Process Dependent Strain Behaviour, Fractal Analysis, and Bonding Network of Nc-Si(SiC) Thin Films

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Abstract
Nanocrystalline silicon embedded silicon carbide, nc-Si(SiC) thin films were deposited on p-type silicon substrates by using a thermal chemical vapor deposition (CVD) with different process temperatures from 700 to 1000 °C. The SEM images reveal the Si particles are embedded with SiC thin films. The estimated crystallite size of nc-Si(SiC) was varied from 14 to 28 nm and 40.7 to 61 nm respectively from the Scherrer formula and Williamson–Hall formula. Similarly, the estimated lattice-strain of nc-Si(SiC) thin films from Williamson-Hall and Bragg law was varied from 0.00227 to 0.00469 and 0.000855 to 0.00574 respectively. The Raman signature at the 1346.19 cm$^{-1}$, 1491.78 cm$^{-1}$, and 1570.94 cm$^{-1}$ bonding correspond to D, G-Si, and G peaks respectively. The estimated bandgap from Tauc’s plot of nc-Si(SiC) thin films are 3.17 to 2.87 eV respectively with increasing process temperature. The possible bonding network of core-orbital of Si(2p), C(1 s), and O(1 s) in the nc-Si(SiC) thin films have been discussed by deconvolution with the Origin 2018.

Keywords Ne-Si(SiC) · XPS · Raman · FTIR · XRD

1 Introduction
To overcome the Shockley–Queisser (S–Q) limit for enhancing the device performance the quantum size effect of silicon dots has been proven to be able to tune the bandgap in a wide range by controlling the dot size [1]. Hence, to regulate optical properties nanocrystalline Si (nc-Si) embedded in the amorphous silicon carbide (a-SiC) matrix (nc-Si(SiC)) proven beneficial for photovoltaics and light-emitting diode applications [2–7]. However, the real challenge for technology development to achieve nc-Si(SiC) thin films, as the precursors are either co-sputtered of rapid thermal annealing of a-Si and a-SiC at 900°C (RTA) [1, 2], SiH$_4$ + CH$_4$ or SiH$_4$ + CH$_4$ + H$_2$ [3–23]. There has been a considerable study in recent years on nc-Si(SiC) thin films and their properties [8–23]. Kar et al. synthesized conducting wide-bandgap nc-Si(SiC) films for window layers using inductively coupled plasma aided chemical vapor deposition (ICP-CVD) and investigated the effect of increasing C incorporation on the structural, optical, and electrical properties of the nc-Si(SiC) films [8]. Ji et al. investigated optical properties of high conducting nc-Si(SiC) and obtained high carrier mobility 630 s/cm of nc-Si(SiC) thin films [9]. Swain et al. were studied in structural properties of nc-Si(SiC) deposited by hot-wire chemical vapor deposition (HWCVD) and compare the crystallite size among small-angle x-ray diffraction (SAXD), Raman scattering in the nc-Si(SiC) thin films [3]. Kole et al. investigated the tunability of the optical band gap, $E_g$ varied from 1.58 eV to 2.45 eV of nc-Si(SiC) thin films by the thermal treatment for potential applications in the all-silicon tandem solar cell [10]. Kim et al. investigated photoluminescence properties of 500–650 nm thickness nc-Si(SiC) thin films, which observed the quantum confinement of hexagonal crystal structure [11]. Leoper et al. investigated charge carrier transport and recombination process silicon nanocrystals embedded in silicon carbide [12]. Park et al. investigated spectroscopic and microscopic studies of self-assembled nc-Si(SiC) thin films grown by low-pressure high-density spontaneous plasma processing [13]. Weiss et al. investigated the structural and optical properties of nc-Si(SiC) of single layers and multilayer structures [14]. Yamada et al. investigated hydrogen plasma treatment for reducing defects in silicon quantum dot superlattice structure with amorphous silicon carbide matrix [15]. Kurokawa et al. investigated the preparation of nc-Si in an amorphous silicon...
carbide matrix [16]. Song et al. investigated the structural characterization of annealed Si\textsubscript{1-x}C\textsubscript{x}/SiC multilayers targeting the formation nc-Si(SiC) thin films [17]. Song et al. investigated structural and electronic properties of Si nanocrystals embedded in an amorphous SiC matrix [18, 19]. Summonte et al. investigated the crystallized fraction correlated with the total silicon volume fraction in the silicon carbide environments [20]. Künle et al. investigated nc-Si(SiC) thin films network has higher mobility than embedded with SiO\textsubscript{2} and SiN network due to SiC is lower bandgap than Si(SiC) thin films network has higher mobility than embedded [21]. Künle et al. investigated structural and optical transformations during thermal annealing at 700 °C of nc-Si(SiC) thin films and concluded PL signal originates from the SiC matrix [22]. Canino et al. investigated the identification and tackling of a parasitic surface compound in SiC and Si-rich carbide films [23]. The above research discussed the deposition process of nc-Si(SiC) thin films by using sputtering, PECVD, HWCVD, ICP-CVD techniques, however, none of the research work focused on the thermal CVD deposited nc-Si(SiC) thin films. Moreover, nc-Si(SiC) thin films were very difficult to achieve in a single step process by alternating various process parameters (e.g. substrate temperature, process pressure, precursor gas, etc). Initially, silicon-rich silicon-carbon films have to deposited and finally a post-annealing treatment at high temperatures (700-1000 °C). Therefore, it is paramount important to synthesize nc-Si(SiC) thin films by a thermal CVD technique using the nc-Si powder as precursor materials.

In the article, we emphasized on following points (a) to investigate the morphology and fractal dimension of nc-Si(SiC) thin films with different process temperature from 700 to 1000 °C, (b) to investigate the lattice-strain of nc-Si(SiC) and compare between the estimated value from Williamson-Hall (W-H) formula and Bragg’s formula, (c) to investigate vibrational properties of nc-Si(SiC) thin films and (d) to investigate electronic environments of nc-Si(SiC) with different process temperature.

2 Experimental Details

2.1 Synthesis

The nc-Si(SiC) thin films were deposited on a p-type Si(100) substrate by a thermal chemical vapour deposition (CVD) process. The substrates were cleaned using an ultrasonic treatment in acetone, etched by a 2% hydrogen fluoride solution, rinsed in deionized water, and dried on N\textsubscript{2} gas before loading into the CVD system [24–30]. Thereafter, the cleaned Si substrate was placed inside a thermal CVD using Si powder, C\textsubscript{2}H\textsubscript{2}, and H\textsubscript{2} as the precursor gas for the deposition of nc-Si(SiC) thin films. The flow rate of C\textsubscript{2}H\textsubscript{2} (5 sccm) and H\textsubscript{2} (100sccm) were fixed but the processing temperature is varied from 700 to 1000\textsuperscript{0} C. After deposition, the samples were handled carefully to avoid moisture and oxidation from the environment. The structural property and bonding configuration of the nc-Si(SiC) films were characterized using X-ray diffractometry (XRD), Fourier transfer infrared absorption spectroscopy (FTIR), and X-ray photoelectron spectroscopy (XPS) respectively. The microstructure and surface roughness of nc-Si(SiC) thin films were observed by scanning electron microscopy (SEM, JEOL-JEM-3000F) and Gwyddion software. The Raman spectrum was recorded at room temperature with an optical microscope using the 488 nm excitation line of an Ar+ laser as an excitation source. The spectral resolution was set as 1 cm\textsuperscript{-1}, acquisition time 10s, and laser power 3 mW. The elemental and composition analysis were carried out by XPS using non-monochromatic Mg K\textsubscript{x} X-ray radiation (hv = 1253.6 eV). The full width at half maxima (FWHM) and the binding of core orbital spectra were fitted and manipulated to extract the information of the nc-Si(SiC) thin film. The FTIR spectra were recorded using a Perkin Elmer model (Spectrum Two) with a resolution of 1 cm\textsuperscript{-1} in the range of 500–4000 cm\textsuperscript{-1}. The FTIR spectrum of the Si(100) substrate was recorded as a reference and finally normalized with the FTIR spectrum of the silicon substrate to yield the spectrum of the nc-Si(SiC) thin film [24–30].

3 Results and Discussion

3.1 Surface Morphology

Figure 1 shows the surface morphology of the nc-Si(SiC) films grown at various temperatures (700–1000\textsuperscript{0} C) by a thermal CVD reactor. The grain size of the nc-Si(SiC) thin films was 296.7 nm, 326.7 nm, 324.6 nm, and 447.9 nm for the process temperature varied from 700 to 1000 °C. The RMS surface roughness of nc-Si(SiC) thin films is 195.2 nm, 247.9 nm, 222.8 nm, and 360.4 nm from 700 to 1000 °C respectively. However, the SEM grain size is much larger than the XRD crystallite size.

3.2 Fractal Dimension

The fractal dimensions of nc-Si(SiC) thin-film surfaces were determined by Gwyddion software with Fourier analysis (power spectrum distribution, partitioning function) and the box-counting (cube counting and triangulation methods) respectively. Figure 2(a) shows a log-log plot of power spectral density function (PSDF), W with the frequency, k of surface morphology of nc-Si(SiC) thin films with different process temperatures from 700 to 1000 °C. The PSD plots of nickel thin films were considered using the k-correlation model by the k-correlation model for the auto-covariance function PSBaC for spatial frequency k, is given by [31].

\[
W(k), PSD_{ABC} = \frac{A}{(1 + Bk^{2})^{(C+1)/2}} 
\]

(1)
Fig. 1  SEM images of nc-Si(SiC) deposited at 700, 800, 900, and 1000 °C process temperature

Fig. 2  (a) power spectral density function (PSDF), (b) partition function, (c) triangular and (d) cube counting of SEM images deposited with different process temperature varied from 700 to 1000 °C
An obtained at low spatial frequencies that depend on the height of the rough surface. B represents the slope of a connecting line between two points on the surface. A and C represents the mean grain size and the slope of the linear part of the PSD plot at high special frequencies, which is greater than 2. The slope of regions (i), (0 < log k < 2) indicated in the intensity of log W(k) for 1000 °C is higher than deposited at 700 °C, indicated the grain size of nc-Si(SiC) prepared at 1000 °C are larger on compared to 700 °C or, the nc-Si(SiC) deposited at 1000 °C is less thick than the nc-Si(SiC) deposited at 700 °C. The (ii) region, (2 < log k < 4) indicated the new grain distribution smaller than the region (i) associate with the SEM images. The morphology further analyzed by Hurst exponent (H) express as.

\[ H = \frac{\delta}{2} - 1 \]  

(2)

H value is 0.532 for nc-Si(SiC) thin films and varied from 0.384 to 0.995 for nc-Si(SiC) thin films. This indicated increasing in the correlated surface with increasing of nc-Si(SiC) thin films with increasing process temperature [25]. The fractal dimension of nc-Si(SiC) films with defined (Df = 3−H) varied from 2.616 to 2.005 with increasing process temperature from 700 to 1000 °C. This indicated decreasing in the irregular and fragmenting surface with increasing in process temperature.

If we assume the particle distribution of nc-Si(SiC) are coalescence in the SEM images and defined by.

\[ S(h) = L \xi(h) \]  

(3)

Where S is the shape factor of total SEM morphology, L is a segment of the same morphology and \( \xi(h) \) is the fractal dimension in the real space.

Where the positive slope represents the strong coalescence properties and the negative coalescence properties indicated the isolation system. Figure 2(c) shows a log-log plot of partition function as the function of the size of particle distribution in a fractal system is defined by.

\[ S(h) \propto h^{-\alpha_1/2} \text{ for } 0 < \alpha_1 < 1 \]  

(4)

Consider as mass fractal.

\[ S(h) \propto h^{-\alpha_2/2} \text{ for } 1 < \alpha_2 < 3 \]  

(5)

where \( \alpha_2 = 2 \) consider as surface fractal in the SEM images.

Figure 2(c & d) shows square and triangular box-counting of undoped and nc-Si(SiC) thin films with different process temperatures from 700 to 1000 °C. The square and triangular fragment distribution defined

\[ D = \log_{10} - \frac{\log N(s)}{\log s} \]  

(6)

Where N is the number line segment and s is the scaling factor. The details of fractal behavior are shown in Table 1.

Figure 2(d) shows uniformity and the fractal dimension for the cube counting indicates a single slope varied from 2.273–2.330. However, Fig. 2(c) indicates two different fractal dimensions (i) higher slope region varied from 0.454–0.536 and (b) lower slope region which is parallel to the square segment region varied from 0.194–0.273.

3.3 Structural and Lattice-Strain

Figure 3(a) shows the XRD pattern of nc-Si(SiC) film grown on p-type Si(100) substrate at different processing temperatures from 700 to 1000 °C. The XRD planes at 28.66°, 47.66° and 56.51° correspond to the (111), (220), and (311) crystallographic planes of Si in the nc-Si(SiC) thin films respectively. The sharp peaks of (111), (220), and (311) also associate with broad amorphous XRD signature proves nc-Si embedded with an amorphous network of SiC. The crystallite sizes, D were calculated by using the Scherer formula,

\[ D = 0.9\lambda/\beta\cos\theta \]  

(7)

where \( \lambda \) is the wavelength of X-ray and \( \beta \) is the full width at half maxima (fwhm) of XRD peak.

The estimated D from (111), (220) and (311) are varied from 21.94 to 28.25, 18.86 to 27.51 and 13.37 to 17.46 respectively. Which indicates the nc-Si phase is embedded with amorphous SiC films.

Williamson-Hall (W-H plot) for evaluating lattice-strain in the nc-Si(SiC) thin films

\[ \beta \cos\theta = K\lambda/D + 4\varepsilon \sin\theta \]  

(8)

Where \( \beta \) is the full width at half maxima, \( k \) is the shape factor whose value is taken as 0.9, D is crystallite size, and \( \varepsilon \) is the lattice strain of thin films.

Figure 3(b) shows the plot of \( \beta \cos\theta \) vs. 4sin \( \theta \) with the variation of process temperature from 700 to 1000 °C. The slope of the plot and the y-axis intercept gives information on lattice strain and crystallite size of nc-Si(SiC) thin films. The evaluated value of lattice strain calculated from the W-H formula varied from 0.00227 to 0.00469. However, the crystallite size of nc-Si(SiC) varied from 61.06 to 40.67 nm with an increase of processing temperature from 700 to 1000 °C. The lattice-strain also calculated from Bragg’s law

\[ \varepsilon = -\Delta\theta \cot\theta \]  

(9)

Where \( \Delta\theta \) is the peak shift from the reference silicon.

Figure 3(c) shows -\( \Delta\theta \) Cos \( \theta \) vs. Sin \( \theta \) for the nc-Si(SiC) with different processing temperatures from 700 to 1000 °C. The slope of Fig. 3(c) provides the lattice strain of the nc-
Table 1 Different fractal dimension regions estimated from different regions

| Temperature (°C) | Power spectral density function | Partition Function | Triangular Counting | Cube count |
|------------------|---------------------------------|--------------------|---------------------|------------|
|                  | (i) region                      | (ii) region        | (iii) region        | (i) region | (ii) region |
| 700 °C           | -0.487                          | -1.695             | -1.618              | 1.238      | 0.385       | 0.487 0.273 | 2.315 |
| 800 °C           | -0.642                          | -2.044             | -1.716              | 1.136      | 0.515       | 0.454 0.194 | 2.273 |
| 900 °C           | -0.549                          | -1.988             | -1.657              | 1.293      | 0.469       | 0.528 0.209 | 2.311 |
| 1000 °C          | -0.529                          | -1.669             | -1.625              | 1.209      | 0.452       | 0.536 0.217 | 2.330 |

Fig. 3 (a) XRD of nc-Si(SiC) with different process temperature from 700 to 1000 °C, (b) lattice strain calculated from Williamson–Hall formula, (c) lattice strain calculated from Scherrer Equation, and (d) Crystallite size, $I_{(311)}/I_{(111)}$, and $I_{(220)}/I_{(111)}$ with different processing temperature from 700 to 1000 °C.
Si(SiC) thin films. The $\Delta \theta$ is calculated concerning the planes peak 28.443, 44.303, and 56.123° corresponds to (111), (220), and (311) respectively [32]. The lattice strain of the nc-Si(SiC) monotonically decreased from 0.01572 to 0.00342 with increasing process temperature from 700 to 1000 °C (Table 2). The lattice strain calculates from Bragg’s formula is higher than the lattice strain estimated from the W-H equation. These possible reasons for higher lattice strain observed may due to (a) in using Bragg’s law as strain measurement does not include fwhm of planes which have contributed from size, strain, and instrument. However, in the practical proposal instrumental broadening can be eliminated by standard sample but Bragg’s is completely silent on the size of materials. (b) The strain calculated from Bragg’s law propositional to cot $\theta$, which again depends on $\theta$. At the higher angle, the lattice strain approaches zero. Hence, the lattice strain calculated from the W-H formula is more appropriate as size and strain factors are included. The ratios of reflection from different planes are shown in Fig. 3 (d). $I_{(220)}/I_{(111)}$ and $I_{(311)}/I_{(111)}$ value varied between 0.35 and 0.25. Therefore, it is concluded that with an increase in processing temperature the incorporated carbon and hydrogen atoms induce amorphization in the Si network due to local deformation caused by carbon and hydrogen atoms.

3.4 Chemical Bonding

The chemical bonding of nc-Si(SiC) thin films was investigated by FTIR spectroscopy. Figure 4(a) shows the FTIR transmission spectra of nc-Si(SiC) thin films deposited on Si (100) substrates at processing temperatures from 700 to 1000 °C. Five distinguish vibration bands can be observed in the nc-Si(SiC) thin films. Region I, confined the broad range between 500 and 800 cm$^{-1}$, peak at 728 cm$^{-1}$ is assigned as the vibration Si-C complexes. Region II, spreads in between 790 and 1185 cm$^{-1}$, with a peak at 1034 cm$^{-1}$ is assigned oxygen mediated Si-C complexes. Region III, confined in between 1185 and 1440 cm$^{-1}$, with a peak at 1275 cm$^{-1}$ is assigned at the Si-CH$_3$ complex. Region IV, in between 2750 and 2950 cm$^{-1}$, corresponds to C-H$_n$ vibrational bonding. The region V, in between 3100 and 3600 cm$^{-1}$ corresponds to O-H vibrational bonds. As the FTIR spectra of Region I, II and III are very broad, the vibrational bonds can be deconvoluted into ten Gaussian peaks. Figure 4(b) shows the deconvoluted vibrational band of the region I, II and III. The 687.33 and 735.59 cm$^{-1}$ correspond to Si-H$_n$ wagging and rocking modes and Si-C stretching modes [27, 28]. The FWHM of Si-H$_2$ wagging and Si-C stretching are 90.48, and 20.34 cm$^{-1}$ respectively. The vibrational peak positions at 862.89, 908.51, 995.70, 1077.0, and 1174.5 cm$^{-1}$ correspond to Si-H$_2$ wagging, SiC-H$_3$ wagging, Si(C-H$_2$)$_2$ stretching, TO Si-O-Si, LO Si-O-Si stretching. The FWHM of corresponding vibrational peaks is 69.74, 69.58, 98.74, 67.26, and 19.11 cm$^{-1}$ respectively. The vibrational peaks at 1239.6, 1274.4, and 1321.0 cm$^{-1}$ corresponds to Si-CH$_3$(polysiloxanes), C-C-H$_n$ stretching vibrational band respectively. The FWHM of the corresponding vibrational peak is 32.47, 27.01 and 57.23 cm$^{-1}$ respectively [33–36]. Considering this aspect, most parts of the vibrational

| Process Temperature (°C) | The crystallite size (nm) | Lattice-Strain |
|--------------------------|---------------------------|----------------|
|                          | Scherrer formula | Williamson – Hall | Williamson – Hall | Bragg’s formula |
|                          | (111)       | (220)     | (311)          |                  |                |
| 700                      | 24.38       | 23.47     | 17.14          | 61.06            | 0.00227 0.01572 |
| 800                      | 21.94       | 18.86     | 13.37          | 68.95            | 0.00407 0.01511 |
| 900                      | 26.28       | 24.79     | 17.46          | 52.51            | 0.00264 0.01496 |
| 1000                     | 28.25       | 27.51     | 14.02          | 40.76            | 0.00469 0.00342 |
peaks shifted to higher values due to the presence of impurities such as oxygen and hydrogen.

### 3.5 Structural Network

Figure 5 shows the Raman spectra of nc-Si(SiC) thin films with different process temperatures from 700 to 1000 °C in the range of 150–1850 cm\(^{-1}\). The Raman spectra of nc-Si(SiC) can be classified into four regions (a) the signatures at 206.72 cm\(^{-1}\) and 260.86 cm\(^{-1}\) corresponds to \(\nu-(Si-C)\) and \(\alpha\nu-(Si-C)\) respectively, (b) the signatures at 439.66 cm\(^{-1}\) to 514.5 cm\(^{-1}\) corresponds to LO-(Si-Si) and TO-(Si-Si) respectively, (c) the TO and LO phonon peaks of Si-C bonding corresponding to 772.47 cm\(^{-1}\) and 938.76 cm\(^{-1}\) respectively and (d) 1346.19 cm\(^{-1}\), 1491.78 cm\(^{-1}\), and 1570.94 cm\(^{-1}\) bonding corresponds D, G-Si and G peaks respectively. The defective carbon bonding, D, and graphitic carbon bonding in the nc-Si(SiC) thin films. The main observations in the nc-Si(SiC) are the following (i) The relative intensity of \(\nu-(Si-C)\) to \(\alpha\nu-(Si-C)\) increased with increasing process temperature. (ii) The D peak intensity relative decreased with increasing process temperature indicates the secondary phase Si attached to C bond increased.

### 3.6 Optical Properties

As both the Si and SiC are indirect semiconductors, the bandgap can be determined as interpolation of plotted \((\alpha h\nu)^{1/2}\) vs \(h\nu\) with different process temperatures from 700 to 1000 °C. Where \(\alpha\) is the absorption coefficient of the nc-Si(SiC) materials.

\[
\alpha \left( \text{cm}^{-1} \right) = \frac{1}{t} \ln \left( \frac{1-R}{T} \right). \tag{10}
\]

Where \(R, T,\) and \(t\) are reflectance, transmittance, and thickness of the nc-Si(SiC) thin films.

Figure 6(a) shows the square root of the absorption coefficient of nc-Si(SiC) at various process temperatures from 700 to 1000 °C. The bandgap of nc-Si(SiC) thin films varied from 3.19, 3.13, 3.00, and 2.91 eV with the process temperature 700, 800, 900, and 1000 °C respectively calculated from \(\alpha^{1/2}\) with \(h\nu\). The absorption coefficient \((\alpha)\) of the nc-Si(SiC) thin films were calculated by

\[
(\alpha h\nu) = B(E-E_{opt})^r. \tag{11}
\]
$E_{\text{opt}}$ is the optical bandgap of the material, $h\nu$ is the incident photon energy and $r$ is the transition coefficient. The value of $r$ is 1/2, 3/2, 2, and 3, depending on the nature of the electronic transition responsible for the absorption. $r = 1/2$ for allowed direct transition, $r = 3/2$ for forbidden direct transition, $r = 2$ for allowed indirect transition and $r = 3$ for forbidden indirect transition. Hence, the optical bandgap of nc-Si(SiC) can be estimated by Tauc’s plot

$\left(\alpha h\nu\right)^{1/2} = B(E-E_{\text{opt}})$ \hfill (12)

Figure 6(b) shows Tauc’s plot of nc-Si(SiC) with different process temperatures from 700 to 1000 °C. The estimated bandgap from Tauc’s plot of nc-Si(SiC) thin films are 3.17, 3.11, 3.02, and 2.87 eV respectively. This indicates the bandgap calculated from both $\alpha^{1/2}$ vs $h\nu$ and Tauc plot are almost the same and nc-Si bandgap is influenced by embedded a-SiC thin films.

### 3.7 Composition and Electronic Environmental Analysis

Figure 7 (a) shows the binding energy in the range of 0 to 900 eV of nc-Si(SiC) thin films with the process temperature varied from 700 to 1000 °C.
atomic percentage of Si and C can be estimated by \[ \text{at} \% = \frac{A_i}{\sum A_i} \times 100 \] with different process temperatures from 700 to 1000 °C. The shows the at.% of the Si and C in the nc-Si(SiC) thin films contamination present in the nc-Si(SiC) thin films. Figure 7(b) shows the at.% of the Si and C in the nc-Si(SiC) thin films with different process temperatures from 700 to 1000 °C. The atomic percentage of Si and C can be estimated by [30–36].

\[ X \text{ at} \% = \frac{(A_i/S_i)}{\sum (A_i/S_i)} \times 100 \]  

Where \( A_i \) and \( S_i \) are the area under the core orbital spectra and surface sensitivity of elements present in the nc-Si(SiC) thin films. The surface sensitivity factor of C(1 s) and Si(2p) are 0.25 and 0.66 respectively. The composition of Si and C varied from 53.27 to 59.12 at.% and 46.72–40.87 at.% respectively with increasing of process temperature from 700 to 1000 °C. This indicates the at.% incorporation of Si more than C, which reflects silicon-rich films in the nc-Si(SiC) thin films, which supports the agglomeration of Si nanoparticles within the SiC network. Figure 7(c) shows the deconvolution spectra of Si(2p) spectra with different process temperatures from 700 to 1000 °C in the nc-Si(SiC) thin films. The Si(2p) core orbital can be deconvoluted into three individual Gaussian sub-core orbital according to their coordination number and electron negativity of Si, C, and O associates with nc-Si(SiC) thin films. The binding energy at 97.57, 99.52, 101.67 eV corresponding to Si associate with Si (Si-Si), Si associate with C (Si-C), and Si associate with O (Si-O) respectively at the 700 °C process temperature. However, the binding energy of Si-Si, Si-C, and Si-O are at 97.15, 99.37, and 101.56 eV respectively for the nc-Si(SiC) thin films deposited at 1000 °C. This indicates decreasing of binding with increasing of process temperature by incorporation of Si with increasing of process temperature to 1000 °C. This indicates the at.% incorporation of Si more than C respectively with increasing of process temperature from 700 to 1000 °C. Fig. 7(e) shows O(1 s) core orbital spectra varied from 528 to 536 eV with increasing process temperature from 700 to 1000 °C. The peak position of O(1 s) is invariant 532.2 eV for all nc-Si(SiC) indicates the oxygen contamination is associate with the handling of samples or atmospheric exposure [37–44].

4 Conclusions

In this work, the lattice strain of SEM images of nc-Si(SiC) thin films were varied from 0.00227 to 0.00469, and 0.01572 to 0.00342 from Williamson-Hall, and the Bragg’s formula respectively with increasing of process temperature from 700-1000°C. The SEM images reveal the Si particles are embedded with SiC thin films. The Raman signature at the 1346.19 cm⁻¹, 1491.78 cm⁻¹ and 1570.94 cm⁻¹ bonding correspond to D, G-Si, and G peaks respectively. The estimated bandgap from Tauc’s plot of nc-Si(SiC) thin films are 3.17 to 2.87 eV respectively with increasing process temperature. The observed crystalline size of nc-Si in nc-Si(SiC) is from 21 nm to 27 nm from 700 to 1000 °C respectively. The possible bonding network of core-orbital of Si(2p), C(1s), and O(1s) in the nc-Si(SiC) thin films have been discussed by deconvolution with the Origin 2018.

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Availability of Data and Material  Data generated during the study are subject to a data-sharing mandate and available in a public repository that does not issue datasets with DOIs.

Author Contributions  The author has taken full responsibility for this manuscript.

Declarations  The accepted principles of ethical and professional conduct have been followed.

Consent to Participate  The participant has consented to the submission of the case report to the journal.

Consent for Publication  All authors consent to the publication of the manuscript.

Conflict of Interest  The author has no conflict of interest.
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