Curving of tellurium nanowires with gold in the presence of bovine serum albumin

Radha Perumal Ramasamy¹

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Abstract

Controlling the shapes of one dimensional nanostructures could advance electronics at nanoscale. In this article the curving of Tellurium Nanowires (Te NWs) with gold in the presence of bovine serum albumin (BSA) is studied. The reactivity of Te NWs with NaOH showed that Te NWs were etched along their ends. When HAuCl_4 was added, it was observed that gold nanoparticles formed on the Te NWs. Incorporation of BSA resulted in the formation of gold decorated curved nanowires at 50 mM NaOH. Also, the nanowires became curved. When the concentration of NaOH was increased to 250 mM the original shape of the Te NWs was preserved. XRD data indicated that gold and tellurium did not form any mixed phases. Photoluminescence and UV/Vis studies showed that the optical characteristics of gold decorated Te NWs is different from that of Te NWs. Photoluminescence and UV/Vis studies also showed that the optical characteristics of luminescent Au quantum clusters using BSA (BSA-Au NC) was modified in the presence of Te NWs. This research shows that nanowire could be curved using gold, protein and mild reducing agent (NaOH). This research could benefit fields such as nanoelectronics where controlling the shapes of the nanowires might of useful.

Keywords Nanowires · Tellurium · Protein

1 Introduction

One dimensional nanostructures (1D nanostructures) have gained a lot of attention recently. They have potential applications in electronics [1], ultrahigh density magnetic recording, ultrafast optical switching, and microwave devices [2]. They have potential to be used in making devices for optoelectronics and transistors in nanoscale [3]. Synthesis of 1D nano structures such as nanorods [4], nanowires [5] nanotubes [6] have been reported in the literature. A wide variety of materials such as metals and semiconductors have been used to make 1D nanostructures [7]. The effect of size confinement upon electrical, magnetic, optical and mechanical properties can be studied using one dimensional nano structures [8]. In 1D nanostructures electron conductivity takes place along the

long axis making it as an interesting candidate for ballistic electron transfer [9]. Formation of nanowires is a challenging topic and it involves techniques such as template and self-assembly methods [10]. Semiconducting tellurides has received much attention recently since some of the properties like electrical and magnetic properties are enhanced due to quantum confinement [11, 12]. Te is a p-type semiconductor having band gap energy of 0.35 eV [13, 14] and thus it is an interesting material for fabricating nanodevices. Te atoms are bound together due to Van Der Waals interactions in a hexagonal lattice, forming 1D nanostructures. Te has high anisotropic growth tendency. Several techniques have been used to make nanostructures of Te [15–17]. These techniques involve self seeding technique [15], hydrothermal method [16], surfactant assisted growth process [17], biomolecules assisted approach [18],

✉ Radha Perumal Ramasamy, perumal.ramasamy@gmail.com; perumalramasamy@annauniv.edu | ¹Department of Applied Science and Technology, ACT Campus, Anna University, Chennai 600 025, India.

microwave assisted approach [19] and chemical reduction approach [20]. One dimensional tellurium nano structures have been used as templates to make bimetallic nano structures. The reduction potential of $\text{TeO}_3^{2-}/\text{Te}$ system is system (0.589 V), hence tellurium nanostructures can be used as templates for forming various tellurides [19]. Te nanowires (Te NWs) are useful templates since the morphology of the nanowires may dependent upon the morphology of the Te NWs [21].

The reactivity of Te NWs is a fairly new topic of research. The reactivity of metals with Te has been investigated [22]. Metals like gold and platinum are known to be reduced from the ionic state to the atomic form by Te NWs [23]. For graphite, from studies regarding reactivity of Te NWs with graphite oxide (GO) [22] it was found that upon mixing specific quantities of GO and Te NW, GO gets converted into leaf-like graphenic structures and Te NWs gets oxidized to TeO_3^{2-} . Time-dependent TEM showed that Te NWs are getting etched away continuously. The reactivity of tellurium nanowires (Te NWs) with thiol-containing molecules has also been studied [23] and it was reported that there was a redox reaction between TeO_2 , present on the NW surface, and thiols added into the solution that resulted in the reduction of TeO_2 to Te (0) with simultaneous oxidation of thiols to disulfides. These studies and studies such as the formation mechanism of Tubular Nanostructures of $\text{Cr}_2\text{Te}_4\text{O}_{11}$ and Mn_2TeO_6 through room temperature chemical transformations of Te NWs indicated the combined effect of both redox reactions and nanoscale Kirkendall effect (NKE) in its formation [24]. As An example for the biocompatibility of NWs, Tellurium Platinate Nanowires has recently been used for Photothermal therapy of Cancer cells [25]. Development of shape controlled nanowires is crucial for nanoelectronics. While these studies deal with inorganic and other toxic non-biological chemicals [23, 24] it is very much necessary to explore use of biological materials that are environmentally friendly to create nanowires of desires shapes. Also the study of reactivity of Te NWs with metals in the presence of biological molecules will be very useful in nanomedicine. For this study BSA protein was chosen as the biological material of interest as it is a very dominant part of biological matter. Proteins are varied in their structures and are very friendly to the environment. The presence of different amino acids with (different charges) in them makes their surface very active for chemical reactivity with specificity. BSA is a stable molecule that is stable against biochemical degradation [26] and has been used for several applications that include sensing, imaging and self-assembly [27]. Also, BSA reacts with gold in the presence of mild reducing agents like NaOH to form quantum clusters that are fluorescent. Xie and coworkers reported the synthesis of luminescent Au quantum clusters (BSA-Au NC) using BSA

[28]. Therefore, in this research the shape of Te NWs in the presence of BSA and NaOH at every stage of the reaction was studied and the findings are reported as under.

2 Materials and methods

2.1 Synthesis

BSA-Au NC were made using the procedures developed by Xie et al. [28]. For this 1 mL of aqueous solution containing 50 mg of BSA was added 1 ml containing 10 mM HAuCl_4 . The mixture was vigorously stirred for 2 min. Then NaOH solution was added to have a final concentration of 50 mM NaOH. It was then stirred for 24 h and then dialyzed. This reaction will be referred as reaction-I. Tellurium dioxide (TeO_2 , 99.9%) powder was purchased from Alfa Aesar. Te NWs were prepared by the chemical method reported by Chang et al. [29]. In this procedure, 160 mg of TeO_2 powder was added to a round-bottom flask containing 100 mL of hydrazine hydrate. The reaction was allowed to continue at room temperature under constant stirring. The powder was completely dissolved and the color of the solution changed from colorless to blue after 1 h. Blue color indicated the formation of Te NWs. After a few hours it turned as dark grey in color. The reaction was stopped after 24 h by centrifugation at 18,000 g for 10 min to remove excess hydrazine. The residue was re-dispersed in deionized water and centrifuged twice for the complete removal of unreacted species. It was then freeze dried to obtain Te NWs as powder.

2.2 Characterization

UV-visible absorption spectra were recorded using a Perkin-Elmer Lambda 25 spectrophotometer in the range 200–1100 nm. High-resolution transmission electron microscopy (HRTEM) and energy dispersive analysis of X-rays (EDAX) were carried out with an Oxford EDAX apparatus housed in a JEOL 3010, 300 kV instrument equipped with a UHR pole piece. The samples were prepared by dropping the dispersion on carbon coated copper grids and drying in ambience. UV/Vis spectra were measured with a Perkin Elmer Lambda 25 instrument in the range 200–1100 nm. Luminescence excitation and emission spectra was recorded at room temperature, using HORIBA JOBIN-YVON Fluoromax 4 spectrofluorometer with excitation and emission slits at 5 nm. X-ray diffraction (XRD) data were collected with a Bruker AXS, D8 Discover diffractometer using CuKR ($\lambda = 1.54 \text{ \AA}$) radiation. The samples were scanned in the 2θ range from 10 to 90° . All the peaks were assigned and

compared with the database published by the Joint Committee on Powder Diffraction Standards (JCPDS).

3 Results and discussions

The shape of Te NWs in the presence of gold, BSA and NaOH at every stage of the reaction is as under.

3.1 Morphology of Te NWs

The Te NWs were straight with their lengths $\sim 700 \pm 125$ nm and thickness $\sim 90 \pm 6$ nm (Fig. 1a, b). They were found to be rough on their surface. These are shown in Fig. 1a, b. The aspect ratio is ~ 10 . The length of the obtained NWs are not all the same possibly due to difference in initial nucleation rates of the individual rods as hydrazine hydrate is rapidly mixed with TeO_2 powder.

3.2 Effect of BSA on Te NWs

To know the effect of BSA on Te NWs, Te NWs were added to aqueous solutions containing BSA at pH 7. The concentration of BSA in the solution was 50 mg/ml (780 μM) while the concentration of the Te NWs was 10 mM. It was incubated for 6 days at 25 $^\circ\text{C}$. It was observed that the dimensions of the Te NWs remained the same. This is shown in Fig. 1c, d.

3.3 Effect of NaOH on Te NWs with BSA

To know the effect of NaOH upon the Te NWs, Te NWs were added to two different containers with 50 and 250 mM NaOH solutions containing 780 μM BSA in it. The concentration of the Te NWs was 10 mM. It was incubated for 6 days at 25 $^\circ\text{C}$. For 50 mM NaOH solutions it was observed that the length of the Te NWs was reduced to 724 ± 65 nm from 700 ± 125 nm and the width was reduced to 74 ± 14 nm from $\sim 90 \pm 6$ nm (Fig. 1e, f). Tiny whiskers were observed at the tip of the Te NWs (red circle Fig. 1f). For samples having 250 mM NaOH it was observed that the length of the nanowires decreased significantly from $\sim 700 \pm 125$ nm to 430 ± 130 nm (Fig. 1g, h). It was also observed that the whiskers were more prominent. The thickness of the nanowires also reduced from $\sim 90 \pm 6$ nm to 76 ± 14 nm. Hence the etching rate is higher along the length of the rod ($\langle 001 \rangle$ direction) [29] than along the width of the rod due to the high anisotropy of the Te NWs.

3.4 Reactivity of fully grown BSA-Au NC with Te NWs in DI water

To know if the BSA-Au NC reacted with the Te NWs, the BSA-Au NC (grown using technique developed by Xie

Fig. 1 TEM images of Te NWs (pristine and after reaction with BSA and NaOH)

et al. [28] were dialyzed from 50 mM NaOH. Te NWs (4 mg) were added to 2.5 mL of 50 mg/ml BSA-Au NC in water. It was then incubated at 25 $^\circ\text{C}$ for 6 days. Then it was centrifuged three times and then imaged. It was observed that the thickness (90 ± 6 nm) and its length (700 ± 125 nm) are unaffected indicating that BSA-Au clusters do not react with Te (Fig. 2a, b). The EDAX image shows that there is very little gold and nitrogen indicating that BSA-Au NC does not react with Te in DI water.

3.5 Reactivity of gold with Te NWs in the presence of NaOH

To see the effect of addition of gold to Te NWs, 4 mg (10 mM TE) of the TE NWs was added to 50 mM NaOH aqueous solution for 24 h and after that HAuCl_4 was added to have a final concentration of 5 mM HAuCl_4 . It was then incubated for 6 days and then imaged (Fig. 3). It was observed that gold nanoparticles formed upon the surface

of the Te NWs. Also, the interior of the nanowires looked lighter when compared to the edge of the nanowires. It was also observed that the sizes of the nanoparticles were almost uniform 9.4 ± 1.7 nm. The widths of the nanowires were 97 ± 23 nm and their lengths were 700 ± 180 nm. This indicates that NaOH reduced gold on the Te NWs. Figure 7a shows that the Te-Au NWs touch along their length. The line of contact seems to be invisible suggesting that the Te-Au NWs might have fused.

Fig. 2 Te NWs added to BSA-Au NC in water

Fig. 3 NaOH reduced gold on the Te NWs

3.6 Effect on Te NWs due to growing BSA-Au NC

To see the effect on Te NWs due to growing BSA-Au NC; 20 mM of Te NWs was mixed with 1 mL of aqueous solution containing 50 mg of BSA. It was incubated for 2 h. To this 1 mL of 10 mM HAuCl₄ was added. The mixture was vigorously stirred for 2 min. To these solutions taken in two different containers, NaOH solution was added to have a final concentrations of 50 and 250 mM NaOH respectively. It was then stirred for 12 h and then incubated at 25 °C for 6 days and then centrifuged at 10000 RPM three times before analyzing. This reaction will be referred as reaction-II.

Figure 4 shows the optical and UV light image for (a) BSA-Au NC formed using 50 mM NaOH in reaction-I, (b) BSA-Au NC formed using 250 mM NaOH in reaction-I, (c) Supernatant obtained from using 50 mM NaOH in reaction-II after centrifuging once and (d) Supernatant obtained from using 250 mM NaOH in reaction-II after centrifuging once. The supernatants would contain BSA-Au NC and the Te NWs would settle at the bottom of the tube as it is heavy. BSA-Au NC formed using 50 mM NaOH in reaction-I is orange in color in white light and red in color under UV light. BSA-Au NC formed using 250 mM NaOH in reaction-I is brown in color in white light and deep brownish red under UV light. The Supernatant obtained from using 50 mM NaOH in reaction-II looks light brown in white light and brownish orange under UV light. Supernatant obtained from using 250 mM NaOH in reaction-II looks light brown under white light and greenish blue under UV light. These differences in

Fig. 4 (a) BSA-Au NC formed using 50 mM NaOH in reaction-I, (b) BSA-Au NC formed using 250 mM NaOH in reaction-I, (c) Supernatant obtained from using 50 mM NaOH in reaction-II and (d) Supernatant obtained from using 250 mM NaOH in reaction-II

the colors of the supernatants indicate reaction between growing BSA-Au NC and Te NWs.

The UV/vis measurements, photoluminescence measurements, Raman spectroscopy measurements and TEM measurements for TE NWs added to growing BSA-Au NC are discussed as under.

3.6.1 UV vis measurements

UV/Vis measurements were made on the BSA-Au NC, supernatants and Te NWs before and after the formation of gold nanoparticles. Figure 5 A shows the absorbance spectra for BSA-Au NC formed using 50 mM NaOH in reaction-I, BSA-Au NC formed using 250 mM NaOH in reaction-I, supernatant obtained from using 50 mM NaOH in reaction-II and supernatant obtained from using 250 mM NaOH in reaction-II.

For BSA-Au NC formed using 50 mM NaOH in reaction-I a very weak shoulder peak was observed at ~510 nm. For BSA-Au NC formed using 250 mM NaOH in reaction-I a prominent shoulder peak was observed at 550 nm. This indicates that when the NaOH concentration is increased from 50 mM to 250 mM; the size of BSA-Au NC increases. For Supernatant obtained from using 50 mM NaOH in reaction-II it was observed that a shoulder peak developed at 550 nm indicating that Te and gold had reacted to form nanoparticles in 50 mM NaOH solution. For Supernatant obtained from using 250 mM NaOH in reaction-II it was observed that the absorption intensity decreased and also that that shoulder peak was shifted to ~585 nm. The

Fig. 5 UV/Vis spectrum of the (a) supernatants, (b) Te NWs and Te NWs decorated with gold nanoparticles

red shift is indicative of formation of larger sized nanoparticles. The decrease in the absorption is attributable to the attachment of gold to the Te NWs thereby reducing the concentration of gold in the supernatant leading to reduction in the absorption. Figure 5b shows the UV/Vis spectrum of the as-prepared Te NWs after two rounds of centrifugation-redispersion cycles and Te NWs decorated with gold nanoparticles. Te NWs show two characteristic peaks depending upon the thickness and the length of the NWs [29]. According to the Hartree–Fock–Slater study peak I (in the range of 3–6 eV) is due to the transition from the valence band (p-bonding VB2) to the conduction band (p-antibonding CB1), and peak II (in the range of 0–3 eV) is assigned to be the transition from the valence band (plone- pair VB3) to the conduction band (p-antibonding CB1). It was observed from the UV/Vis spectrum that Te NWs had a broad peak at ~300 and ~700 nm. It was observed that Te NWs added to solutions containing 50 mM NaOH and 250 mM NaOH in reaction-II showed peaks at 260 and 570 nm. The peak at 260 nm is due to proteins. This change in the spectra of Te NWs is due to change in the surface plasmon characteristics of Te NWs due to incorporation of gold upon its surface.

3.6.2 Photoluminescence measurements

BSA-Au NC show an emission maxima at 650 nm when excited at 470 nm [28].

Te NWs are semiconducting, known to show luminescence depending upon the aspect ratio of the NWs [24]. The as grown Te NWs show an emission maxima at 394 nm when excited at 352 nm. Photoluminescence measurements were made on BSA-Au NC made using 50

and 250 mM NaOH in reaction 1, Te NWs and gold decorated Te NWs. Figure 6a shows the excitation and emission spectra for BSA-Au NC formed using 50 mM NaOH in reaction-I, BSA-Au NC formed using 250 mM NaOH in reaction-I, supernatant obtained from using 50 mM NaOH in reaction-II and supernatant obtained from using 250 mM NaOH in reaction-II.

From Fig. 6a it is observed that BSA-Au NC formed using 50 mM NaOH in reaction-I, had excitation maximas at 380 and 505 nm. When excited at 505 nm the emission maxima was found to be at 667 nm. For BSA-Au NC formed using 250 mM NaOH in reaction-I, it was observed that the excitation maxima was at 530 nm and the emission maxima was at 725 nm. The shift in the excitation and emission maxima is attributable to the change in the particle size for BSA-Au NC. For supernatants obtained from using 50 mM NaOH in reaction-II, it was observed that the excitation maximas were at 372 and 505 nm while emission maxima was at 677 nm. The intensities of the excitation and emission spectras of the supernatants obtained from using 50 mM NaOH in reaction-II was lesser than that of intensities of the excitation and emission spectras for BSA-Au NC formed using 50 mM NaOH in reaction-I. The ratio of the intensity at the emission maxima for supernatants obtained from using 50 mM NaOH in reaction-II and BSA-Au NC formed using 50 mM NaOH in reaction-I was ~40%. This indicates that gold had got attached to Te NWs, as a result of which the concentration of gold available to react with BSA became less leading to decrease in the photoluminescence intensities. For supernatant obtained from using 250 mM NaOH in reaction-II, it was observed that the intensities of both the excitation and emission spectras were greatly reduced. The ratio of the intensity at the

Fig. 6 (a) Photoluminescence of BSA-Au NC formed using 50 m NaOH in reaction-I, BSA-Au NC formed using 250 m NaOH in reaction-I, Supernatant obtained from using 50 m NaOH in reaction-II

and Supernatant obtained from using 250 m NaOH in reaction-II. (b) Photoluminescence of pristine Te NWs and gold decorated Te NWs formed using 50 and 250 Mm NaOH in reaction-II

emission maxima for supernatant obtained from using 250 mM NaOH in reaction-II and BSA-Au NC formed using 250 m NaOH in reaction-I was $\sim 2.5\%$. This indicates that as the NaOH concentration increases, then more gold gets reduced on Te NWs.

Figure 6b shows the photoluminescence spectra for pristine Te NWs, Te NWs with gold formed using 50 mM NaOH in reaction-II and Te NWs with gold formed using 250 mM NaOH in reaction-II. It was observed that Te NWs showed excitation maxima at 349 nm and emission maxima at 395 nm. Te NWs decorated with gold formed using 50 mM NaOH in reaction-II showed excitation maxima and emission maxima at 351 and 394 nm. The shift in the excitation and emission maxima is attributed to the formation of gold nanoparticles upon the surface of Te NWs. Te NWs decorated with gold formed using 250 mM NaOH in reaction-II showed excitation maxima and emission maxima at 353 and 393 nm. The greater shift in the positions of the maximas due to 250 mM NaOH when compared to 50 mM NaOH indicates higher concentration of gold on Te NWs due to increase in NaOH concentration.

3.6.3 Raman spectroscopy measurements

Figure 7a shows the Raman spectra for pristine Te NWs. It is observed that a sharp peak exists in the region $100\text{--}200\text{ cm}^{-1}$ and a broad peak is observed in the region $1500\text{--}3000\text{ cm}^{-1}$ with maxima at $\sim 2400\text{ cm}^{-1}$. BSA-Au NC showed fluorescence in the region $300\text{--}2400\text{ cm}^{-1}$ (Fig. 7b). In order to locate Te, the Raman images were extracted by using the spectral region from 100 to 200 cm^{-1} while the region $600\text{--}2200\text{ cm}^{-1}$ was used to locate gold.

Figure 7c shows the optical and Raman image for pristine Te NWs. Figure 7d shows the optical image and Raman images (for regions containing Te and gold) for Te NWs decorated with gold made using 50 Mm NaOH in reaction-II. It was observed that tellurium could not be located while some little gold could be located. The Raman spectra at the point "P" is also shown in the figure. At the point "P", the peak $100\text{--}200\text{ cm}^{-1}$ was absent and a broad peak at 2400 cm^{-1} was observed indicating the absence of Te. The absence of Te in the image could be because of Te diffusing into the solution during reaction with gold. Figure 7e shows the optical and Raman images for regions containing tellurium and gold for Te NWs decorated with gold obtained using 250 mM NaOH in reaction-II. It was observed that a little Te was found to be present while the concentration of gold was high. The Raman spectra at point R (on the Te NWs) and S (away from the Te NWs) are also shown. It was observed that at "R" the spectra showed a prominent and broad peak from the region $600\text{--}2000$ indicative of presence of gold while the spectra at "S" was nearly flat. The slightly higher concentration of Te in Fig. 7e than in Fig. 7d indicates that gold trapped Te when 250 mM NaOH was used. This could be because of higher reduction of gold on Te NWs by 250 mM NaOH (leading to trapping of Te) than by using 50 mM NaOH in reaction-II. The higher concentration of gold in the image 12E when compared to 7D indicates that more gold gets reduced on TE NWs for 250 mM NaOH than for 50 mM NaOH in reaction II. The images were not very clear due to limitations in the resolution of the microscope.

Fig. 7 (a) Raman spectra for Te NWs, (b) Raman spectra for BSA-Au NC made using 50 mM NaOH and 250 mM NaOH in reaction (I), (c) Optical and Raman image for pristine Te NWs, (d) Optical image and Raman image (for regions containing Te and gold) for Te NWs

decorated with gold made using 50 Mm NaOH in reaction-II, (e) Optical image and Raman image (for regions containing Te and gold) for Te NWs decorated with gold made using 250 Mm NaOH in reaction-II

3.6.4 TEM measurements

Te NWs decorated with gold made using 50 Mm NaOH in reaction-II The Te NWs decorated with gold made using 50 Mm NaOH in reaction-II that settled at the bottom of the tube due to centrifugation was found to be decorated

with gold nanoparticles of size 7.3 ± 1.9 nm (Fig. 8). The thickness of the nanowires was 57.6 ± 14.1 nm. Interestingly, it was also observed that many nanowires were bent (Fig. 8a–f). In some nanowires, gaps were observed indicating absence of Tellurium (Fig. 8c, d).

The EDAX image showed the presence of Au, Te, and N indicating that the proteins also anchored on the Te NWs along with the gold. It was also observed from the intensity of the peaks that there was more Au and less Te. The reduction in both the thickness of the nanowires and the intensity of Te from EDAX indicates that tellurium gradually diffused into the solution while gold reduced on the surface of Te NWs. The bending of the nanowires could be due to (1) anchoring of the proteins upon the Te NWs facilitating formation of nanoparticles upon it due to reduction of Au by NaOH thus forming defects and (2) Diffusion of Te into the solution due to NKE leading

to weakening of the Te NWs and favoring its curving. These are in agreement with Bending and shell formation of tellurium nanowires induced by thiols reported by Sreepasad et al. [23].

Te NWs decorated with gold made using 250 Mm NaOH in reaction-II The Te NWs decorated with gold made using 250 Mm NaOH in reaction-II that settled at the bottom of the tube due to centrifugation were not bent (Fig. 9a–f). It was also observed that the nanowires were uniformly decorated by gold nanoparticles. The average size of the nanoparticles was 8.9 ± 1.9 nm.

Fig. 8 TEM images, EDAX images and spectra of Te NWs decorated with gold nanoparticles at 50 mM NaOH concentration in reaction-II

The EDAX image shows the presence of gold, tellurium and nitrogen (Fig. 9). It also shows that there is more tellurium in this case than for 50 mM NaOH. This is attributable to higher reduction of gold on tellurium by 250 mM NaOH than by 50 mM NaOH as a result of which gold traps tellurium. The difference in the morphologies of TE NWs upon reaction with Au in the presence of BSA at 50 mM NaOH and 250 mM NaOH indicates the effect of both redox reaction and NKE during the transformations. Effect of NKE being more at 50 mM NaOH (leading to curving of wires), than at 250 mM NaOH leading to

trapping of tellurium by gold and preserving initial rod like morphology of the Te NWs.

Close to the surface of the gold decorated TE NWs isolated Au nanoparticles and isolated Te nanoparticles were seen. Figure 10 shows one such region with Au nanoparticles (d spacing is 0.205 nm due to (200) plane) and Te nanoparticles (d spacing is 0.290 nm due to (100) plane).

3.6.5 XRD measurements

In order to check if Au and Te formed any mixed phases, XRD was used (Fig. 11). It was observed that the peaks

Fig. 9 TEM images, EDAX images and spectra of Te NWs decorated with gold nanoparticles at 250 mM NaOH concentration in reaction-II

Fig. 10 HRTEM image of the surface of gold decorated TE NWs showing isolated Au and Te nanoparticles

Fig. 11 XRD for gold decorated TE NWs, standard powder data of Te and Au

in Au (JCPDS: 04-0784) and peaks in Te (JCPDS: 34-1452) were both present in the XRD for gold decorated TE NWs. It was also observed that the peaks corresponding to the Au-Te phases that were mentioned in JCPDS for Au-Te system were absent in it. This implies that Au and Te exist as separate and not in any mixed phases in the gold decorated TE NWs.

4 Conclusion

In this research the curbing of tellurium is illustrated using gold and bovine serum albumin. Upon inclusion of HAuCl_4 to Te NWS in solutions containing NaOH, gold nanoparticles are formed indicating the reduction of Au ions into nanoparticles upon Te NWs. UV/Vis, photoluminescence measurements of the supernatants obtained from reaction of Te NWs with growing BSA-Au NC showed that the optical characteristics of BSA-Au NC were modified due to reaction with Te. It was observed that in the presence of BSA, for 50 mM NaOH, gold nanoparticles are formed on the nanowires and the TE NWs are bent while at higher NaOH concentration (250 mM) the TE NWs do not curve. EDAX images confirm that in the presence of BSA, Tellurium is replaced by gold at 50 mM NaOH while Te gets trapped by gold at 250 mM NaOH. UV/Vis and photoluminescence measurements show that the optical characteristics of Te NWs are modified as a result of formation of gold nanoparticles. The difference in the morphologies of TE NWs upon reaction with gold in the presence of BSA at 50 mM NaOH and 250 mM NaOH is attributed to the effect of both redox reaction and NKE during the transformations. Effect of 50 mM NaOH in the shape of the wire (bending of wires) is more than at 250 mM NaOH (trapping of tellurium by gold and preserving its initial rod like morphology of the Te NWs). XRD data indicates that while gold gets reduced upon Te NWs, there are no mixed phases of Te and Au. Hence it is possible to curve of Te-gold NWs using proteins. This research is limited to formation of semicircle shaped wires. Nanowires with more than one curve in it is to be explored in future. Such nano wires with different curvatures can be used for nano electronics where the shapes of the wires may play a crucial role in electronics. Also, while Te is a semiconductor Te-gold NWs is a metal as Te is replaced by gold. Hence this method of using proteins with gold to form nanowires of desired shapes can help in making hybrid materials.

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Compliance with ethical standards

Conflict of interest No conflicts of interest exist.

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