Ultrasonic effect on optical, structural, topographical and morphological studies of Cu2CdSnS4 quaternary alloy nanostructures

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Abstract

Cu2CdSnS4 quaternary alloy nanostructures are useful for photovoltaic applications were successfully synthesized on p-type silicon substrate using the spin coating technique at different annealing temperatures up to 500 °C. The optical properties were investigated through UV–vis and photoluminescence (PL) spectrophotometers, these nanostructures have a direct energy band gap of 1.29–1.31 eV. The refractive index and optical dielectric constant are investigated. The structural properties were explored by using X-ray diffraction (XRD). Morphological and topographical studies were carried out by scanning electron microscopy (SEM) and atomic force microscopy (AFM) techniques. The particle size and shape have a proportional relationship with annealing temperature under ultrasonic effect. The obtained results are in accordance with available theoretical and experimental data.

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1. Introduction

I2–II–IV–VI4 (I = Cu, Ag; II = Zn, Cd; I = Si, Ge, Sn; VI = S, Se) quaternary alloys have drawn intense interest for their suitable energy band gaps (Eg); 1.1–1.5 eV, high optical absorption coefficient; 104–105 cm−1 and high abundant elements for potential application in photovoltaics. There is a need to expand the range of materials that can be incorporated into effective-cost solar cells. Hence, expensive and scarce elements such as indium and gallium are replaced by other materials such as zinc and tin to have photovoltaic characteristics such as Voc, Jsc and FF [8]. As well, CuInS2 microspheres were synthesized by Ultrasonic method in propylene glycol as solvent and copper oxide, indium chloride and thioacetamide as precursors. The optical band gap of the CuInS2 microsphere was estimated to be 2.28 eV [9]. CuInS2 nanocrystals were synthesized by a new precursor complex, [bis(2-hydroxyacetophenato)copper(II)], [Cu(HAP)2], via a microwave method, the nanoparticles of CuInS2 were used to prepare CuInS2 film by doctor’s blade technique [10]. CdS quantum dots, gold nanoparticles (GNPs) and gold nanorods (GNRs) are incorporated into the active layer for enhancing light absorption in comparison with single nanoparticles, which led to dye synthesized solar cells with a power conversion efficiency accounting for a 147% enhancement [11].

Another quaternary alloy that drawn increasing interest in the past few years is Cu2ZnSnS4 where synthesized with high quality of morphology, phase purity and the energy band gap was around 1.44–1.48 eV [12]. A few works on Cu2CdSnS4 (CCTS) quaternary alloys have been reported, many kinds of methods have been used to synthesize Cu2CdSnS4 quaternary alloy, through solvothermal approach under controlled temperatures [13], a combination of successive ionic
layer absorption, reaction method and the chemical bath deposition method [14], microwave irradiation method [15], facile synthesis [16], simple solvothermal method [17], spray pyrolysis deposition [18] and co-sputtering deposition [19]. Recently, the electronic and optical properties of Cu2ZnSiS4 and Cu2ZnSiSe4 in wurtzite-kesterite and wurtzite-stannite structures are studied using first-principles calculations by Zhang et al. [20]. They have discussed and presented optical transitions at high symmetry points between valence bands, conduction bands and band structures to analyze different properties. In addition, they have obtained optical constants and dielectric function spectra as well. While, Wang and Lou [21] have developed analytical absorption model for 0.53 eV GaInAsSb alloy for both p–n and n–p configurations. It is observed spectrum-insensitive optimal doping, \( N_e(a) = 3 \times 10^{17} \text{cm}^{-3} \) in diode light-doped layer for all concerned configurations. By improving the doping in the light-doped layer, thickness compensation between emitter and base has been noticed for normal structures and, for each considered structure can be employed by consuming less material to achieve comparable output as that for optimal one. Comparing to GaSb diode, 2–3 fold efficiency enhancement can be expected for low-temperature spectrum illumination, making the concerned device an efficient candidate for low-temperature applications. Moreover, Adegoke et al. [22] have fabricated highly luminescent and photo stable alloyed quaternary CdSeTeS core QDs of two different sizes via the organometallic hot-injection synthetic route. Characterization of the nanocrystals were performed using TEM, XRD, UV/vis and fluorescence spectrophotometric techniques. They have demonstrated alloyed quaternary CdSeTeS core QDs possess unique optical properties that are advantageous over conventional core/shell systems.

Herein, Cu2CdSnS4 quaternary alloy nanostructures deposited via spin coating technique on p-type silicon substrate under a wide range of annealing temperature from room temperature to 500 \(^\circ\)C. Meanwhile, optical, structural, morphological and topographical properties were investigated in details. This paper is organized as follows; Section 2 details the experimental procedure whereas, Section 3 details the results and discussions. Finally, conclusion is summarized in Section 4.

2. Experimental

All the chemicals and solvents that used were analytically graded and obtained from Sigma-Aldrich Company, the solution of Cu2CdSnS4 quaternary precursors was prepared from copper chloride (CuCl2) (0.8 mol/L), cadmium chloride (CdCl2) (0.8 mol/L), tin chloride (SnCl2) (0.8 mol/L), thiourea (CH4N2S) (0.8 mol/L), 2-methoxyethanol (2-metho) and monoethanolamine (MEA). The solvent and stabilizer were the 2-metho and MEA, respectively.

\[
\text{Molarity}(M) = \frac{M_s}{V}.
\]

\[
M_s = \frac{W(\text{grams})}{M_{\text{rel}}(\text{moles})}.
\]

where \( M_s \) is number of moles, \( V \) is liquid volume, \( W \) is weight (gm) and \( M_{\text{rel}} \) is molecular weight (gm/mol).

After preparing the precursors individually, they were mixed together in a beaker at a molar ratio of 2:1:1:4, in order to be consistent with the stoichiometric composition of Cu2CdSnS4. The mixing process was done using a magnetic stirrer (WiseStir MSH 30D, Germany) for 3 h with a stirring speed of 1500 revolution per minute (RPM) at a temperature of 50 \(^\circ\)C to completely dissolve the metals during stirring. Excess thiourea was necessary to compensate for sulfur loss during deposition, the milk solution became yellow and transparent. The resulting solution has been divided into two parts equally, one part is used as is in the deposition process and the other part has been covered with laboratory film and placed inside ultrasonic cleaner (DELTA DC200H, Taiwan) that filled with deionized water at 50 \(^\circ\)C for 30 min. As a result, two solutions are ready for using, one with ultrasonic and the other is without ultrasonic. Precisely and concisely, the specifications of the silicon wafer used in this work are as follows: p-type, one side polished, 525 \(\mu\)m thickness, 100 orientation and 100 mm diameter. Silicon wafer is being cleaved into pieces with size of 2 cm \times 2 cm. Thus, every piece is considered to be an independent substrate. These substrates have been cleaned by using a standard that explained by Ref. [23] for cleaning silicon wafers which need to be performed before high-temperature processing steps such as oxidation and annealing of silicon wafers.

A few drops of the resulted solutions — with and without ultrasonic — was dropped by using plastic dropper onto the silicon substrate. A spin coater (Laurell WS-400B, USA) has been used at a
rotation speed of 500 rpm for 30 s for depositing the solution on the substrate in a more homogenous way. After the deposition process is ended, the substrate was dried at 80 °C for 1 min on a hot plate. The spin coating and drying processes were repeated 15 times for all substrates to obtain a uniform nanostructures layer with a proper thickness. As a result, ten samples have been prepared, five are with ultrasonic solution and other five are without ultrasonic solution.

Annealing was applied to eight samples out of ten by using a diffusion furnace (MODU-LAB, USA) designed to heat substrates up to 1300 °C in a contained, controlled atmosphere. Both types, with and without ultrasonic have been annealed at four different temperatures 200, 300, 400 and 500 °C and without ultrasonic at room Temp., 200, 300, 400 and 500 °C.

Nitrogen gas N₂ to keep the deposited nanostructures coherent, and then, the samples were cooled to room temperature. The optical properties have been tested by UV–vis spectrometer (Perkin Elmer Lambda 35, USA). The reflection spectra of the Cu₂CdSnS₄ quaternary alloy nanostructures were recorded over the wavelength range 200–1000 nm. In addition, energy band gap has been tested by using photoluminescence (PL) (Flourolog-3, USA), the wavelength range between 200 nm and 1100 nm is selected.

The structural properties of Cu₂CdSnS₄ quaternary alloy nanostructures have been investigated by using X-ray diffractometer (Philips PW 1710, USA), which record the intensity as a function of Bragg’s angle in 2θ range from 10°–60° degree at a rate of 5°/min using Cu kα (λ = 1.5406 Å). The major diffraction peaks have been
recorded and attributed to the corresponding planes. The surface morphology was investigated using Scanning Electron Microscopy (SEM JSM-6010LV, USA). The topography of the quaternary alloy was characterized by Atomic Force Microscopy (AFM) (SPA 400, Seiko Instruments Inc., Japan) with scanning area of 5000 nm and a scanning rate of 1 Hz.

3. Results and discussion

3.1. Optical properties

Reflection measurements are performed at room temperature using UV–vis spectroscopy in the range of 200–1000 nm to investigate the reflection spectra at different annealing temperatures: room temperature, 200, 300, 400 and 500 °C. It is observed that the effective wavelength ranges are found between 820 and 960 nm as shown in Fig. 1. The lowest reflectance for with ultrasonic samples at 500 °C is 25%, while the highest reflectance at 300 °C is 63%. Other side, lowest reflectance for without ultrasonic samples at 400 °C is 57%, while the highest reflectance at 500 °C is 70%.

Two main observations can be extracted from Fig. 1; first, the reflection levels for with ultrasonic samples are lower than that without ultrasonic samples. Secondly, the ultrasonic affect in a clear
way on reflection spectra at different temperatures therefore, the reflection levels at 400 and 500 °C are away from the others, which mean that there is a clear distinction between different reflections spectra unlike without ultrasonic samples.

According to Tauc formula for direct band gap semiconductors, the energy band gap of Cu$_2$CdSnS$_4$ quaternary alloy nanostructures can be estimated using the following formula:

$$(a\nu)^2 = A(h\nu - E_g)$$

where $a$ is the absorption coefficient, $A$ is a constant, $E_g$ is the energy band gap, $\nu$ is incident photon frequency and $h$ is the Planck's constant. To measure the energy band gap from absorption spectra $(a\nu)^2$ versus $h\nu$ for Cu$_2$CdSnS$_4$ quaternary alloy at different annealing temperatures by extrapolating the straight line portion of the curve to zero absorption coefficients as shown in Fig. 2. For with ultrasonic effect in Fig. 2, the $E_g$ at room temperature is 1.29 eV, it is dropped to 1.28 eV with increasing the annealing temperature to 200 °C and to 1.275 eV for 300 °C. Suddenly, it is increased to 1.33 eV at 400 °C, but it is dropped again slightly to 1.31 eV at 500 °C. Whereas, a closer look at without ultrasonic effect revealed that $E_g$ starts with 1.285 eV and dropped to 1.26 eV with increasing the annealing temperature to 200 °C, followed by slight increase to 1.265 eV at 300 °C, then increased to 1.27 eV with increasing the annealing temperature to 400 °C. It is dropped again to 1.26 eV at 500 °C. It is noticed that the variations between different levels of energy band gap for without ultrasonic samples are almost half that with ultrasonic samples. These variations are due to ultrasonic effect that leads to reduce electron velocity as shown in Fig. 3. The PL spectra of Cu$_2$CdSnS$_4$ quaternary alloy nanostructure are shown in Fig. 4. For with ultrasonic, the $E_g$ at room temperature is 1.59 eV, dropped to 1.57 eV with increasing the annealing temperature to 200 °C and another drop to 1.56 eV at 300 °C. It is continued to drop to 1.55 eV at 400 °C. Lastly, it is reached 1.54 eV at 500 °C. Whereas, for without ultrasonic, the $E_g$ starts also with 1.59 eV and dropped to 1.57 eV and 1.54 eV, with increasing the annealing temperature to 200 °C and 300 °C, respectively. It is then dropped to 1.52 eV at 400 °C, but increased to 1.53 eV with increasing the annealing temperature to 500 °C.

In brief, the deduced band gaps in this study are in good agreement with the reported Cu$_2$CdSnS$_4$ band gap values [13–19]. The band gaps are quite close to the optimum band gap, which indicate that Cu$_2$CdSnS$_4$ quaternary alloy nanostructures are promising materials for optoelectronic applications. The measured energy band gaps of Cu$_2$CdSnS$_4$ quaternary alloy nanostructures for UV−vis and PL spectrosocopies are given in Table 1. It is notably that there is a clear difference between the energy band gaps that deduced from UV−vis and PL. This is due to the difference between the used instruments in both cases and ambient circumstances for both of them.
The band structural and quantum-dielectric formulations of Penn Herve and Vandamme [26] have proposed an empirical relation as:

\[ n = \sqrt{1 + \left( \frac{A}{E_g + B} \right)^2} \]  

where \( A = 13.6 \) eV and \( B = 3.4 \) eV.

Ghosh et al. [27] had taken a different approach by considering the band structural and quantum-dielectric formulations of Penn [33] and Van Vechten [34]. Introducing, \( A \) (contribution from the valence electrons) and \( B \) (constant additive to the lowest band gap \( E_g \)), the expression was written as:

\[ n^2 - 1 = A \sqrt{E_g + B} \]  

where \( A = 25E_g + 212 \), \( B = 0.21E_g + 4.25 \) and \( (E_g + B) \) refers to an appropriate average energy gap of the material. Thus, these three models for variation of \( n \) with energy gap have been tried. In [35], the calculated values of the optical dielectric constant \( (\epsilon_{\infty}) \) were obtained using the relation \( \epsilon_{\infty} = n^2 \).

### 3.2. Structural properties

The Cu₂CdSnS₄ (CCTS) quaternary alloy nanostructures have been investigated by XRD as shown in Fig. 5. XRD patterns have provided information about the crystalline structure of nanoparticles as well as the crystallite size. By studying with ultrasonic patterns (Fig. 5a), the CCTS nanostructures deposited at room...
temperature have ten major diffraction peaks appeared at $2\theta = 13.5808^\circ$, $15.8464^\circ$, $23.7231^\circ$, $28.2515^\circ$, $29.7159^\circ$, $29.9193^\circ$, $39.8234^\circ$, $43.5977^\circ$, $47.9415^\circ$ and $48.9084^\circ$ were attributed to (002), (101), (110), (100), (112), (202), (114), (204) and (222), respectively. While, the CCTS nanostructures deposited at 200 $^\circ$C have ten major diffraction peaks appeared at $2\theta = 16.3054^\circ$, 29.8463$^\circ$, 31.4023$^\circ$, 33.8285$^\circ$, 36.4505$^\circ$, 39.8351$^\circ$, 43.6715$^\circ$, 47.9921$^\circ$, 48.9813$^\circ$ and 57.8588$^\circ$ were attributed to (002), (112), (021), (101), (004), (202), (116) and (222) and (116) planes, respectively. Whereas, the CCTS nanostructures deposited at 300 $^\circ$C have seven major diffraction peaks appeared at $2\theta = 20.2058^\circ$, $29.7189^\circ$, $39.8248^\circ$, $43.7231^\circ$, $49.0561^\circ$ and $57.9906^\circ$ were attributed to (101), (110), (202), (114), (204), (222) and (224) planes, respectively. All the mentioned peaks are exactly matched with the tetragonal stannite structure of Cu$_2$CdSnS$_4$ that corresponding to the standard (ICDD PDF2008, 00-029-0537).

It is noticed that the highest peak at (112) plane for both types except the first peak at 500 $^\circ$C for with ultrasonic. In addition, it is observed the existence of peaks is more with ultrasonic than that without ultrasonic due to difference in electron velocity. The lattice constants a and c were calculated from XRD patterns of the (112) plane, using the given equations according to the tetragonal crystal system. Table 2 displays the values of a and c along with other structural properties at different annealing temperatures, with and without ultrasonic. The inter-planer distance (d) was calculated using Bragg’s law [36];

![Fig. 5. XRD patterns of Cu$_2$CdSnS$_4$ Quaternary alloy nanostructures deposited on p-Si at different annealing temperatures a with ultrasonic, b without ultrasonic.](image)

### Table 2

The structural parameters of Cu$_2$CdSnS$_4$ quaternary alloy nanostructures using XRD at different annealing temperatures.

<table>
<thead>
<tr>
<th>T (°C)</th>
<th>2θ</th>
<th>Particle size (D) (nm)</th>
<th>Full width at half maximum (FWHM)</th>
<th>Miller indices (hkl)</th>
<th>Interplaner distance (d) Å</th>
<th>Lattice constants (a and c) Å</th>
<th>Strain ($\varepsilon$)</th>
<th>Dislocation density ($\rho$) ($10^{14}$ lines/m²)</th>
<th>Number of crystallites particles/area (N) ($10^{15}$)</th>
<th>Thickness (t) (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>With ultrasonic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Room Temp.</td>
<td>29.71</td>
<td>43.7</td>
<td>0.1968</td>
<td>112</td>
<td>3.0065</td>
<td>a = 5.2, c = 10.41</td>
<td>0.047</td>
<td>5.23</td>
<td>1.607</td>
<td>136</td>
</tr>
<tr>
<td>200</td>
<td>29.84</td>
<td>43.9</td>
<td>0.196</td>
<td>112</td>
<td>2.99366</td>
<td>a = 5.18, c = 10.37</td>
<td>0.047</td>
<td>5.19</td>
<td>1.5</td>
<td>127</td>
</tr>
<tr>
<td>300</td>
<td>29.67</td>
<td>22</td>
<td>0.39</td>
<td>112</td>
<td>3.01068</td>
<td>a = 5.2, c = 10.43</td>
<td>0.094</td>
<td>20.6</td>
<td>3.015</td>
<td>34</td>
</tr>
<tr>
<td>400</td>
<td>29.86</td>
<td>109.12</td>
<td>0.0787</td>
<td>112</td>
<td>2.99197</td>
<td>a = 5.18, c = 10.36</td>
<td>0.019</td>
<td>0.83</td>
<td>0.00633</td>
<td>8.23</td>
</tr>
<tr>
<td>500</td>
<td>29.77</td>
<td>37.33</td>
<td>0.23</td>
<td>112</td>
<td>3.00037</td>
<td>a = 5.19, c = 10.39</td>
<td>0.055</td>
<td>7.17</td>
<td>0.392</td>
<td>20.4</td>
</tr>
<tr>
<td>Without ultrasonic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Room Temp.</td>
<td>29.59</td>
<td>29.8</td>
<td>0.288</td>
<td>112</td>
<td>3.0159</td>
<td>a = 5.22, c = 10.44</td>
<td>0.07</td>
<td>11.26</td>
<td>1.035</td>
<td>7.4</td>
</tr>
<tr>
<td>200</td>
<td>29.78</td>
<td>21.8</td>
<td>0.3936</td>
<td>112</td>
<td>2.99982</td>
<td>a = 5.19, c = 10.39</td>
<td>0.095</td>
<td>21.04</td>
<td>98</td>
<td>1015.7</td>
</tr>
<tr>
<td>300</td>
<td>29.89</td>
<td>6.23</td>
<td>0.13776</td>
<td>112</td>
<td>2.98829</td>
<td>a = 5.17, c = 10.35</td>
<td>0.033</td>
<td>2.57</td>
<td>1.42</td>
<td>344.6</td>
</tr>
<tr>
<td>400</td>
<td>29.55</td>
<td>18.1</td>
<td>0.47232</td>
<td>112</td>
<td>3.02232</td>
<td>a = 5.23, c = 10.46</td>
<td>0.114</td>
<td>30.52</td>
<td>11.28</td>
<td>66.9</td>
</tr>
<tr>
<td>500</td>
<td>29.93</td>
<td>43.6</td>
<td>0.1968</td>
<td>112</td>
<td>2.98465</td>
<td>a = 5.16, c = 10.34</td>
<td>0.047</td>
<td>5.26</td>
<td>0.52</td>
<td>42.7</td>
</tr>
</tbody>
</table>

a Ref. [22] Theo.

where \( \lambda \) is wavelength of XRD using \( \lambda = 1.5406 \) Å and \( \theta \) is the Bragg’s angle. Lattice constants \( a \) and \( c \) for tetragonal system were calculated from XRD patterns

\[
\frac{1}{d^2} = \frac{h^2 + k^2}{a^2} + \frac{l^2}{c^2}
\]  

(8)

where \( hkl \) is Miller indices, \( a \) and \( c \) are the lattice constants. By combining Eqs. (7) and (8), \( a \) and \( c \) can be calculated in terms of \( \sin \theta \).

\[
d = \frac{n \lambda}{2 \sin(\theta)}
\]  

(7)

\[
\sin^2 \theta = \frac{\lambda^2}{4a^2} (h^2 + k^2) + \frac{\lambda^2}{4c^2} (l^2)
\]  

(9)

The crystallite size \( D \) was calculated by Scherrer’s formula [37].

\[
D = \frac{k \lambda}{\beta \cos(\theta)}
\]  

(10)

where \( k \) is a constant, taken to be 0.94, and \( \beta \) is the full width at half maximum (FWHM) of the diffraction peak in radian. The dislocation density, strain and number of crystallites per unit area \( N \) for (112) plane as given in Table 2 are calculated by the following equations.

**Fig. 6.** 3D and 2D AFM images of Cu2CdSnS4 quaternary alloy nanostructures deposited on p-Si substrates with ultrasonic at a room Temp., b 200, c 300, d 400 and e 500 °C and without ultrasonic at f room Temp., g 200, h 300, i 400 and j 500 °C.
\[ \delta = \frac{1}{D^2} \]  
\[ \varepsilon = \frac{\beta \cos \theta}{4} \]  
\[ N = \frac{t}{D^3} \]

where \( t \) is the thickness as indicated in Table 2.

3.3. Topographical studies

To characterize the surface topography of Cu_{2}CdSn_{2} quaternary alloy nanostructures, Fig. 6 shows the AFM images at different annealing temperatures, room temperature, 200, 300, 400 and 500 °C with and without using ultrasonic. The 2-D and 3-D images show the topography of 5 \( \times \) 5 \( \mu \)m area with 1 Hz scan rate. The surface roughness is related to quaternary alloy diffusion, type of substrate, annealing temperatures and spin coating speed. As can be seen in Table 3, the roughness starts with 0.92 nm at room temperature for with ultrasonic samples and continued to increase with increasing the annealing temperature until 10.8 nm at 400 °C, the roughness drop to 3.91 nm at 500 °C. Whereas, the roughness starts with 0.695 nm at room temperature for without ultrasonic samples and continued to increase with increasing the annealing temperature up to 84.5 nm at 300 °C, then dropped to 1.86 nm at 400 °C but incremented again to 59 nm at 500 °C. From the previous results, Table 3 exhibits the relationship between annealing temperature and roughness as it increases with increasing the annealing temperature. Both samples, with ultrasonic at 400 °C and without ultrasonic at 300 °C have the highest roughness and also the second in reflection vs. wavelength as...
shown in Fig. 1, which means that they have a high absorption coefficient.

3.4. Morphological studies

The SEM images in Fig. 7 display the surface morphologies of Cu$_2$CdSnS$_4$ quaternary alloy nanostructures deposited at various
annealing temperatures with and without ultrasonic in the deposition process. A closer look at with ultrasonic images, the deposition at room temperature does not exhibit a robust structure, and it looks more blurring and scattered. Moreover, small cavities can be seen. However, with increasing the annealing temperatures, the morphologies are found to be improved and cohesive layer of grained structures can be observed. As the annealing temperature of 400 °C takes place, the surface morphology increases dramatically compared to that prepared at lower temperatures, this is in accordance with crystallite size estimated from XRD patterns in Table 2. While, for without ultrasonic images, the deposition at room temperature is also looks more scattered and blurring and it improves with increasing the annealing temperature but the maximum grain size is observed at 300 °C.

4. Conclusions

Cu2CdSnS4 quaternary alloy nanostructures were successfully synthesized and deposited on p-Si substrates via spin coating technique within a wide substrate temperature range from room temperature to 500 °C. XRD results reveal that using ultrasonic in synthesizing the solution lead to introducing more peaks and as a result, the crystallite size increases. UV—vis and PL measurements demonstrate that the optical band gaps are 1.29—1.31 eV and

<table>
<thead>
<tr>
<th>T (°C)</th>
<th>Roughness (with ultrasonic) (nm)</th>
<th>Roughness (without ultrasonic) (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room temp.</td>
<td>0.92</td>
<td>0.695</td>
</tr>
<tr>
<td>200</td>
<td>1.25</td>
<td>1.77</td>
</tr>
<tr>
<td>300</td>
<td>2.54</td>
<td>84.5</td>
</tr>
<tr>
<td>400</td>
<td>10.8</td>
<td>1.86</td>
</tr>
<tr>
<td>500</td>
<td>3.91</td>
<td>59</td>
</tr>
</tbody>
</table>

Fig. 7. SEM images of Cu2CdSnS4 quaternary alloy nanostructures deposited on p-Si substrates with ultrasonic at a room temp., b 200 °C, c 300 °C, d 400 °C and e 500 °C and without ultrasonic at f room Temp., g 200, h 300, i 400 and j 500 °C.
1.59–1.54 eV, respectively, which are quite close to the optimum band gap. The measured lattice constants are in accordance with available data in the literature. The morphological and topographical studies indicate that using annealing temperature will cause an increase in crystallite size thus, making a consistent thin layer. Ghosh et al. model is recommended model with ultrasonic effect at 400 °C. These results indicate that Cu2CdSnS4 quaternary alloy nanostructures are a potential absorbing layer for effective-cost application.

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References
