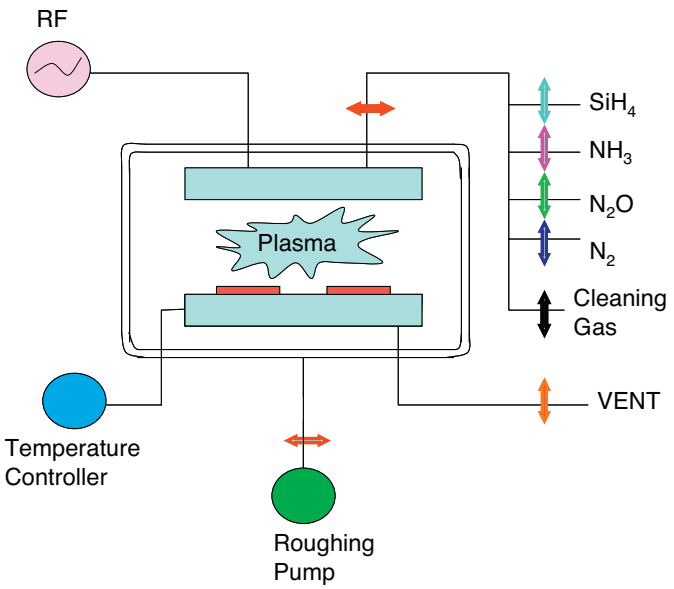

Fig. 1. Schematic diagram of a PECVD reactor used for deposition of SiO_xN_y thin films.

between electrode and substrate was 20 mm. RF power applied to the upper electrode while the samples were placed on the bottom grounded electrode, which can be heated up to 400 °C. The system was operated at a pressure range of 0.1–10 Torr. RF frequency was 13.56 MHz and the applied RF power tuned up to 300 W. The available gases used as precursors for film growth were silane (2% SiH_4/N_2: diluted in nitrogen because of silane being highly unstable at room temperature and it has tendency to burn in air), ammonia (NH_3), and nitrous oxide (N_2O).

The RF plasma power, deposition temperature and precursors used for the deposition of silicon oxynitride interconnect films were 80 W, 300 °C and NH_3, SiH_4, N_2O of flow rate 30, 25,100 sccm, respectively. A series of silicon oxynitride samples were deposited by PECVD technique and process parameters were optimized precisely by number of individual experiments to obtain a high eminence performance and reliable interconnect thin film for on chip optical/photonics applications. These films were subjected to the post-deposition annealing (PDA) at temperature of 400 °C and 600 °C for 30 min in vacuum (3.2×10^{-6} Torr). The thicknesses and refractive index of the as deposited silicon oxynitride and PDA treated thin films were measured using an imaging ellipsometer (EP3, Nanofilm Germany). The computed film thickness of as deposited silicon oxynitride thin film is (80 ± 0.5 nm). AFM measurements of silicon oxynitride as deposited and PDA treated thin films were conducted using Molecular Imaging (MI), USA system. All measurements carried out for the topography study of the samples by the AFM in non-contact, acoustic AC (AAC) mode. Cantilevers used for AAC mode NSC 12 (c) were from MikroMasch having force constant ~4.5 N/m and frequency ~150 kHz.

The structural analysis of silicon oxynitride thin films for interconnects optical/photonics applications were carried out by the WiTec CRM 200 Raman spectrometer coupled with a high resolution Confocal optical microscope. Excitation was provided by the 514.5 nm line of an argon ionized laser. The microscope objective used was Nikon 100×, with working distance 0.26. Thus, the laser beam diameter at the focus is approximately in submicron regime. All the measurements were carried out at room temperature to avoid heating effects. All the measured spectra were systematically compared with those obtained on cover slip under the same experimental conditions.

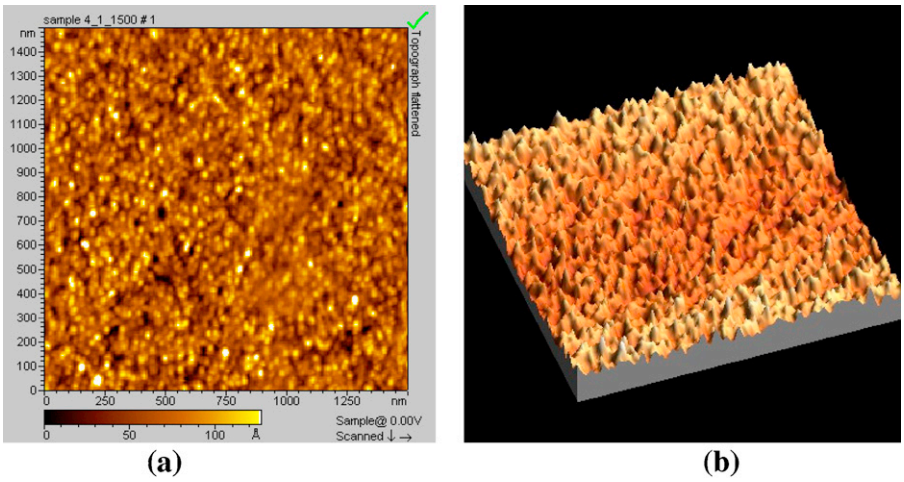

Fig. 2. AFM topography of PECVD based as-deposited SiO_xN_y thin films (a) 2D and (b) 3D images. The surface roughness of as-deposited film was RMS (60.9 Å).

Photoluminescence (PL) measurements were recorded on a FluoroMax-3 (Jobin-Yvon, Edison, NJ, USA) equipped with photomultiplier tube and a xenon lamp.

The characterization of the silicon oxynitride thin films disorderness, film stress and composition were carried out by FTIR ABB BOMAN system for as-deposited and PDA treated. The scanned range, resolution, scan number used for measurements were 6000–250 cm^{-1}, 4 cm^{-1} and 1024 cm^{-1}, respectively. Before obtaining the infrared spectrum of the samples, a background scanning was obtained using the same substrate.

3. Results and discussion

The surface roughness of PECVD based silicon oxynitride (SiO_xN_y) thin films, play an important role in determining the quality of thin films for the optical/photonic on chip interconnect applications. The surface topography of thin film is a prime requirement of a typical oxynitride based waveguide as well as on chip interconnects device applications (Yu et al., 2008; Yang et al., 1998; Hiroyuki et al., 2000). Therefore, the endeavour always made by various researchers to tune the processing precursors and pre/post deposition of thin films treatment parameter. The variations in surface morphology of as deposited silicon oxynitride thin films upon post deposition annealing (PDA) treatment were analyzed by means of AFM technique. As shown in Fig. 2(a) and (b) represents the 2D and 3D, AFM topography images of the PECVD based as-deposited silicon oxynitride thin films. The root mean square (RMS) magnitude of surface roughness ~60.9 Å was computed for the as-deposited silicon oxynitride thin films.

Figs. 3 and 4 show the AFM topographical images of the oxynitride thin films after post deposition annealing (PDA) treatment at 400 °C and 600 °C, respectively for 30 min. The measured RMS roughnesses were 47.0 Å and 23.4 Å, respectively. Though, PECVD is a well established technique for the deposition of a uniform thickness and smooth interconnect thin films at low temperature in the presence of the specific environment and reacting precursor for the optical/photonic on chip interconnects applications. These results indicate that the roughness of the as deposited oxynitride film ~60.9 Å is in the order of the typical dimension of waveguide cross-section as well as optical/photonics on chip interconnects device applications. Although, it could decreases with the effect of the post deposition annealing treatment to tune precisely for the various dimension of waveguide cross-section as shown in Figs. 3 and 4. Moreover, by this significant variation in surface roughness as deposited to the PDA treated thin films could resolve the major concern of optical loss for nano optical/photonics on chip

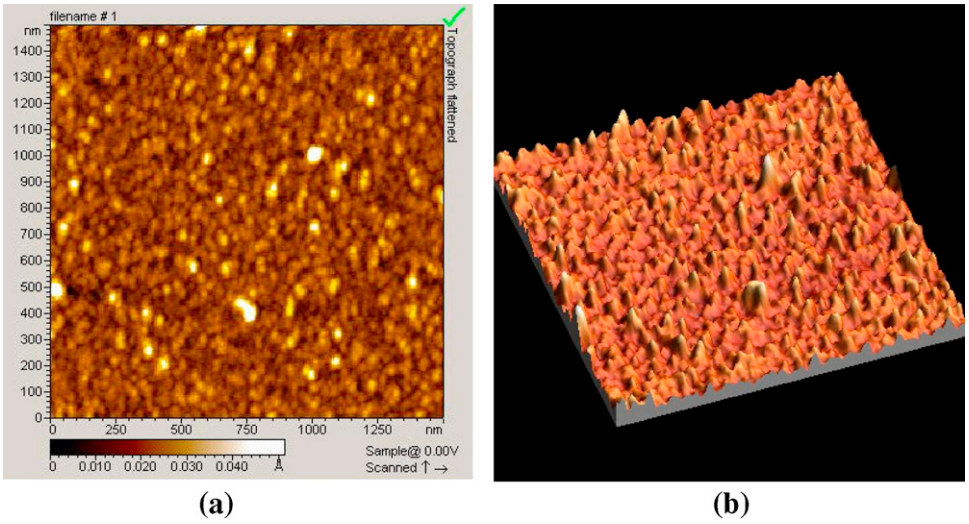

Fig. 3. AFM topography of PECVD based SiO_xN_y thin films after PDA treatment at 400 °C (a) 2D and (b) 3D images. The surface roughness after PDA treatment at 400 °C was RMS (47.0 Å).

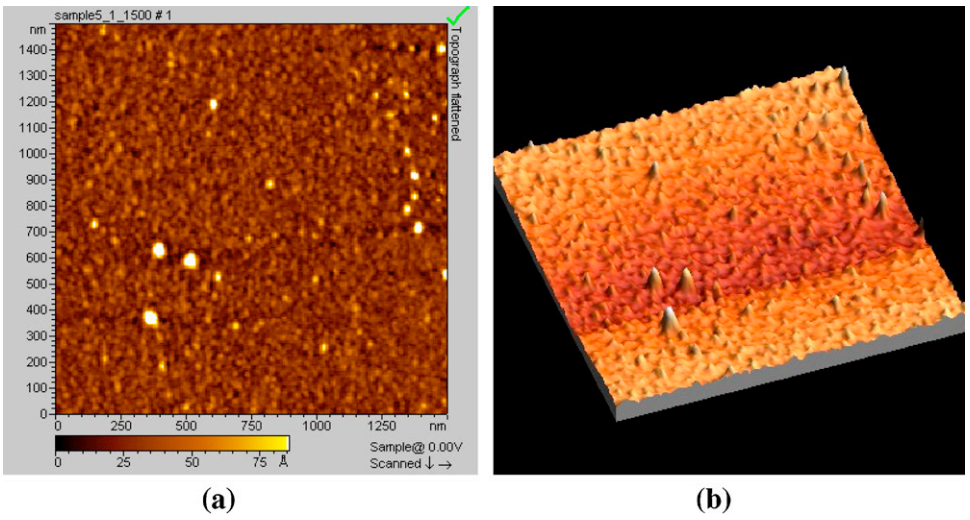

Fig. 4. AFM topography of PECVD based SiO_xN_y thin films after PDA treatment at 600 °C (a) 2D and (b) 3D images. The surface roughness after PDA treatment at 600 °C was RMS (23.4 Å).

interconnects. However, the major sources of optical losses are the presence of hydrogen-related absorption bond in the silicon oxynitride thin films network. Therefore, the decrease in surface roughness of as deposited silicon oxynitride thin films after PDA treatment, attribute to the out diffusion of hydrogen and densification of the silicon oxynitride nano metric regime thin films (Mathad et al., 1999).

Furthermore, Figs. 2–4 show successive AFM images of as-deposited and after PDA treated SiO_xN_y thin films. As shown in Fig. 2(b) topography image reveals that the islands are formed selectively along the domain boundary of PECVD based as-deposited silicon oxynitride thin films. While, Figs. 3(b) and 4(b) demonstrate that the reduction in islands formed selectively along the domain boundary of SiO_xN_y films after PDA treatment at 400 °C and 600 °C, respectively. Therefore, it could be due to the immediate out diffusion of the hydrogen related species, incorporated within the as deposited silicon oxynitride thin films. Hence, it altered the subsequent surface migration of domain boundaries and result the reduction in surface roughness, because of densification of silicon oxynitride thin films (Mao et al., 2005; Perera et al., 2003).

Thus in order to the support of these AFM results a model is proposed as shown in the schematic of Fig. 5, to the verification of alteration surface roughness of as deposited silicon oxynitride thin films and as a result of after PDA treatment. This significant gradually variation in surface roughness of SiO_xN_y thin film is a consequence of structural variation in thin film island formation, which can be understood by the Kelvin equation (Adamson, 1967):

$$\Delta G = 2V\gamma \left[\frac{1}{R^*} - \frac{1}{R}\right] \quad (1)$$

where V is the molar volume, γ is the surface energy, and R is the radius of curvature. The reduction of free energy according to the Kelvin equation presents the driving fore for the change of the surface roughness magnitude (RMS) of SiO_xN_y thin films after PDA treatment. Therefore the curvature of the roughness features must decrease (R increases).

As shown in Fig. 2 of as-deposited PECVD SiO_xN_y films had higher rough surfaces with protrusions closely packed island feature width. Moreover, the island features height of as deposited SiO_xN_y thin film is inversely proportional radius (R) of curvature and directly proportional to the width (W) of curvature, which attributes to the higher surface roughness of as deposited SiO_xN_y thin films as shown in Fig. 5(a). While surface free energy (ΔG) of SiO_xN_y thin films reduced as per Kelvin relation in Eq. (1) after PDA treatment 400 °C and 600 °C and resulted the smoothening of SiO_xN_y thin films by decreasing the island feature height owing

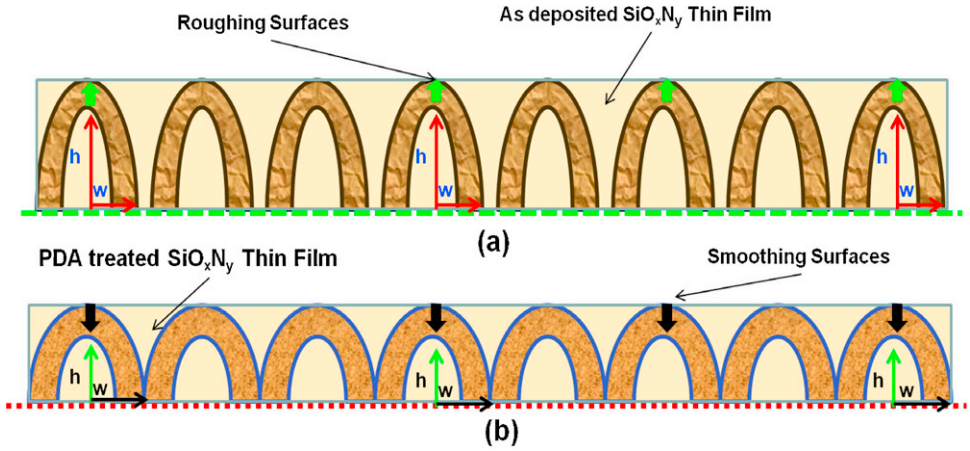

Fig. 5. Schematic of proposed model for higher roughness of PECVD based as deposited SiO_xN_y thin films (a) and smoothing of rough PECVD based thin films surfaces after PDA treatment (b). The radius R^* and R of curvature is proportional to w and inversely proportional to h. The arrows indicate the change of the protrusions or variation in island dimension with radius of curvature.

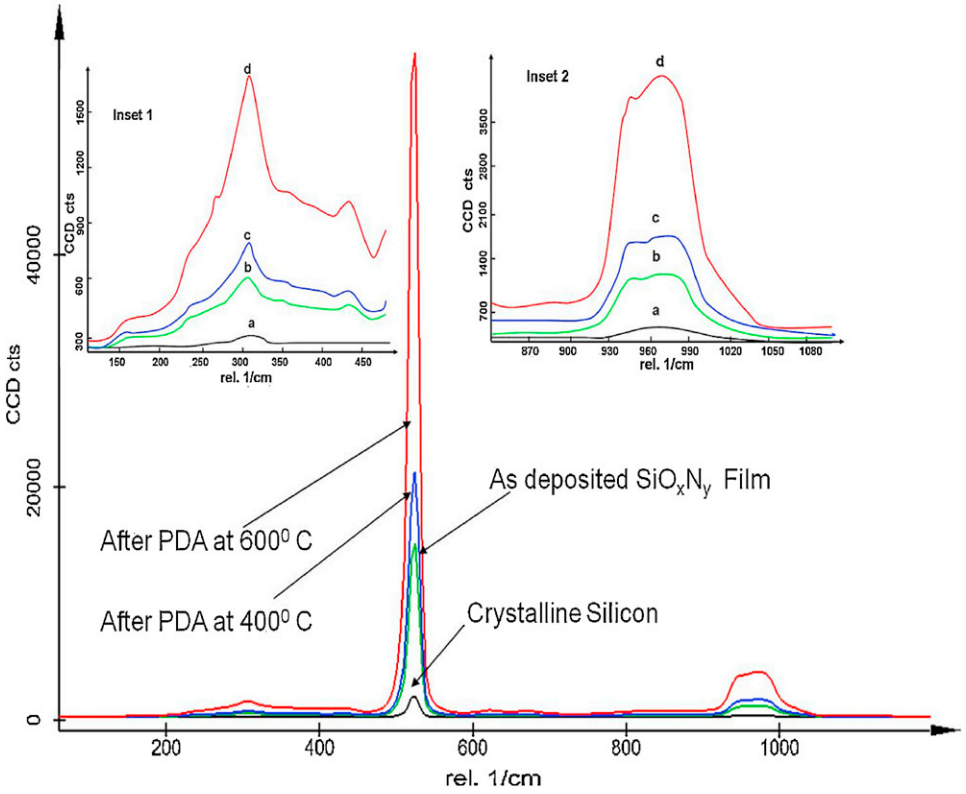

Fig. 6. Micro Raman spectrum of crystalline Si, as deposited SiO_xN_y film and after PDA at 400 °C and 600 °C, respectively [Inset 1 and Inset 2 show the third and second order amorphous band at 320 cm^{-1} and 920–1060 cm^{-1}, respectively, which becomes better defined after the PDA treatment at 400 °C and 600 °C as compared to as deposited films].

to the increase in radius of island curvature as shown in Fig. 5(b), which introduced a smooth SiO_xN_y thin films surface (small RMS magnitude) as shown in Figs. 2–4 (Lee et al., 2004; Singh et al., 2012; Singh and Nahar, 2010; Konofaos et al., 2004).

In addition to this, if PECVD based SiO_xN_y thin films subjected to the higher PDA treatment then the alteration of the curvature behaved in another way. At the temperature higher than 600 °C, some atoms or clusters at the surface could obtain enough energy to become diffusive, and the protrusions could grow in an increase in height of island manner (Adamson, 1967; Lee et al., 2004; Singh et al., 2012; Singh and Nahar, 2010; Konofaos et al., 2004; Zhu et al., 2005), by absorbing the activated atoms or clusters diffusing from adjacent protrusions and results the increase in surface roughness (RMS, which increase the optical losses for nano optical/photonic interconnect applications.

Therefore, the silicon oxynitride thin films in this work is treated at the optimum temperature to reduced the surface roughness, while the islands beyond the critical size do not completely disappeared even after low temperature PDA treatment. The variation for the as deposited silicon oxynitride (80 ± 0.5 nm) and PDA treated at 400 °C and 600 °C thin films refractive index computed by an imaging ellipsometer (EP3, Nanofilm Germany) are 1.46, 1.52 and 1.59, respectively.

Raman spectroscopy is one of the established and precise methods for materials characterization related to the crystalline structure, disorderness and amorphization. Thus in the present work the Micro-Raman investigation was carried out to estimate stress, deformation and compositional analysis with in bulk silicon and silicon oxynitride thin films by observing the band shift in Raman spectrum (Krishnan, 1989; Zi et al., 1996; Cheng and Ren, 2002; Fu et al., 2006; Ficcadenti et al., 2011). Fig. 6 shows the Raman spectrum of bare crystalline silicon along with the PECVD based as deposited silicon oxynitride thin film and after PDA treated at 400 °C and 600 °C. The Raman spectrum of crystalline silicon shows the band centred at 520 cm^{-1} (Szekeres et al., 2005). Further, the investigation has been accomplished on PECVD based silicon oxynitride thin films samples suitably deposited on a silicon substrate and then treated with the post deposition annealing (PDA) treatment at 400 °C and 600 °C. The measurement system has been calibrated to the well known peak associated to the monocrystalline silicon, located at 520 cm^{-1}.

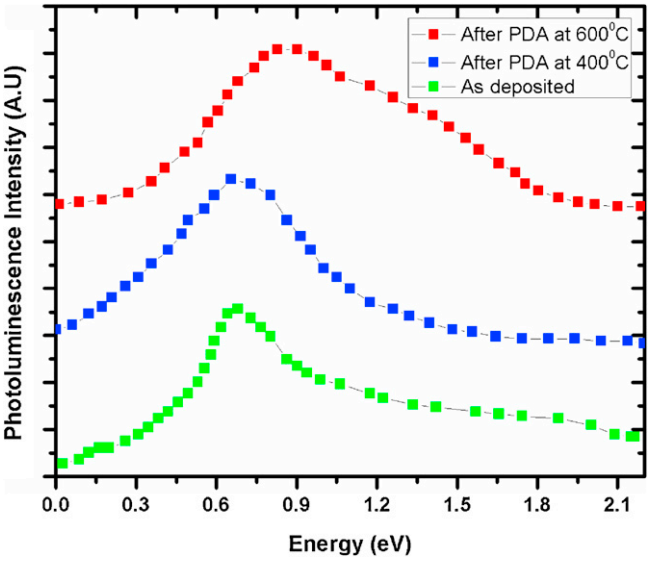

Fig. 7. Photoluminescence spectrum of as-deposited and after PDA treated silicon oxynitride films at 400 °C and 600 °C for 30 min.

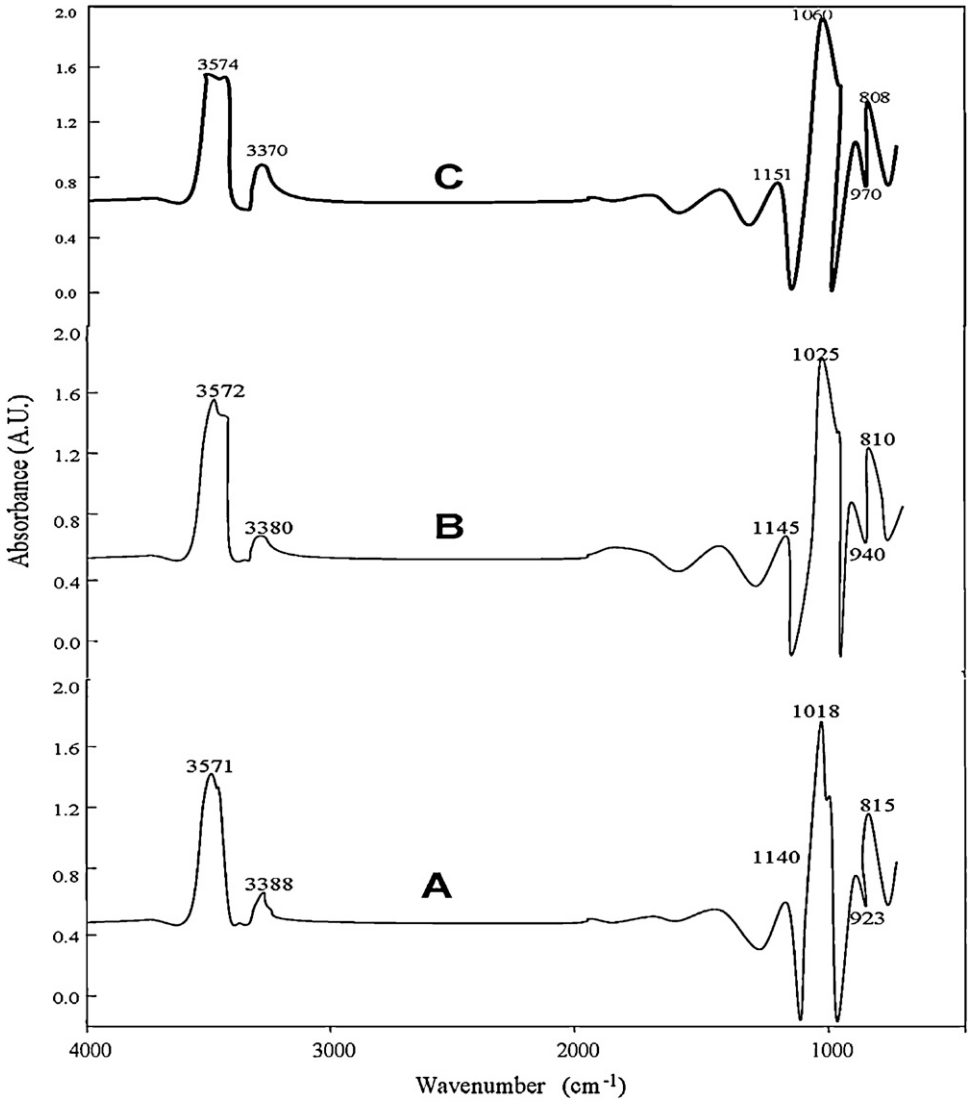

Fig. 8. FTIR spectra of as-deposited (A) and after PDA treatment at 400 °C (B) and 600 °C (C) PECVD based silicon oxynitride.

The fraction of variation in strain Si—OH, Si—NH, O—H and N—H bonds and the number density of silicon oxynitride thin films has been estimated by means of the integrated area calculated by the deconvolution of the Raman spectra. These Raman spectrum have been fitted by Gaussian and Lorentzian peak functions, ascribed to the disparity in chemical composition from the as deposited SiO_xN_y thin films to the PDA treated SiO_xN_y films, respectively (Fu et al., 2006; Ficcadenti et al., 2011). The spectrum of as deposited silicon oxynitride and PDA treated samples show the increase in FWHM of band centred at 520 cm^{-1} as compared to the crystalline silicon peak. There was a significant widening perceived in the position of Raman peak associated to the silicon oxynitride, with respect to the crystalline value located at 520 cm^{-1} and after PDA treatment as shown in Fig. 6. This shift has been attributed to the alteration in the Si—NH and Si—OH strain after PDA treatment due to the breaking of old bonds and formation newer one. It results the reduction in Si—OH bonds and increase the Si—N bonds. This behaviour shows the densification of silicon oxynitride film after PDA treatment because of reduction in O—H and N—H bonds in silicon oxynitride network. Similar trend of peak shift have been observed several other research groups also (Cheng and Ren, 2002; Fu et al., 2006; Ficcadenti et al., 2011; Zi et al., 1996).

The brooding of amorphous band in the region 920–1060 cm^{-1} corresponding to oxygen-rich silicon oxynitride thin films as shown in Inset 2 (Pan et al., 2001; Ray et al., 2001; Ay and Aydinli, 2004). The enhancement of the band in 920–1060 cm^{-1} region is observed with increasing PDA temperature, due to increase in bond concentration. These results indicate that the concentration of Si—O bonds is more than the Si—N with in SiO_xN_y films after PDA treatment.

Similarly, as-deposited sample as well as PDA treated silicon oxynitride films shows the brooding of the third order band at 320 cm^{-1}, which becomes better defined after the PDA treatment at 400 °C and 600 °C as shown in Inset 1. The increase in peak intensity for the sample treated at 600 °C shows significant shift towards amorphous nature of thin films. This significant shift in the amorphous component might be attributed to an increase in cluster size after PDA treatment and reduction in surface roughness.

Photoluminescence (PL) spectra for the as-deposited and PDA treated silicon oxynitride thin films for interconnects applications are shown in Fig. 7. As-deposited, silicon oxynitride thin film exhibits a broad PL emission band in the 0.5–1.1 eV spectral region. After PDA treatment at 400 °C induces a red shift associated with an increase in PL intensity. While, after further PDA treatment at 600 °C enhanced PL intensity and shift the peak towards longer wavelength (red shift) as compared to as-deposited and 400 °C treated

Table 1
Infrared vibration observed in the silicon oxynitride samples (Szekeres et al., 2005; Vogt and Hauptmann, 1995; Vossen and Kern, 1991).

Vibration type	As-deposited		After PDA at 400 °C		After PDA at 400 °C	
	Peak frequency, ω (cm^{-1})	FWHM	Peak frequency, ω (cm^{-1})	FWHM	Peak frequency, ω (cm^{-1})	FWHM
Si—O bending	815	82	810	84	808	87
Si—N stretching	923	95	940	93	970	91
Si—O symmetric stretching	1018	107	1025	97	1061	82
Si—O asymmetric stretching	1140	111	1145	105	1151	103
N—H stretching	3388	118	3380	99	3572	96
Si—O—H stretching	3571	124	3370	93	3574	90

samples. These results reveal that the silicon oxynitride interconnects layers have a strong dependence of the PL emission with post deposition annealing treatment. It endorsed that the size of silicon oxynitride clusters increases after PDA treatment at 400 °C and 600 °C (Kenyon et al., 1996; Ribeiro et al., 2003). However, the PECVD based as-deposited silicon oxynitride thin films did not show crystallite formation. These results were also correlated with the above reported AFM and Raman data.

Fig. 8 shows the FTIR absorption spectra of the as-deposited and PDA treated silicon oxynitride thin films. The characteristic of Si—O and Si—N vibration bonds are shown in Fig. 8, while the assignment of the whole spectra are summarized in Table 1. The FTIR studies of silicon oxynitride as-deposited and PDA treated films have shown that Si—O and Si—N strong adsorption bonds are closer to each other and therefore they could overlap in the spectrums. The strongest peak in all FTIR spectra corresponds to Si—N, Si—O symmetric as well as asymmetric stretching vibration mode observed in the range of 923–1151 cm^{-1} indicating that the film consist predominately of Si—O—N.

The FWHM result from Table 1 reveals that the FWHM of Si—N, Si—O symmetric as well as asymmetric vibration decreases after PDA treatment with respect to as-deposited silicon oxynitride samples. It attributes that after PDA treatment consequence to the release bonds strain and disorderness between Si—O and Si—N bonds within the silicon-oxynitride films for on chip photonic interconnect applications. The vibration modes observed at 3388–3372 cm^{-1} and 3571–3574 cm^{-1} are related to the stretching of N—H and Si—O—H. The reduction in FWHM in this region after PDA treatment with respect to as-deposited thin film indicates the out-diffusion of hydrogen containing species from the SiO_xN_y network and formation of oxygen and nitrogen rich oxynitride films after PDA treatment (Ay and Aydinli, 2004), which alter the refractive index as well as optical properties of silicon oxynitride thin films for nano optical/photonics on chip interconnects device applications.

4. Conclusions

The SiO_xN_y thin films were successfully deposited on the silicon wafers using the PECVD technique at low temperature for nano optical/photonics on chip interconnects applications. The surface topography analysis composition and the bonding structure and optical property of the oxynitride films were investigated with AFM, Raman spectroscopy, Fourier transform infrared spectroscopy (FTIR) and Photoluminance study of as deposited thin films and after PDA treatment. The AFM and Raman techniques have demonstrated that PECVD grown as-deposited silicon oxynitride based thin films show the presence of fairly high surface roughness and structural disorderness. However, after PDA of optimum temperature at 400 °C and 600 °C, the surface roughness and Si—O & Si—N concentrations have been found to be significantly varied, probably due to the decrease in island height by increasing the radius of island, which results the densification of as-deposited silicon oxynitride films after PDA. The PL and FTIR result demonstrated that the variation in cluster and Si—O and Si—N bond strain after PDA treatment *w.r.t.* as-deposited samples and result the variation in refractive index. Therefore, PDA treated at optimum temperature as-deposited SiO_xN_y films can be successfully used for nano optical/photonics on chip interconnects device applications as the process integration complexity increases onto the state of art technology.

Acknowledgement

One of the authors (S.K.S.) acknowledges financially grant funding for Department of Science and Technology (DST), New Delhi, India under Fast Track Young Scientist research project.

References

Adamson, A.W., 1967. Physical Chemistry of Surface. Wiley, New York.
Ay, F., Aydinli, A., 2004. Comparative investigation of hydrogen bonding in silicon based PECVD grown dielectrics for optical waveguides. Optical Materials 26, 33.
Biberman, A., et al., 2009. First demonstration of on-chip wavelength multicasting. In: Optical Fiber Communication Conference, March.
Bona, G.-L., Germann, R., Offerin, B.J., 2003. SiON high refractive-index waveguide and planar light wave circuits. IBM Journal of Research and Development 47, 239.
Chang, C.Y., Sze, S.M., 1996. ULSI Technology. McGraw-Hill, New York.
Chang, M.-C.F., et al., 2008. RF interconnects for communications on-chip. In: Proceedings of International Symposium on Physical Design, April, pp. 78–83.
Cheng, W., Ren, S.F., 2002. Calculations on the size effects of Raman intensities of silicon quantum dots. Physical Review B 65, 205305–205313.
David, C., Wiesmann, D., Germann, R., Horst, F., Offerin, B.J., Beyeler, R., Salemink, H.W.M., Bona, G.L., 2001. Apodised Bragg gratings in planar waveguides for add-drop filters. Microelectronic Engineering 57–58, 713.
Ficcadenti, M., Pinto, N., Morresi, L., Ferblantier, G., Carrada, M., Slaoui, A., 2011. Si nanotcrystal embedded in a silicon oxynitride matrix. Nanomaterials and Nanotechnology 1 (2), 1–7.
Fu, G.S., Ding, W.G., Song, W.C., Zhang, J.Y., Wei, Y., 2006. Microstructure modification of silicon nanograins embedded in silicon nitride thin films. Chinese Physics Letters 23, 1926–1929.
Green, M.L., Gusev, E.P., Degraeve, R., Garfunkel, E.L., 2001. Ultrathin (<4 nm) SiO_2 and Si—O—N gate dielectric layers for silicon microelectronics: understanding the processing, structure, and physical and electrical limits. Journal of Applied Physics 90 (5), 2057.
Hajji, B., Temple-Boyer, P., Olivie, F., Martinez, A., 1999. Electrical characterisation of thin silicon oxynitride films deposited by low pressure chemical vapour deposition. Thin Solid Films 354 (4), 9–12.
Hernandez, M.J., Garrido, J., Martinez, J., Piqueras, J., 1997. Compositional and electrical properties of ECR-CVD silicon oxynitrides. Semiconductor Science and Technology 12, 927–932.
Hiroyuki, O., Atsuhi, N., Masafumi, L., Masaru, H., Toshio, G., 2000. Formation of silicon nitride gate dielectric films at 300 °C employing radical chemical vapor deposition. Journal of Vacuum Science and Technology B 18 (5), 2486.
Hung, P.Y., Brown, G.A., Zhang, M., Bennett, J., AL-Shareef, H.N., Young, C., Oroshiba, C., Diebold, A., 2002. Materials Research Society Symposium Proceedings, vol. 716.
Husein, I.F., Chan, C., Qin, S., Chu, P.K., 2000. The effect of high-dose nitrogen plasma immersion ion implantation on silicone surfaces. Journal of Physics D: Applied Physics 33, 2869.
Kenyon, A.J., Trwoga, P.F., Pitt, C.W., Rehm, G., 1996. The origin of photoluminescence from thin films of silicon-rich silica. Journal of Applied Physics 79, 9291.
Konofaos, N., Evangelou, E.K., Aslanoglou, X., Kokkoris, M., Vlastou, R., 2004. Dielectric properties of CVD grown SiON thin films on Si for MOS microelectronic devices. Semiconductor Science and Technology 19, 50.
Krishnan, R.S., 1989. Raman spectroscopy: recent trends. Indian Journal of Physics A 63 (1S), S1–S25.

Lee, C., Choi, J., Choi, M., Park, J., Hwang, C.S., Kim, H.J., Jeong, J., 2004. Nitrogen incorporation engineering and electrical properties of high-k gate dielectric (HfO_2 and Al_2O_3) films on Si(1 0 0) substrate. Journal of Vacuum Science and Technology B 22, 1838.

Lee, B., et al., 2009. Multi-wavelength message routing in a non-blocking four-port bidirectional switch fabric for silicon photonic networks-on-chip. In: Optical Fiber Communication Conference, March.

Mao, L.F., Wang, Z.O., Wang, J.Y., Yang, G.Y., 2005. The effective mass issues in light nitride silicon oxide. Semiconductor Science and Technology 20 (10), 1078.

Mathad, G.S., Hess, D.W., Meyyappan, M., 1999. Electrochemical Society Interface, 34.

Mattsson, K.E., 1995. Plasma-enhanced growth, composition, and refractive index of silicon oxy-nitride films. Journal of Applied Physics 77 (12), 6616.

Melloni, A., Costa, R., Monguzzi, P., Martinelli, M., 2003. Ring-resonator filters in silicon oxynitride technology for dense wavelentgh-division multiplexing systems. Optics Letters 28, 1567.

Netti, M.C., Charlton, M.D.B., Parker, G.J., Baumberg, J.J., 2000. Visible photonic bandgap engineering in silicon nitride waveguides. Journal of Applied Physics Letters 76, 991.

Orfert, M., Richter, K., 1999. Plasma enhanced chemical vapor deposition of SiN-film for passivation of three-dimensional substrates. Surface and Coatings Technology 116–119, 622–628.

Pan, T.M., Lei, T.F., Wen, H.C., Chao, T.S., 2001. characterization of ultrathin oxynitride (18–21 A) gate dielectrics by NH_3 nitridation and N_2O RTA treatment. IEEE Transactions on Electron Devices 48, 907–912.

Perera, R., Ikeda, A., Hattori, R., Kuroki, Y., 2003. Trap assisted leakage current conduction in thin silicon oxynitride films grown by rapid thermal oxidation combined microwave excited plasma nitridation. Microelectronic Engineering 65, 357–370.

Rand, M.J., Standley, R.D., 1972. Silicon oxynitride films on fused silica for optical waveguides. Applied Optics 11, 2482–2488.

Ray, S.K., Maikap, S., Samanta, S.K., Banerjee, S.K., Maiti, C.K., 2001. Charge trapping characteristics of ultrathin oxynitrides on $Si/Si_{1-x}Ge_xC_y/Si$ heterolayers. Solid-State Electronics 45, 1951–1955.

Ribeiro, M., Pereyra, I., Alayo, M.I., 2003. Silicon rich silicon oxynitride films for photoluminescence applications. Thin Solid Films 42, 200–204.

Saraswat, K., et al., 2008. Performance comparison between copper carbon nanotube and optical interconnects. In: Proceedings of IEEE International Symposium on Circuits and Systems.

Singh, V., Nahar, R.K., 2010. Improved thermal stability of nitrogen annealed sputtered hafnium oxide thin films for VLSI technology. Microelectronics International 27 (2), 93–97.

Singh, V., Sharma, S., Kumar, K., Nahar, R.K.D., 2012. Study of rapid thermal annealing on ultra thin high-K HfO_2 films properties for nano scaled MOSFET technology. Microelectronic Engineering 91, 137–143.

Srivastava, N., et al., 2005. Performance analysis of carbon nanotube interconnects for VLSI applications. In: Proceedings of International Conference on Computer Aided Design.

Szekeres, A., Simeonov, S., Gushterov, A., Nikolova, T., Hamelmann, F., Heinzmann, U., 2005. Electrical properties of plasma assisted CVD deposited thin silicon oxynitride films. Journal of Optoelectronics and advanced materials 7, 553–556.

Togo, M., Watanabe, K., Terai, M., Kimura, S., Yamamoto, T., Tatsumi, T., Mogami, T., 2002. Oxynitridation using radical-oxygen and -nitrogen for high-performance and highly reliable n/pFETs. IEEE Transactions on Electron Devices 49 (10), 1761.

Torrison, L., Tolle, J., Kouvetakis, J., Dey, S.K., Gu, D., Tsong, I.S.T., Crozier, P.A., 2003. Stoichiometric and non stoichiometric films in the Si—O—N systems: mechanical, electrical and dielectric properties. Material Science and Engineering B 97, 54–58.

Vogt, M., Hauptmann, R., 1995. Plasma deposited passivation layers for moisture and water protection. Surface and Coatings Technology 74 (2), 676–681.

Vossen, J.L., Kern, W., 1991. Thin Film Processes II. Academic Press, Inc., New York.

Yang, G.-R., Zhao, Y.-P., Hu, Y.Z., Chow, T.P., Gutmann, R.J., 1998. XPS and AFM study of chemical mechanical polishing of silicon nitride. Thin Solid Films 333, 219–223.

Yu, L., Xu, J., Dong, S., Kojima, I., 2008. Surface morphology and growth mechanisms for sputtered amorphous silicon nitride thin films. Thin Solid Films 516 (8), 1781–1787.

Zhu, L.Q., Fang, Q., He, G., Liu, M., Zhang, L.D., 2005. Microstructure and optical properties of ultra thin zirconia films prepared by nitrogen assisted reactive magnetron sputtering. Nanotechnology 16, 2865–2869.

Zi, J., Buscher, H., Falter, C., Ludwig, W., Zhang, K., Xie, X., 1996. Raman shifts in Si nanocrystals. Applied Physics Letters 69, 200–202.