Chapter 5
Nanostructured CuO thin films prepared through anodization of copper substrate for solar selective absorber applications

5.1. Introduction

The properties of materials at nanoscale level strongly depend on their size and shape. In the past decade, one dimensional (1D) nanostructures have attracted great scientific and technological interest, owing to their unique electronic, mechanical, magnetic and chemical properties (Cui et al., 2001). Moreover, the 1D nanostructures exhibit high solar absorbance due to their simple geometrical model in which the incident solar radiation is subjected to a series of multiple reflections. Solar radiation with a wavelength smaller than or similar to the inter-dendritic spacings penetrates the dendritic structure and their multiple reflections on the surfaces have the effect of enhancing the solar absorptance. This type of selective absorbers are not very sensitive to the severe environmental effects like oxidation and thermal shocks (Pellegrini, 1980).

Metal oxide nanostructures have attracted much attention because of their prominent applications in the fields of optics, optoelectronics, catalysis, biosensors, etc (Zhang et al., 2006; Bigi et al., 2002; Chen et al., 2004; Lu et al., 2008 and Chen et al., 2007). In this respect, cupric oxide (CuO) is an inexpensive, environmentally benign and easily producible transition metal oxide with monoclinic unit cell and square planar coordination with a band gap of 1.2 eV (Wu et al., 1987 and He et al., 2002). The CuO is found to have potential applications in magnetic storage, solar energy transformation, electronics, batteries, sensors and catalysis (Liao et al., 2001 and Ramirez-Ortiz et al., 2007).
Due to the versatile properties and diverse applications, various kinds of CuO nanostructures and microstructures like nanorods, nanowires and nanoribbons have been synthesized by a number of research groups (Jiang et al., 2002; Cao et al., 2003; Wang et al., 2003 and Chang and Zeng, 2004). A variety of fabrication techniques that include heating of Cu sheets in O₂ atmosphere (Fan et al., 2008), electrodeposition (Allam and Grimes, 2011) and sol-gel (Armelao, et al., 2003) were used for the preparation of CuO nanostructures.

Basic Cu(II) salts and Cu(OH)₂ with an orthorhombic structure have been studied extensively for the preparation of CuO nanostructures in the past several years. Matijevic and co-workers (Kratochvil and Matijevic, 1991 and Rodriguez-Clemente et al., 1994) investigated the relationship between the morphologies of homogeneously precipitated Cu(OH)₂ and the solution compositions. Polycrystalline Cu(OH)₂ nanowires and nanoribbons were synthesized through a two-step wet chemical route as well as through the interaction between a copper complex and NaOH at the aqueous–organic interface. Single crystalline Cu(OH)₂ nanoribbon and nanotubes were successfully synthesized by surface oxidation of copper foil in alkaline solutions (Wen et al., 2003) or by anion exchange reaction using NaOH solution (Park and Kim, 2004). Among these techniques, the anodization method is attractive due to its low reaction temperature, facile and cost-effective nature. Moreover, the shape and atomic compositions of final compound films can be controlled during anodization by means of modulating the potential, reaction time and integrated charge passed through the experimental cell (Wu et al., 2005).

By considering the above facts, in this work, we have prepared nanostructured CuO thin films were prepared by anodization of copper substrate at different applied potentials in the presence of different concentrations of aqueous NaOH electrolyte
solution. The thin films obtained with diverse morphologies and chemical compositions under different experimental conditions were studied for their viability in the solar selective absorber applications.

5.2. Experimental

5.2.1. Preparation of nanostructured CuO thin films

The anodization process being followed in the preparation of nanostructured CuO thin films makes use of an inexpensive two electrode system in the presence of aqueous NaOH (0.5, 1.0 and 1.5 M) electrolyte solution of various concentrations. Two pieces of copper (Cu) substrates were used as anode and cathode. Before anodization, 0.4 mm thick copper foil substrates (1.5 cm × 2 cm) were soaked in 4 M hydrochloric acid solution for 15 min and subsequently rinsed with double distilled water thrice to eliminate any surface adsorbed impurities and native oxide layer. The cleaned copper substrates were then immersed in the electrolyte solution (NaOH solution) and made one as anode and the other as cathode. The distance between the anode and cathode was kept constant as 1 cm. The anodization reaction was performed at different applied voltages (0.25, 0.50, 0.75 and 1.0 V) for duration of 1 h (which was considered as the optimum anodization time) at room temperature. The experiments were also conducted at 50 °C in one molar NaOH. The desired voltages were applied using a computer controlled Keithley 2400 source meter. After the specified reaction time, a thin film was formed on the surface of the anode copper substrate. The copper substrate containing the thin film was then taken out from the reaction solution, successively washed with double distilled water and dried at 100 °C for 2 h in a hot air oven. The thin films were then heated to 250 °C in a muffle furnace for dehydration and kept at the same temperature for 2 h to promote
crystallization. Finally, the thin films were cooled down to room temperature and used for further characterization studies.

The anodization reaction rate was controlled by the applied voltage. When the experiment was carried out at NaOH concentration < 0.5 M, gas bubbles were formed at both working (anode) and counter electrode (cathode) surfaces instead of film formation. This is mainly due to the formation of Cu(OH)$_2$ in the solution rather than the formation of Cu(OH)$_2$ on the Cu surface (which subsequently form CuO). The observed blue color formation in the solution supports this contention.

5.3. Results and Discussion

5.3.1. XRD analysis

![XRD patterns of the thin films prepared using 0.5 M aqueous NaOH electrolyte solution at the applied potentials of 0.25 and 0.50 V. Anodization time = 1 h.](image)

**Fig. 5.1.** XRD patterns of the thin films prepared using 0.5 M aqueous NaOH electrolyte solution at the applied potentials of 0.25 and 0.50 V. Anodization time = 1 h.
The XRD patterns of the thin films prepared in 0.5 M aqueous NaOH electrolyte solution at the applied potentials of 0.25 and 0.50 V are shown in Fig. 5.1. The thin film formed at an applied potential of 0.25 V has exhibited diffraction peak at 2θ value of 36.5° which can be attributed to the (1 1 1) diffraction plane of cubic phase of Cu₂O. When the applied potential is increased to 0.5 V, the diffraction peak corresponding to Cu₂O disappeared and the peaks corresponding to (−1 1 1) and (1 1 1) planes of monoclinic CuO appeared at 2θ values of 35.5 and 38.7°, respectively. These results reveal that the oxidation of Cu substrate is more at the applied potential of 0.5 V. However, further increase in the applied potential to 0.75 V restricts the film formation. The film thickness has reduced from 5 µm to 2 µm while the applied potential is increased from 0.25 V to 0.75 V.

![XRD Patterns](image)

**Fig. 5.2.** XRD patterns of the thin films prepared using 1.0 M aqueous NaOH electrolyte solution at different applied potentials. Anodization time = 1 h.
Fig. 5.2 shows the XRD patterns of thin films prepared in 1.0 M aqueous NaOH electrolyte solution at the applied potentials of 0.25, 0.50 and 1.0 V. The thin films formed at the different applied potentials composed of both Cu$_2$O and CuO. The presence of cubic phase of Cu$_2$O is confirmed by the presence of diffraction peaks at 20 values of 36.5 and 61.5° referred to the (1 1 1) and (2 2 0) diffraction planes of Cu$_2$O (JCPDS card no. 77-0199). The presence of monoclinic CuO is confirmed by the peak at 35.4°. The thickness of the films have decreased from ~5 µm to ~3 µm when the applied potential is increased from 0.25 to 1.0 V.

Fig. 5.3. XRD patterns of thin films prepared using 1.5 M aqueous NaOH electrolyte solution at different applied potentials.

The XRD patterns of thin films prepared in 1.5 M aqueous NaOH electrolyte solution at applied potentials of 0.25, 0.50 and 1.0 V are presented in Fig. 5.3. The thin film formed at an applied potential of 0.25 V has showed a peak at 36.5°
indicating the predominant presence of Cu$_2$O in this sample. When the applied potential is increased to 0.5 V, additional diffraction peak belonging to CuO has appeared at 32.4° corresponding to the (1 1 0) diffraction plane of CuO. The diffraction peaks appeared at 20 values of 43.3 and 50.4° are due to the (1 1 1) and (2 0 0) planes of the face-centred cubic structured Cu (JCPDS card no. 04–0836) (Jana et al., 2010 and Figueiredo et al., 2009). These can be attributed to the diffraction line produced by the underneath copper (Cu) substrate. At an applied potential of 1.0 V also the thin films richly contained Cu$_2$O. The above results revealed that an effective anodization has taken place at the applied potential of 0.5 V. The relatively intense diffraction peaks of Cu observed in the XRD patterns suggest that both very low and very high applied potentials (0.25 and 1.0 V) have significantly obstructed the oxidation of the Cu substrate during anodization reactions. The thicknesses of the film ranged between ~13 and 15 µm. The thin films exhibited no characteristic peaks indexed to Cu(OH)$_2$ which suggests that the Cu substrates are completely covered with polycrystalline thin films of Cu$_2$O and CuO.

![XRD patterns of thin films prepared in 1 M aqueous NaOH electrolyte solution with applied potential of 0.5 and 1 V at 50 °C.](image)

**Fig. 5.4.** XRD patterns of thin films prepared in 1 M aqueous NaOH electrolyte solution with applied potential of 0.5 and 1 V at 50 °C.
Fig. 5.4 shows the XRD patterns of thin films prepared in 1 M aqueous NaOH electrolyte solution at the applied potential of 0.50 and 1 V and at a reaction temperature of 50 °C. The thin film formed at an applied potential of 0.5 V has exhibited diffraction peak of monoclinic copper oxide (CuO) at 20 value of 35.5° originating from (−1 1 1) diffraction plane (JCPDS card no. 89-5895). When the applied potential is increased to 1 V, the intensity of the diffraction peak has also increased correspondingly, which indicated the predominant formation of CuO phase at 50 °C. No other peaks corresponding to Cu(OH)$_2$ or Cu$_2$O are appeared. The thickness of the film formed at a applied potential of 0.5 V is 4.1 µm, which increased to 5.9 µm upon increasing the applied potential to 1 V.

5.3.2. SEM analysis

The SEM images of CuO thin films, prepared through anodization of Cu substrate, using different concentrations of aqueous NaOH electrolyte solution at different applied potentials were recorded and are shown in Figs. 5.5 and 5.6. From the SEM images it is that the change in the concentration of NaOH solution and applied potential have played crucial role in the formation of resultant CuO nanostructures. The CuO thin film obtained in the presence of 0.5 M aqueous NaOH electrolyte solution at an applied potential of 0.5 V has showed one dimensional (1D) nanorod-like morphology whose length ranges between 1.0 and 1.5 µm with a thickness of about 80 nm (Fig. 5.5a and b). The CuO nanorods are randomly oriented, uniform in size and densely distributed over the whole region of the Cu substrate without any voids. These 1D CuO nanorods are highly
advantageous as they are known to facilitate high surface area for absorbing significant proportion of heat energy from the solar radiation when compared to zero dimensional (0D) spherical nanoparticles and transfer the same in unidirectional motion. When the concentration of sodium hydroxide is increased to 1 M by keeping the applied potential at 0.5 V, the resultant CuO thin film has exhibited two dimensional (2D) CuO nanoflakes structure, resembling feather-like morphology with an average size of ~500 nm as shown in its SEM images (Fig. 5.5c and d). The CuO nanoflakes are similar in size and have covered the entire Cu substrate. These 2D CuO nanoflakes are greatly desirable as they also favor the unidirectional motion of the absorbed heat energy similar to that of 1D CuO nanorods. The SEM images of the CuO thin films formed by using 1.0 M aqueous NaOH electrolyte solution and an applied potential of 1.0 V have showed vertically oriented 1D CuO nanorods with size ranging between 0.75 and 1.0 µm (Fig. 5.6a and b). However, the CuO nanorods are observed as separate bunches in the SEM image with large proportion of voids between each bunch. This indicates that the increase in the concentration of NaOH electrolyte solution and the applied potential have caused the decreased in the size of the CuO nanorods as well as their distribution on the Cu substrate. Fig.5.6c and d show the SEM images of CuO thin films obtained through the anodization of Cu substrate at 0.5 V applied potential in 1.5 M aqueous NaOH electrolyte solution. It is observed from the SEM images that irregular and compactly adjoined CuO nanoparticles with diameter ranging between 100 and 200 nm are distributed entirely on the Cu substrate.
Fig. 5.5. SEM images of CuO/Cu$_2$O nanostructures prepared in aqueous NaOH electrolyte solutions of 0.5 M (a, b) and 1.0 M (c, d) at 0.5 V anodization potential.
Fig. 5.6. SEM images of CuO/Cu$_2$O nanostructures prepared in aqueous NaOH electrolye solutions of 1.0 M (1.0 V) (a, b) and 1.5 M (0.5 V) (c, d).
Fig. 5.7. SEM images of CuO nanostructures prepared using aqueous NaOH electrolyte solutions at reaction temperature 50 °C (a) 1.0 M (0.5 V); (b) 1.0 M (0.5 V) 1h; (c)1.0 M (1 V) 1 h and (d) EDS spectrum of 1.0 M (1 V) 1 h

In order to elucidate the effect of reaction temperature on the formation of CuO thin films, the anodization experiments were carried out at 50 °C. The thin film formed in 1 M NaOH at a reaction temperature of 50 °C and at an applied potential of 0.5 V for 30 min has exhibited the presence of 2D nanoflakes (Fig.5.7a). On the other hand, the thin films
prepared by using the same experimental parameters but with a reaction time of 1 h has showed spherical CuO nanoparticles of size raging from 50–100 nm (Fig. 5.7b). This impiles that apart from the reaction temperature, reaction time also has pronounced influence on the resultant CuO nanostructures. The thin film formed in 1 M NaOH at a reaction temperature of 50 °C and at an applied potential of 1 V for 1 h indicated the formation of sparsely distributed palm-tree-leaf like CuO morphology with size range of 200-500 nm (Fig. 5.7c). These results reveal that the reaction temperature has significant influence on the resultant CuO nanostructures.

5.3.3. EDS studies

The energy dispersive spectra (EDS) of the thin films prepared in the presence of different concentrations of aqueous NaOH electrolyte solution and at different applied potentials were simultaneously recorded during SEM analysis in order to elucidate the proportion of elements present in the thin films (Fig. 5.8). The EDS results indicate that the peaks corresponding to Cu and O elements only are present in the spectra, which confirms that the poly-crystalline CuO thin films prepared through the anodization technique are free from impurities. The atomic weight proportion between Cu and O for the films prepared at an applied potential of 0.5 V in 0.5 M, 1 M and 1.5 M NaOH electrolytes are found to be 3:2, 4:3 and 5:3 respectively, which reveals that the thin films are formed with both CuO and Cu₂O which is also supported by the corresponding XRD results. The EDS analysis of the thin films prepared at reaction temperature of 50 °C has clearly disclosed the presence of Cu and O elements only (Fig. 5.7d). Hence, it is confirmed that the thin films formed through the anodization technique are made up of both CuO and Cu₂O.
Fig. 5.8. EDX spectra of CuO thin films prepared using aqueous NaOH electrolyte solution at various concentrations (a) 0.5 M, 0.5 V; (b) 1.0 M, 0.5 V; (c) 1.0 M, 1.0 V and (d) 1.5 M, 0.5 V.

5.3.4. Optical properties

The UV–vis and IR reflectance spectra of CuO thin films prepared on Cu substrate through anodization technique in different concentrations of aqueous NaOH electrolyte solution and at various applied potentials are presented in Fig. 5.9a-c and 5.10a-c. It is obvious from the reflectance spectra that the CuO thin films possess high absorption (very low reflectance) in the visible light region together with high reflectance in the IR region of the solar spectrum. The high IR reflectance profile of these CuO thin films can be ascribed to the scattering effect of light through the
optically anisotropic monoclinic structure. These properties disclose the high selective nature of the CuO thin films. The absorptivity and emissivity values were calculated from the respective reflectance spectrum of the CuO thin film samples and are given in Table 1. One of the main reasons for this significantly high selectivity is the decrease in the emissivity as a consequence of increase in the thickness of CuO thin films obtained through anodization technique without affecting their optical properties. The measured thickness of the CuO thin films ranged from 2.3 to 15.6 µm. The emissivity values changed from 0.04 to 0.06 upon varying the applied voltage and concentration of aqueous NaOH electrolyte solution. The thickness is directly proportional to the applied voltage during anodization process. Another crucial parameter that governs the selectivity is the surface morphology of the CuO thin films. The results of the study indicate that high performance solar selective CuO thin film absorbers can be prepared through this facile and cost effective anodization technique by varying the applied voltage and concentration of aqueous NaOH electrolyte solution. The CuO thin films formed at 50 °C have not exhibited any significant change in the optical properties. Though pure CuO phase could be obtained through anodization at this temperature, the resultant quality of CuO nanostructures laps behind the thin films prepared at room temperature in terms of solar thermal applications (Table 5.2). The photo-thermal conversion efficiencies of these thin films ranged from 66 to 77 %. The implies that, resonably good thickness CuO thin films with nanostructured morphology prepared by anodization technique is capable of absorbing more solar radiation by virtue of their multiple absorption and reflection properties.
**Fig. 5.9a.** UV-vis NIR spectra of thin films prepared in 0.5 M aqueous NaOH electrolyte solution at room temperature. Anodization time =1 h.

**Fig. 5.9b.** UV-vis NIR spectra of thin films prepared 1 M aqueous NaOH electrolyte solution at room temperature. Anodization time =1 h.
Fig. 5.9c. UV-vis NIR spectra of thin films prepared of 1.5 M aqueous NaOH electrolyte solution at room temperature. Anodization time =1h.

Fig. 5.10a. IR spectra of thin films prepared 0.5 M aqueous NaOH electrolyte solution at room temperature.
Fig. 5.10b. IR spectra of thin films prepared by anodization 1.0 M aqueous NaOH electrolyte solution at room temperature.

Fig. 5.10c. IR spectra of thin films prepared by anodization 1.5 M aqueous NaOH electrolyte solution at room temperature.
Table 5.1 Optical properties of CuO nanostructures prepared in different molar concentration of NaOH at various applied potentials.

<table>
<thead>
<tr>
<th>NaOH molar concentration (M)</th>
<th>Applied voltage (V)</th>
<th>Thickness (µm)</th>
<th>Absorptance (α)</th>
<th>Emittance (ε)</th>
<th>Selectivity (ξ)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.25</td>
<td>4.4</td>
<td>0.75</td>
<td>0.05</td>
<td>15.0</td>
<td>70.0</td>
</tr>
<tr>
<td>0.5</td>
<td>0.50</td>
<td>2.6</td>
<td>0.70</td>
<td>0.05</td>
<td>14.0</td>
<td>65.0</td>
</tr>
<tr>
<td>0.5</td>
<td>0.75</td>
<td>2.2</td>
<td>0.63</td>
<td>0.04</td>
<td>15.7</td>
<td>59.0</td>
</tr>
<tr>
<td>1.0</td>
<td>0.25</td>
<td>4.2</td>
<td>0.68</td>
<td>0.04</td>
<td>17.0</td>
<td>64.0</td>
</tr>
<tr>
<td>1.0</td>
<td>0.50</td>
<td>3.7</td>
<td>0.76</td>
<td>0.04</td>
<td>19.0</td>
<td>72.0</td>
</tr>
<tr>
<td>1.0</td>
<td>0.75</td>
<td>3.4</td>
<td>0.70</td>
<td>0.05</td>
<td>14.0</td>
<td>65.0</td>
</tr>
<tr>
<td>1.5</td>
<td>1.0</td>
<td>3.7</td>
<td>0.73</td>
<td>0.03</td>
<td>14.6</td>
<td>70.0</td>
</tr>
<tr>
<td>1.5</td>
<td>0.25</td>
<td>3.4</td>
<td>0.77</td>
<td>0.04</td>
<td>19.2</td>
<td>73.0</td>
</tr>
<tr>
<td>1.5</td>
<td>0.50</td>
<td>15.5</td>
<td>0.73</td>
<td>0.03</td>
<td>14.6</td>
<td>70.0</td>
</tr>
<tr>
<td>1.5</td>
<td>0.75</td>
<td>14.6</td>
<td>0.75</td>
<td>0.05</td>
<td>15.0</td>
<td>70.0</td>
</tr>
</tbody>
</table>

Table 5.2 Optical properties of CuO nanostructures prepared at different alkaline conditions at 50 °C.

<table>
<thead>
<tr>
<th>NaOH molar concentration (M)</th>
<th>Applied voltage (V)</th>
<th>Reaction time (h)</th>
<th>Absorptance (α)</th>
<th>Emittance (ε)</th>
<th>Selectivity (ξ)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.5</td>
<td>0.5</td>
<td>0.71</td>
<td>0.05</td>
<td>14.2</td>
<td>66.0</td>
</tr>
<tr>
<td>1.0</td>
<td>0.5</td>
<td>1</td>
<td>0.68</td>
<td>0.05</td>
<td>13.6</td>
<td>63.0</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0</td>
<td>0.5</td>
<td>0.74</td>
<td>0.04</td>
<td>18.5</td>
<td>74.2</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0</td>
<td>1</td>
<td>0.76</td>
<td>0.03</td>
<td>15.2</td>
<td>73.0</td>
</tr>
</tbody>
</table>

5.3.5. Raman studies

The Raman spectra obtained for the CuO samples prepared through anodization in 0.5 M NaOH and 1 M NaOH with the applied potential of 0.5 V are shown in the Fig. 5.11. The Raman analysis confirmed the presence of three known bands of CuO at 297, 345 and 631 cm\(^{-1}\) which corresponds to the A\(_g\) (296 cm\(^{-1}\)), B\(_g\) (346 cm\(^{-1}\)) and B\(_{2g}\) (631 cm\(^{-1}\)) bands which are in good agreement with the earlier reports (Dar et al., 2009). No Cu\(_2\)O modes were found to be present in the CuO
nanostructures prepared at applied potential of 0.5 V. Though the XRD results revealed the presence of mixture of CuO and Cu$_2$O phases in these films, the Raman spectra did not exhibit the Cu$_2$O modes (Reimann and Syassen, 1989). This may be due to the presence of low proportion of Cu$_2$O compared to CuO in these films. Thus, the Cu$_2$O modes may be in very low intensity which could not be detected. Significant peak intensity of CuO modes indicates high crystalline nature of the deposited film.

Fig. 5.11. Raman spectra of thin films prepared by anodization in the presence of 1.5 M aqueous NaOH electrolyte solution.

5.3.6. Mechanism of CuO nanostructures formation

The possible mechanism of the formation of CuO nanostructures can be given based on the previous reports (Wen et al., 2002 and Zhang et al., 2003). When an electric potential is applied to Cu foil in the presence of NaOH electrolyte solution, its surface undergoes an oxidation process as below:

$$\text{Cu}_{(s)} \rightarrow \text{Cu}^{2+}_{(aq)} + 2 \text{e}^- \quad \text{-------} \quad (5.1)$$

$$\text{Cu}^{2+}_{(aq)} + 2 \text{OH}^-_{(aq)} \rightarrow \text{CuO}_{(s)} + \text{H}_2\text{O} \quad \text{-------} \quad (5.2)$$
The reaction was accompanied by the evolution of gas bubbles from the counter electrode surface, supporting the occurrence of a reduction reaction.

\[ 2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2(g) \quad \text{------ (5.3)} \]

Initially, Cu\textsuperscript{2+} is formed in the surface of the anode due to the anodization of Cu foil. Consequently, H\textsubscript{2} gas is released in the cathode surface, which supports the reduction reaction. Then, the Cu\textsuperscript{2+} is combined with OH\textsuperscript{-} to form Cu(OH)\textsubscript{2}. In fact, the Cu(OH)\textsubscript{2} first formed is not stable and tend to break down to CuO and H\textsubscript{2}O. Finally, the obtained CuO nanocrystals are self-assembled among them to form the CuO nanostructures (Xu et al., 2012 and La et al., 2010). At the initial stage, CuO nanoparticles are formed due to the dehydration of Cu(OH)\textsubscript{2}. Subsequently, the CuO nanoparticles which are serving as building blocks self-assemble along the identical direction. With the oriented attachment processes spontaneously continuing, some lateral attachments of CuO nanoparticles along some side defects appear which are accompanied with a slow growth along the width direction. Actually, the growth rate via the oriented attachment along the length and width direction is much different and hence the needle-like CuO nanostructures are formed finally. Therefore, the formation of the CuO mesocrystal is kinetically controlled. However, the driving force for such oriented attachment of CuO nanoparticles remains a myth. Several factors, including electrical and dipolar fields, vander waals forces and hydrogen bonds may have interlocking effects on the self-assembly.
5.4. Conclusions

Nanostructured CuO thin films composed of nanorods, nanoflakes and nanoparticles were synthesized through the anodization of copper (Cu) substrate using different concentrations of sodium hydroxide electrolyte solution at different applied potentials. The XRD study revealed that the thin films are made up of both CuO and Cu\(_2\)O and their relative proportion changes as a consequence of varying the concentration of NaOH solution and the applied potential. While the anodization at room temperature yields the films with CuO and Cu\(_2\)O, the anodization at 50 °C gives pure CuO film in 1 M aqueous NaOH electrolyte solution. The SEM images indicated that different nanostructured CuO thin films, such as nanorods, nanoflakes and nanoparticles are formed through the anodization technique. The thin film samples have low thermal emittance (4 to 5.5%) and high solar absorptance (63.5–77.3%) with significantly high solar selectivity (>10) which suggest that the anodization technique is an effective tool for the preparation of low-cost selective absorbers for solar thermal applications.
References


