Photoluminescence and structural properties of Si/SiC core–shell nanowires growth by HWCVD

Nur Fatin Farhanah Binti Nazarudin, Nurul Jannah Binti Mohd Noor, Saadah Abdul Rahman, Boon Tong Goh

Low Dimensional Materials Research Centre (LDMRC), Department of Physics, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia

1. Introduction

One dimensional (1D) semiconductor nanostructures such as nanowires and nanorods have attracted more and more attention recently, due to their applications in mesoscopic physics and in the building blocks of nanoscale devices [1–3]. As a most important semiconductor 1D nanostructure materials, Si nanostructures, such as nanowires and nanorods, are of great interest owing to their excellent structural [4–6], optical [7–9] and electrical [10] properties. These superior properties have made the Si nanowires achieve excellent performance in solar cells, lithium ion batteries and thermoelectric devices [11–13]. However, due to their intrinsic material properties such as weak mechanical stability and associated side reactions resulting from unprotected surfaces, single-phased nanomaterials cannot fulfill certain application requirements [14,15]. Cui and co-workers reported that a crystalline core–amorphous shell Si nanowires design has shown a significant enhancement in capacity/power rate and efficiency for lithium-ion batteries and solar cell respectively [16]. Ryu et al. [17] and Tang and Bando [18] presented an enhancement of field emission properties of SiC/SiO$_2$ core–shell nanowires. Moreover, Lee group [19] demonstrated a great improvement of light absorption and photocatalytic capability of ZnO/Si hierarchical core–shell heterostructures. For the application in high-temperature and high-power electronics, and electromechanical systems, incorporation of SiC nanostructures into the Si nanowires as a core–shell nanowire therefore is expected to further enhance the properties of the core–shell nanowires due to SiC possess various superior properties of high mechanical stability, chemical inertness, high thermal stability and in a wide range of optical properties [20–22].

Hot-wire chemical vapor deposition (HWCVD) is one of the most promising techniques for low temperature, high deposition rate and large-area deposition for SiC based thin films materials [23–25]. The HWCVD has demonstrated a low-temperature deposition (around 300 °C) of cubic SiC thin films. In the HWCVD process, the decomposition of SiH$_4$/CH$_4$ molecules on filament surfaces at filament temperature above 2000 °C sufficiently generates higher densities of growth precursors (SiH$_3$ and CH$_3$) than plasma processes. Moreover, decomposition of high density of H radicals plays an important role in the low-temperature growth of nanocrystalline SiC thin films. Recent studies on the growth of Si nanowires by HWCVD demonstrated that this technique is a promising technique for the growth of novel 1D Si based nanostructures owing to the lower production cost and large-scale production capability [26–28]. The HWCVD has also been reported to enhance the growth rate of Si nanowires [29]. Moreover, as compared to the conventional plasma enhanced CVD (PECVD), the HWCVD does not utilize high energy ions thus is expected to produce a better crystallinity of the
nanowires [30]. In this work, we grown nickel (Ni)-catalyzed Si/SiC core–shell nanowires by HWCVD at deposition pressures of 0.5 and 1 mbar. The photoluminescence and structural properties of these nanowires were investigated using field emission scanning electron microscopy (FESEM), scanning transmission electron microscopy with energy dispersive X-ray spectroscopy (STEM/EDS) mappings, STEM/High Angle Annular Dark-Field (HAADF), Micro–Raman scattering spectroscopy, glancing-angle small and wide angle X-ray scattering (GI-SWAXS), Micro-photoluminescence (PL) spectroscopy. The growth of the nanowires was found to be significant for the nanowires prepared at low deposition pressure. Results of the PL emissions in relation to the structural properties of the nanowires are also discussed. Moreover, the effects of the deposition pressure on the PL and structural properties are briefly described.

2. Experiments

Si/SiC core–shell nanowires were prepared on Ni coated glass substrates by a home-built HWCVD system. The Ni film thickness of about 30 ± 5 nm was deposited on the heated glass substrates under a vacuum condition. Prior to deposition, the Ni films were treated by atomic hydrogen plasma for 10 min in order to form metal nano-islands. The substrate temperature, pressure, hydrogen flow-rate and radio-frequency (rf) power were fixed at 450 °C, 0.75 mbar, 100 sccm and 5 W respectively. During the deposition, the filament temperature and substrate temperature were fixed at 1900 and 450 °C respectively. The filament temperature was measured using a pyrometer model Reytek, Raynger 31. The filament to substrate distance was fixed at 2 cm. The SiH₄, CH₄ and H₂ flow-rates were fixed at 1, 2 and 100 sccm respectively. The vacuum base pressure was achieved as low as 5 × 10⁻⁷ mbar for the deposition pressures of 0.5 and 1 mbar. The total deposition time was fixed for 5 min.

The FESEM images of the nanowires were obtained using a Hitachi SU 8000 SEM at low electron accelerating voltage of 2 kV. The elemental spectra of the nanowire were collected by EDS detector attached to the SEM (Bruker XFlash 6i100) at 15 kV. The working distances for the imaging and elemental spectra were fixed at 8 mm and 15 mm respectively. In the same machine, the STEM/bright field was carried out on the sample prepared on a copper grid (Lacey Formvar, 300 mesh), for EDS elemental mappings of the nanowire. Furthermore, the details of surface morphology and microstructure of the nanowire were investigated by means of a TEM (JEOL JEM-2100F) with an accelerating voltage of 200 kV.

The elemental spectra of the nanowire were collected by EDS elemental analysis. The formation of the agglomerated grains is clearly illustrated in the inset of the corresponding figure.

3. Results and discussion

The surface morphologies of Ni-catalyzed Si/SiC core–shell nanowires grown by HWCVD at different deposition pressures are depicted in Fig. 1. As can be seen, most of the nanowires possess a tapered morphology with a vertical alignment for the nanowires grown at 0.5 mbar. The inset of Fig. 1(a) clearly illustrates the tapered morphology of the nanowires. It is estimated from the figure that the average length and diameter of these nanowires are 587 and 51 nm respectively. The tapering of the nanowires reveals a radial growth of nanowires which generally occurred in the CVD growth nanowires. The radial growth of the nanowires by HWCVD has been extensively described elsewhere [31–33]. The nanowires prepared at 1 mbar shows a significantly decrease in length and diameter of the nanowires. The roots of these nanowires are surrounded by agglomerated grains. The formation of the agglomerated grains at higher deposition pressure can be due to the increase in gas phase reaction in HWCVD [34]. The enhancement of the gas phase reaction leads to a lateral growth thus induces the formation of the agglomerated grains at the roots of the nanowires. The formation of the agglomerated grains is clearly illustrated in the inset of the corresponding figure.

![Fig. 1. FESEM images of Si/SiC core–shell nanowires prepared by HWCVD at different deposition pressures of (a) 0.5 and (b) 1 mbar. Insets of each figure present a high magnification of the respective FESEM images.](image)

<table>
<thead>
<tr>
<th>Pressure (mbar)</th>
<th>Nanowire</th>
<th>Si</th>
<th>C</th>
<th>O</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>Tip</td>
<td>63.9</td>
<td>2.8</td>
<td>15.3</td>
<td>11.8</td>
</tr>
<tr>
<td></td>
<td>Stem</td>
<td>63</td>
<td>5.5</td>
<td>16.3</td>
<td>10.9</td>
</tr>
<tr>
<td>1</td>
<td>Tip</td>
<td>54.6</td>
<td>12.7</td>
<td>8.9</td>
<td>19.4</td>
</tr>
<tr>
<td></td>
<td>Stem</td>
<td>49.8</td>
<td>25</td>
<td>7.8</td>
<td>15</td>
</tr>
</tbody>
</table>
The elemental analysis of the nanowires at deposition pressures of 0.5 and 1 mbar was done by EDS as tabulated in Table 1. The nanowires mainly consist Si, C, O and Ni. High concentration of Si (more than 50%) reveals that the nanowires are Si-rich Si/SiC core–shell nanowires. For the sample prepared at 0.5 mbar, the nanowire consists of about 63% of Si at the tip and the stem of the nanowire. The C concentration increases from the tip to the stem of the nanowire. The amount of Si decreases with increase in the deposition pressure to 1 mbar. On the other hand, the amount of C increases significantly at the tip and stem of the nanowire. Moreover, the stem of the nanowire showed a higher concentration of C (25%) compare to the tip of the nanowire (12.7%). High percentage of C content at the stem could be due to the formation of the agglomerated grains at the roots of the nanowires. More than 11% of Ni is found on the tip of the nanowires which indicates that the Ni is catalyzing the growth of these core–shell nanowires. The presence of Ni on the stem of the nanowires also reveals a diffusion of the Ni into the nanowire. The diffusion of the Ni into the nanowire could lead to a formation of Ni nanoparticles on the sidewall of the nanowire. Thus, this leads to the tapered morphology attributed to the radial growth and the formation of the agglomerated grains as shown by the nanowires grown at 0.5 and 1 mbar respectively. The presence of O could be due to the formation of SiO on the surface of the nanowires or on the surface of the agglomerated grains that surrounded the nanowires, which is generally occurs at the initial stage of the nucleation during the growth of nanowires by the CVD technique [35,36].

The microstructure and elemental mappings of the nanowire were further investigated by bright-field STEM/EDS mappings as shown in Fig. 2. The EDS mapping was done by SU 8000 SEM at bright-field STEM mode. The bright-field STEM image as shown in Fig. 2(a) depicts a typical single nanowire prepared at 0.5 mbar, on carbon film supported by TEM copper grid. The open green box indicates the selected area of the elemental mappings. Fig. 2(b)–(e) presents EDS elemental mappings of the nanowires for the elements of Ni, Si, C and O respectively. The insets of Fig. 2(b) and (c) demonstrate the EDS mappings of Ni and Si on the bright-field STEM image respectively. High density of Si can be observed at the stem of the nanowire as in the EDS map. However, at the tip of the nanowire which shows a darker area in the nanowire contains almost no Si. The tip of the nanowire is replaced by the high density of Ni as shown in Fig. 2(c). The presence of Ni nanoparticle on the tip of the nanowire with no Si clearly supports the Ni catalyzing the growth of these core–shell nanowires. Furthermore, the presence of uniform distribution of Ni on the stem of the nanowire indicates a diffusion of Ni into the nanowire forming Ni nanoparticles. On the other hand, high densities of Si and C on the surface of the nanowires suggest a formation of SiC layer on the nanowires which could be a shell of the nanowire attributed to the growth mechanism as described later. Moreover, the presence of little of O on the nanowires indicates an oxidation effect on the surface of the nanowire during the nanowire growth.

In this work, the hydrogen plasma treatment on the Ni film surface formed the Ni nanoparticles with the average diameter of 13 nm. During the deposition, the decomposition of SiH₄, CH₄ and H₂ by hot-filament at temperature as high as 1900 °C supplied large amount of Si- and C-rich species impinging on the surface of the Ni nanoparticles. At lower pressure, impinging of Si-rich species on the Ni nanoparticles surface and due to its high solubility of in Ni nanoparticles, therefore these Ni nanoparticles act as metal nano-templates for the diffusion of Si-rich species forming NiSi alloys in solid state at 450 °C and catalyzed the growth of the nanowires subsequently. The measured temperature on the substrate surface was 785 °C due to a hydrogen heat transfer effect from the hot-filament at temperature of 1900 °C. Since the nanowires were grown at substrate temperature lower than the eutectic temperature of Ni–Si (993 °C) and Ni–C (1550 °C) [37,38], therefore the precipitation of these nanowires could be considered follows metal diffusion growth or vapor–solid–solid (VSS) growth mechanism as reported previously [39–41]. Owing to the gas phase reactions, C-rich species impinge in the growth sites latter than Si-rich species. These C-rich species bonded with Si forming SiC on the surface of the NiSi solid alloys or on the sidewall of nanowires subsequently growth as SiC shell layer.

![Fig. 2. (a) Bright-field of STEM image of Si/SiC core–shell nanowires prepared by HWCVD at deposition pressure of 0.5 mbar. The selected box indicates the scanning area of the EDS mapping. (b–e) presents each EDS element maps of the core–shell nanowire. Insets of (b) and (c) demonstrate the EDS maps of Si and Ni on the bright-field STEM images respectively.](image-url)
This shell layer growth radially forms a tapered morphology of the nanowires as demonstrated in Fig. 1. An increase in pressure enhances the gas phase reactions thus generate more C-rich species impinging on the growth sites (on the surface of the NiSi solid alloys or on the sidewall of nanowire) and form the SiC layer radially surrounding the NiSi solid alloys. This prevents subsequent diffusion of Si into Ni nanoparticles. Therefore, this induces formation of spherical grains instead of growth as nanowire.

Fig. 3 shows the TEM and dark-field of STEM images of the nanowire prepared at deposition pressure of 0.5 mbar. The TEM image of a single nanowire reveals a core–shell structure which showed a similar morphology as compared to the FESEM image, as depicted in Fig. 3(a). The dark-field image was obtained by JEM-2100F at STEM mode with HAADF detector as shown in Fig. 3(b). As compare to the STEM/EDS mappings above, the STEM/HAADF gives more information on the microstructure and also the compositions of the nanowire. The nanowire shows a tapered morphology with smaller tip and an increasing in diameter along the nanowire until the root. The diameter of the tip is about 10 nm while the diameter of the nanowire increases from 15 to 72 nm with a length near to 1 μm (rough estimation from the STEM image). The bright tip indicates the presence of Ni catalyst nanoparticle on the tip of the nanowire that induces the growth of the nanowires. The tapering and the broadening at the root of the nanowires are attributed to the radial growth of the nanowires. Fig. 3(c) shows a high magnification of STEM image for the nanowire prepared at 0.5 mbar. The image illustrated clearly the appearance of bright particles on the sidewall of the nanowire near to the root of the nanowires. This reveals the formation of Ni nanoparticles along the nanowire. The formation of Ni nanoparticles is attributed to the diffusion of Ni from the Ni catalyst nanoparticles during the growth of the nanowire. The reduced in size of the Ni catalyst nanoparticle compared to the average size of Ni nano-islands, imply the diffusion of Ni from the Ni nanoparticles into the nanowire. The out-diffusion of the metal catalysts during the growth of nanowires also has been observed by Kodambaka et al. [42,43]. The transmitted electron image reveals a core nanowire above the center of the nanowire. This nanowire is surrounded by the faceting of nano-columns due to the radial growth which leads to the tapering of the nanowires.
The elemental profile of a single nanowire at the stem was obtained by the STEM line scan with HAADF detector and is illustrated in Fig. 3(e) and (f). It is shown that from the horizontal line scan, the density of Si is at maximum at the center of the nanowire. On the other hand, the density of C in the horizontal line scan showed a slightly lower at the center of the nanowire as compared to the near edge of the nanowire. The distributions of Si and C by the EDS line scans indicate that the nanowire consisted of highest densities of Si and C at the center and at the near edge of the nanowire respectively, which reveals the core and the shell are mainly covered by Si and C respectively. Therefore, with the supports of the EDS mappings and the described growth mechanism, the compositions of the core and shell of the nanowires are attributed to Si and SiC respectively.

Fig. 4 shows the Raman scattering spectra of the nanowires prepared by HWCVD at deposition pressures of 0.5 and 1 mbar. These Raman spectra mainly consists of Si, SiC and NiSi Raman excitation bands as illustrated clearly in the figure. In Fig. 4(a), typical Raman excitation bands of Si have been clearly presented, at 150, 300, 380–420 and 480–520 cm\(^{-1}\) which associated to transverse acoustic (TA), longitudinal acoustic (LA), longitudinal optical (LO) and transverse optical (TO) modes respectively [44,45]. Moreover, the TO excitation band of Si can be further divided into two subcomponents: TO\(_1\) excitation mode at 480 cm\(^{-1}\) and TO\(_2\) excitation mode at 510–520 cm\(^{-1}\) correspond to amorphous and crystalline Si phases respectively, as shown in the inset of Fig. 4(c). The appearance of the sharp Si TO excitation bands for the both nanowires could imply a crystalline Si core of the nanowire. The Si TO\(_2\) excitation band shows slight downshifted to 514.5 ± 0.1 cm\(^{-1}\) and asymmetric broader about 10.2 ± 0.1 cm\(^{-1}\) as compared to single crystalline Si with TO\(_2\) excitation band at 521 cm\(^{-1}\) with the width of 4.6 cm\(^{-1}\) [31]. The 2TO appeared at 0.5 mbar indicates a second order of Si TO excitation band. Besides, there is an appearance of small excitation band at 618 cm\(^{-1}\) for the nanowires prepared at 0.5 mbar indicating the presence of SiH mode in the structure [36]. An increase in deposition pressure enhances the Raman excitation bands of SiC at 780 and 910 cm\(^{-1}\) associated to TO and LO modes of SiC phases, respectively [46–48], while the Raman excitation band of Si at around 510 cm\(^{-1}\) degrades with increase in deposition pressure. Moreover, NiSi excitation bands also have been observed in the Raman spectrum for the nanowire prepared at 1 mbar. These excitation bands are located at 187, 207, 286 and 356 cm\(^{-1}\) indicating the presence of single NiSi phase [40]. The visibility of the NiSi excitation bands at higher deposition pressure of 1 mbar is due to the increasing of Ni concentration in the nanowire. Fig. 4(c) shows the removed baseline of the Raman vibration bands of Si TO mode at 510 cm\(^{-1}\) for the nanowires prepared at deposition pressures of 0.5 and 1 mbar. Increase in pressure decreases the intensity of the TO mode significantly however reduces the amorphous phase in the nanowire. The reduction of the amorphous in the nanowire indicates an increase in degree of structural order of the nanowire. This accompanying the appearance of SiC phase in the nanowire reveals a

Fig. 4. Raman spectra of Si/SiC core–shell nanowires prepared by HWCVD at deposition pressures of (a) 0.5 and (b) 1 mbar. (c) Si TO band at Raman shift around 520 cm\(^{-1}\) of the nanowires prepared at 0.5 and 1 mbar. The inset shows a typical decomposition of the Si TO band at around 520 cm\(^{-1}\). The decomposed components are labelled as amorphous (amor), grain boundaries (g.b.) and crystalline (cryst) which are located at around 480, 500 and 520 cm\(^{-1}\) respectively. Another satellite component is the background component of the band.
formation of 3C–SiC nano-crystallites embedded with its matrix. The red-shifts of the SiC excitation bands and the broadening of the bands as compared to the bulk 3C–SiC crystal [49] own to the quantum confinement effects of the SiC nano-crystallites [50]. Therefore, the formation of amorphous SiC is attributed to the shell nanowires.

Fig. 5 shows 2D images of GI-WAXS for the nanowires prepared by HWCVD at deposition pressures of (a) 0.5 and (b) 1 mbar. The 2D GI-WAXS image of the nanowires illustrates the diffraction rings from the scattering on the surface of the nanowires. The brighter region corresponds to the higher intensity of the scattering. Appearance of the sharp inner and outer diffraction rings could be due to the scattering of the crystalline Si (1 1 1) orientation and NiSi respectively. The brighter region as shown in the image (b) could be due to the formation of the agglomerated grains at the root of the nanowires. The formation of the Ni nanoparticles on the root of the nanowire and agglomerated grains leads to the continuous scattering at the lower q-range. The GI-WAXS spectra of the nanowires prepared at different deposition pressures are shown in Fig. 5(c). The inset of the figure shows a typical Gaussian decomposition of the GI-WAXS spectrum into different crystalline diffraction planes of Si and NiSi orientations. The diffraction peak at 19 nm\(^{-1}\) (27.2°) corresponds to crystalline Si (1 1 1) plane. The diffraction peaks at 20.7 (29.5°), 22.9 (32.8°) and 25.6 (36.8°) nm\(^{-1}\) indicate the presence of NiSi in the nanowires with dominant of Ni\(_{31}\)Si\(_{12}\) phase (JCPDS: 00-024-0524). Moreover, there is an appearance of small diffraction peak at 24.4 nm\(^{-1}\) (35°) revealing the presence of SiC phase in the nanowire which could be an indication of 3C–SiC nano-crystallites embedded within an amorphous matrix.

Fig. 6 shows the 2D images of GI-SAXS for the nanowires prepared at deposition pressures of (a) 0.5 and (b) 1 mbar. These images show two different kinds of scattering pattern from different morphologies of the nanowires prepared at 0.5 and 1 mbar. The uniform distribution of the tapered-like nanowires grown at 0.5 mbar leads to an even more scattering distribution. However, the formation of the agglomerated grains at the root of the nanowires prepared at 1 mbar results to uneven scattering distribution on the 2D image with a sharp scattering effect at the horizontal axes direction and a broad scattering effect at the vertical axes direction. The brightest scattering effect at the center of the images indicates the incidence beam of the X-ray. The scattering intensity decreases going from the center of the images towards larger q\(_{xy}\) [51]. The GI-SAXS spectra of the nanowires prepared at different deposition pressures are shown in Fig. 5(c). The dimension of the nanowires can be estimated from the SAXS.
spectrum using Guinier plot at a very small angle region. The Guinier approximation relation as $I = I_0 \exp \left(-\left(R_G^2/3\right)q^2\right)$, where $R_G$ is radius of gyration [52,53]. $R_G$ is estimated from the linear domain expected from the Guinier equation in the very small angle region of 0.008–0.015 Å⁻¹ and it represents the size (diameter) of the nanowires in this case. The Guinier plot of the nanowires prepared at different deposition pressures is shown in Fig. 7. The estimated values of $R_G$ are 17.5 and 12.8 nm for the nanowires prepared at 0.5 and 1 mbar respectively. These values are quite appropriate with the average diameters for the stems of the nanowires that estimated from the SEM images (18.9 and 12.5 nm for 0.5 and 1 mbar respectively).

Fig. 8(a) shows the PL emission spectra of the nanowires prepared by HWCVD at different deposition pressures. These nanowires show broad PL emission spectra over the photon wavelength from 400 to 1000 nm which cover the whole visible and part of near infrared regions. A typical PL spectrum with the Gaussian decomposition components is shown in Fig. 8(b). These decomposed PL emission spectra consist of 7 components where four strong emission bands centered at around 610, 690, 745 and 870 nm. Apart from that, there are three small emission bands at around 820, 525 and 450 nm. The emission bands in the range of 650–800 nm are reported to be originated from the quantum confinement effect of the Si nano-crystallites embedded with an amorphous matrix [54–56]. The emission band in the range of 550–650 nm is generally referred to the emission due to the oxygen related defects and/or to surface and interface effects [54,57,58]. Formation of Si nano-crystallites at the nc-Si/SiO₂ interface creates an intermediate state for electron–hole radiative recombination that leads to the strong emission in the visible region. According to the quantum confinement effect model that has been described by Trwoga [59], the presence of Si nano-crystallites with a diameter less than 10 nm embedded with an amorphous matrix widened the band gap thus resulting the band gap larger the band gap of bulk crystal silicon (1.12 eV at room temperature) thus producing PL emission in the visible region. The origin of the PL emission due to the quantum confinement effect could be verified by applying the quantum confinement effect model of the PL peak position in energy, $E_n$, as [60,61]...
increase of the PL emissions related to the SiC nano-crystallites reduction of these PL emissions is accompanying with a slight carbon content as shown by EDS result in Table 1. Moreover, the 525 nm indicates the emission of SiC nanostructures [64–67] to exhibit any quantum confinement effect of the SiC nano-crystallites embedded within its amorphous matrix instead of increasing in carbon content (as shown by EDS result) in the nanowires for the case of HWCVD deposition. As a summary, the various PL emissions from the nanowires have revealed that the PL emissions strongly depend on the quantum confinement effects attributed to size of the nano-crystallites embedded in the nanowires.

\[ E_{PL} = E_g + 3.73/d^{0.4} \]

where \( E_g \) is the room temperature band gap of bulk c-Si of 1.12 eV and \( d \) is the crystallite size of the Si nano-crystallites that contributed to the PL emission bands at 690 and 745 nm are about 3.7 ± 0.4 nm and this value is quite close to the average crystallite sizes estimated from the shift of the Raman peaks (about 3.5 ± 0.1 nm). The emission band near to 900 nm could be due to the localized state transitions of a-Si nanoclusters [62,63].

The appearance of two small emission bands at 450 and 525 nm indicates the emission of SiC nanostuctures [64–66]. The peak at 450 nm is comparable to the PL emissions from SiC nanowires [64,65] or crystalline SiC nanoparticles [66]. However, the emission peak for these nanowires is obviously shifted to higher wavelength as compared to the reported works above. This phenomenon has been reported due to the quantum size effects of the size of the nanowires or the SiC nano-crystallites embedded within an amorphous matrix. Since the average diameter of the heterostructures is still larger than the Bohr radius of bulk 3C–SiC [67] to exhibit any quantum confinement effects, therefore this PL emission could be attributed to the presence of SiC nano-crystallites embedded within an amorphous matrix. The peak at 525 nm could be due to the presence of defect centers within the band gap of SiC shell as previously reported by Gundiah et al. [68]. An increase in deposition pressure significantly decreases the PL emissions due to the quantum confinement effect of the Si nano-crystallites. This could be probably due to the increasing of the carbon content as shown by EDS result in Table 1. Moreover, the reduction of these PL emissions is accompanying with a slight increase of the PL emissions related to the SiC nano-crystallites and its defect centers within the band gap. The presence of these SiC phases in the nanowires prepared at 1 mbar leads to a blue-shift of the PL emission edge at around 500 nm to a lower photon wavelength (a higher photon energy) as shown in Fig. 7(a). Since the PL emission edge is generally related to the optical band gap of the material, therefore the blue-shift of the PL emission edge implies an increase in optical band gap of the nanowires with increase in pressure. Therefore, the shift of the PL emission edge is more appropriately attributed to the quantum confinement effect of the SiC nano-crystallites embedded within its amorphous matrix instead of increasing in carbon content (as shown by EDS result) in the nanowires.

4. Conclusions

The optical and structural properties of Si/SiC core–shell nanowires grown by HWCVD at different deposition pressures have been investigated. Nickel nanoparticles act as metal nanomaterials for catalyzing the growth of Si nanowires. The growth of the nanowires is assisted by the hydrogen heat transfer effect due to the hot-filament. The precipitation of the nanowires is considered follows the metal diffusion growth or vapor–solid–solid (VSS) growth mechanism. These nanowires showed radial growth morphology of tapered-like nanowires and nanowires with agglomerated grains at the root for the deposition pressures of 0.5 and 1 mbar respectively. These nanowires consisted of crystalline Si and amorphous SiC as core and shell of the nanowires respectively. Formation of Ni nanoparticles along the sidewall of the nanowire leads to the radial growth of the nanocolumns which are attributed to the tapered and agglomerated grains morphology. Increase in deposition pressure leads to an enhancement of the formation of SiC phase in the shell of the nanowires. The presence of Si and SiC nano-crystallites embedded within an amorphous matrix exhibited broad range of PL emission spectra in the room temperature.

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