Electrochemical Deposition of CdTe Thin Film for CdS/CdTe X-Ray Sensor

H. SHAMS [1], H. ABOU GABAL [1], M. SOLIMAN [2], S. EBRAHIM [2], S. AGAMY[1]
[1] Nuclear and Radiation Engineering Department, Faculty of Engineering, Alexandria University, Alexandria, EGYPT
[2] Materials Science Department, Institute of Graduate Studies and Research, Alexandria University, Alexandria, EGYPT

Abstract :- Many methods are used to measure X-ray flux generated by modern X-ray machines. The most common method utilized for monitoring X-ray dose is technically complex and expensive. In this work CdTe has been electrodeposited onto CdS/FTO glass substrate to form with previously fabricated CdS layer 4 µm thickness. The optimum potential for CdTe deposition has been studied by potentiostat measurement, it shows that -1.3 is the optimum working potential. The XRD analysis showed that the CdTe films have highly oriented crystallites with the cubic phase zinc blend with preferred orientation (111). The band gap Eg extrapolated to be 1.4 eV. Four stacked sensors were connected in series to measure the device performance. It was observed that amplitude of the pulse formed due to exposed FTO/CdS/CdTe/Mo detector to X-ray of 33 keV and 1mA intensity is 1.03 V.

Keywords: Environment, Applied Chemistry, CdTe, Thin film, X-ray, Sensors

1 Introduction

Electrodeposition can be described as a liquid medium containing suspended colloidal particles that travel under the effect of applied electric field and deposit on an electrode. Electrodeposition process needs the kind of materials that form colloidal suspensions and can carry a charge, The electrodeposition method has many advantages:

- It produces uniform thickness with very little porosity and cracks.
- The complex surfaces can easily be coated, and the cavities can be coated from inside and outside.
- The deposition can be done in a limited time.
- It produces less impurities surfaces.
- It can be used with different kinds of materials as metals, ceramics and polymers.
- The composition of the coating can be easily controlled.
- The method is usually automatic.
- It is low cost compared to other methods.
- It is less risky method.
- It is now one of the best environmentally friendly deposition methods [1].

I. M. Dharmadasa et al. studied the production of CdS/CdTe thin film for solar cells. They studied the using of an electrochemical method for the deposition of CdTe. They concluded from the results that CdTe of n, I, and p-type can be prepared by electroplating. They reported that the material could be converted from n to p type or p to n type with heat treatment. While the $CdCl_2$ treatment showed one-way conversion from n-type to i-type or p-type [2].

F. Lisco et al. studied electrodeposition of CdTe films on CdS layers deposited using magnetron sputtering and chemical bath. Electrodeposition was done at room temperature by three-electrode cell using potentiostat. The reference electrode was a saturated KCl silver/silver chloride electrode. A Pt foil served as a counter electrode and the working electrode was made of a CdS thin film. They compared the structural and optical properties of electrodeposited cadmium telluride films. The films were characterized using scanning electron microscopy (SEM), transmission electron microscopy (TEM), energy dispersive X-ray spectroscopy (EDS) and Spectrophotometry. They reported that the microstructure of the CdTe film was influenced by the deposition method used for the underlying thin film CdS. The CdTe films deposited on CdS films showed development of bigger crystallites compared to the films grown on the sputtered CdS layer. Thickness measurements showed that the substrate had significant influence on the growth rate of the CdTe, with the material grown on sputtered CdS having 3 times higher deposition rate. Transmission measurement showed that the material deposited on the sputtered CdS had a narrower band gap,1.41eV, compared to that deposited on CBD CdS, 1.46eV [3].

Gennadiy Khrypunov et al. studied the electrodeposition of cadmium telluride thin films. They showed up the fabrication of stoichiometric doped cadmium telluride films as well as they investigated the deposition parameters of single-phase CdTe layers. They studied the using of different acidities and $CdSO_4$ concentrations. Also, they studied the effect of film illumination on the deposition as well as the effect of the illumination and chloride treatment on the film crystallinity. They used for illumination 500 W halogen lamp. They completed the treatment by chemical and air annealing. They used chloride treatment through vacuum deposition of $CdCl_2$ film onto CdTe surface and subsequent air annealing. They used X-ray diffraction (XRD) method to study the crystallinity of the electroplated film. They concluded that the produced CdTe film was good adherent smooth and stoichiometric single-phase with cubic structure. They found that the illumination of the produced thin film increased its thickness and improved its crystallinity [4].

C. Lepillera, et al. studied the rate of electrodeposition of cadmium telluride for solar cells applications. They investigated if they can increase the electrodeposition rate of cadmium telluride. Their study was based on theoretical analysis which has allowed them to set new electrodeposition conditions depending on an increase of the tellurium concentration. They also studied other deposition parameters like effect of pH and potential. They reported that the films were deposited at highest rate of around 17 microns per hour. The produced films have been characterized before and after annealing. They reported the best produced solar cell with efficiencies about 6% obtained with the electrodeposition rate of 2.7 μm/h [5].

Jun Wanga et al. studied the influence of sodium chloride (NaCl) on electrodeposition of cadmium telluride CdTe films, and they tested the morphology of the produced films. They deposited the CdTe thin film onto nickel foils using the electrodeposition technique. They noticed that when the sodium chloride was directly added to the electrolyte solution a good morphology layer was produced. The shape of the cadmium telluride film was rod shape film, then converted to the clustered shape, at the end a double-layer film was formed. They found that this effect increased with the increase in the NaCl concentration. They used for the characterization the field-emission scanning electron microscopy (FESEM), X-ray diffraction (XRD) to measure crystallinity, UV-vis optical measurement, transmission electron microscopy (TEM) for measurement of morphology and composition, and electrochemical measurements to optimize the electrodeposition parameters. They reported that the concentration of sodium chloride was an effective parameter in the enhancement of cadmium telluride film morphology. Their measurements showed that the cadmium telluride morphology highly affected the photoelectrical properties. The produced homogeneous cadmium telluride film which was prepared with NaCl concentration of

0.05 mol/L showed better photoelectrical properties [6].

Jun Wang et al. investigated the deposition of thin films of cadmium telluride onto Nickel foils using electrodeposition technique in two steps. They reported that the initial step was the production of a Tellurium-rich CdTe film, it was produced at -0.3 V onto a substrate made from Ni foil. The second layer was electrodeposition onto the first layer under applied voltage of -0.6 V. They reported that the use of two-step electrodeposition technique gave better densities of short-circuit current. They concluded that the potential properties for the solar cells and the crystallinity of the produced film were also enhanced. The results were proved by the characterization using the XRD. The CdTe peaks were sharp indicating better crystallinity. The results of UV-visible showed high absorption intensity in the visible region. The conclusion was the use of two step electrodeposition technique might improve the absorption range of CdTe solar cell which will enhance the photovoltaic performance to visible light [7].

Utpal Madhuet al. studied the properties of CdS and CdTe thin films deposited by an electrochemical technique. The cadmium telluride and cadmium sulfide films were electrodeposited onto transparent conducting (TCO) glass substrate. They used foil of cadmium to work as a sacrificial anode. They indicated in their discussion that the electrodeposition of the films was done with no applied potential. They used several techniques to characterize the produced film. The characterization was done by SEM, XRD and optical absorption measurements. The film crystallinity showed by XRD was cubic structure for CdTe. The SEM indicated good morphology polycrystalline CdTe film and the UV-visible optical measurement displayed nearly standard values for the band gap [8].

Qian Li et al. studied electrodeposition of a novel CdTe array on nickel(Ni) foils and photoelectron chemical performance. A novel perpendicularly aligned CdTe array was fabricated on a Ni substrate using a simple electrochemical synthesis method. The samples were characterized by XRD, EDX and FESEM. They reported that a high-purity, uniform CdTe array was obtained. Rod lengths can reach to 3.0 mm, with nanoparticles stacking along the rod growth direction, keeping the diameter at 1.5 mm. The results proved that the fabricated film had improved photoelectrical properties. The results showed high absorption coefficient of the electrodeposited CdTe film as well as good rod quality and electronic structure [9].

2 Materials and Methods

2.1 Materials

Cadmium chloride pentahydrate was obtained from Sigma Aldrich. Cadmium sulfate hydrate (98%, MW = 769.51 g/mole) was obtained from Merck, Tellurium dioxide (99%,MW = 159.6 g/mole) was obtained from Sigma Aldrich, Fluorine doped tin oxide (FTO) coated glass slide with sheet resistance of 7 ohm/sq and Transmittance of 80-82% (visible), was bought from Sigma Aldrich.

2.2 Preparation and thermal chemical treatment of CdTe thin films

CdTe films had been deposited by potentiostat electro deposition and carried out using a 2-electrode cell according to the comparative study of O. K. Echendu et al [10]. Potentiostat controls the voltage between reference and working electrodes while the device is passing the current through a counter electrode. So the potentiostat is controlling the voltage and measuring the change in the passing current.

The electrodeposition system consists of glass/FTO working electrode as cathode and a graphite electrode as anode immersed in an electrolyte. The aqueous electrolyte solution was prepared by Cadmium sulfate (3.8×10-2 M) solution, (4.2×10-2 M) of CdCl2, (10-3 M and 2×10-3 M) of TeO2. The pH was then adjusted to 2.00 ± 0.02 using high purity H_2SO_4. The produced films have been chemically heat treated at 350oC for 15 min with 1 N $CdCl_2$.

2.3 Fabrication of CdS/CdTe X-ray detector

CdTe was electrodeposited onto prepared CdS/FTO substrates. Molybdenum thin films were produced on CdTe/CdS FTO glass substrates using RF sputtering system. The substrates were rinsed in running distilled water and dried using oven. They were subsequently introduced into the vacuum chamber and placed at a distance of 10 cm from the Mo target. The vacuum chamber was initially evacuated to a base pressure of 6×10^{-4} Torr. Then pure Argon (99.999%) flow of 0.094 standard liter per minute (SLPM) was introduced into the chamber to keep the pressure during the film deposition at a value around 1.45 mTorr. The power supply was then turned on. The power was adjusted at 60 W. A series of sixteen Mo films back contact was prepared, according to the study of molybdenum thin film deposition by N.Dhara et al [11].

The schematic diagram of the fabricated detector with different layers is shown in Figure (1).

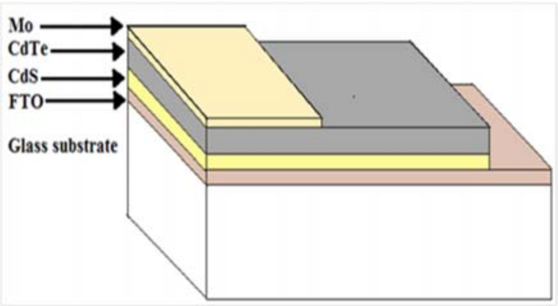


Figure : 1 The structure of the fabricated X-ray sensor.

2.4 Characterization techniques

Different of techniques were used to characterize the prepared films and its performance. Material characterization includes determination of composition and structure, determination of energy bandgap by the photoluminescence technique. The X-ray sensor performance is characterized by measuring the electrical output signal during its exposure to X-ray.

A scanning electron microscopy QUANTA FEG250 is used to observe the surface morphology and to measure the film thickness. The chemical compositions of the films were determined with an Energy Dispersive X-ray spectrometer QUANTA FEG250.

The crystalline structure is studied by means of X-ray diffraction using (X-ray 7000 Shimadzu-Japan) at room temperature. The Bragg angle (2θ) in the range from 5 to 50 degrees for CdS and from 5 to 80 degrees for CdTe were used. The X-ray source was Cu (λ = 1.54 ^{o}A) target generated at 30 KV and 30 mA with scan speed 4 deg/min.

X-ray generator Geratogram Roentgen instrument had been made in Germany 1987, is used to produce X-ray with energy adjustable range of 21 to 42 keV (wave length λ range 29.5 to 59.0 picometer, pm). Also its emission intensity is adjustable in the range from 0.05 to 1 mA, the local dose rate at a distance of 0.1m from touchable surface of the device is ≤ 5µSv [12].

To enhance the exposed area of the sensor, we stacked four sensors in series. The positive electrode of first sample (Mo) is connected directly to the negative electrode of the second sample (FTO) and so on. The sensor performance is investigated by exposing the stacked sensor directly perpendicular to the X-ray source. The output signal of the stacked sensor was connected to computerized oscilloscope DS03064 Kit V.

3 Results and Discussion

3.1 Preparation and optimization of the electrodeposited CdTe films on FTO glass substrate

The aqueous electrolyte solution was prepared by Cadmium sulfate (3.8×10^{-2} M), (4.2×10^{-2} M) of $CdCl_2$, (10^{-3} M) of TeO_2. The optimum voltage for Cd deposition had been determined. Figure (2) shows the voltammogram of cathodic peak at (-1 V) which indicates the reduction of Cd^{2+} to Cd and anodic peak at (-0.7 V) which indicates oxidation of Cd to Cd^{2+}. From the voltammogram chart the cathodic peak which indicates the highest rate of Cd deposition is at -1.5 V in the forward cycle. The anodic peak at - 0.7 V is due to the dissolution of Cd from the cathode surface during reverse cycle as the following equation [13].

$$\mathrm{Cd^{2+} + 2e^-} \xLeftrightarrow{\text{reduction/oxidation}} \mathrm{Cd}$$

The optimum voltage for Te deposition has been determined. Figure (3) shows the voltammogram of the two cathodic peaks at (-1.6 V) and (-1.2 V) which indicates the reduction of both Te^{4+} to Te^0 and Te^0 to Te^{2-} and anodic peak at (-0.13 V) which indicates the oxidation of Te^{2-} to Te^0 as the following equations [13].

$$\mathrm{HTeO^{2+} + 3H^+ + 4e^-} \xRightarrow{\text{reduction}} \mathrm{Te^0 + 2H_2O}$$

$$\mathrm{Te^0 + 2H^+ + 2e^-} \xLeftrightarrow{\text{reduction/oxidation}} \mathrm{H_2Te}$$

The optimum voltage for CdTe deposition has been chosen. Figure (6.15) shows the voltammogram of a cathodic peak at (-1.3 V) which indicates the deposition of CdTe and anodic peak at (-1 V) which indicates the dissociation of CdTe. This can be explained by the fact that Te ions begin to be reduced when the current density starts to increase with the increase of cathodic voltage from -1.8 to 2 V. In this region, elemental Te is deposited and the formed layer is a mixture of CdTe and Te. A rapid increase of current is observed around -1.3 V, which indicates the electrodeposition of CdTe layer at this value of cathodic voltage, as can be seen from Figure (4). The anodic peak at -1 V is due to negative currents which are attributed to the removal of Cd from CdTe and then Te from the cathode surface. We concluded from these results that , the optimum voltage for the electrodeposition of CdTe is chosen to be in the range of -1.3 V which is in a good agreement with the work performed by D. G. Diso et al. [14].

3.2 Effect of TeO_2 concentration of CdTe films electrodeposited on CdS/FTO glass substrate

The influence of TeO_2 molar concentration on the morphology of the CdTe films is shown in Figure (5). Two concentrations of TeO_2 have been investigated. The aqueous electrolyte solution was prepared by Cadmium sulfate (3.8×10^{-2} M), (4.2×10^{-2} M) of $CdCl_2$, (10^{-3} M and 2 $\times10^{-3}$ M) of TeO_2. The SEM micrograph shows that the clusters of CdTe film have varying sizes in the range of sub-micron. The grain shape and crystalline structure of the lower Te molar concentration sample is better compared to those with higher concentration. This is in a good agreement with the results obtained by I. M. Dharmadasa et al. [15].

Figure (6) presents the EDX spectra of the CdTe films which display the effect of the TeO_2 molar concentration on the composition of the CdTe films. The atomic percent of Cd/Te were 49.34/50.66 and 41.38/58.62 respectively. The higher concentration of Te causes systematically the sample to be Te-rich as suggested by Catherine Lepiller et al. [16]. While it is noticed that Cd/Te ratio equal 0.97 for lower Te molar concentration samples. The peaks of Sn and Si because we are using FTO glass substrate and the peak of S due to the presence of CdS layer.

3.3 Effect of deposition time of CdTe films electrodeposited on FTO glass substrate

The aqueous electrolyte solution was prepared by Cadmium sulfate (3.8×10^{-2} M), (4.2×10^{-2} M) of $CdCl_2$, (10^{-3} M) of TeO_2. The influence of the electrodeposition time on the morphology of the CdTe films is shown in Figure (7). The SEM micrograph shows that by increasing the deposition time, the morphology of the thin films changed from spherical grains to rod-like grains, which are growing upward. The films are found to preserve a dense and homogeneous microcrystalline structure. Moreover, the FTO surface is covered by spherical grains, and the grains start to coalesce together forming larger grains. Longer deposition time leads to a smooth and homogeneous layer. This results is with good agreement to with those obtained by Azam Mayabadi et al [17].

Figure (8) presents the EDX analysis data. EDX data reveals the that the atomic ratio Cd/Te are 27.07/72.73, 35.05/64.95, 43.11 /56.89 and 47.54/52.46 corresponding to 1, 2, 3 and 4 hrs respectively. These results confirm the good stoichiometric characteristics of the films deposited with 4 hrs deposition time. The presence of peaks of Sn and Si is due to the use of FTO glass substrate.

3.4 Effect of $CdCl_2$ heat treatment of CdTe films electrodeposited onto FTO glass substrate

The influence of heat treatment on the morphology of the CdTe films is shown in Figure (9). The effect of $CdCl_2$ heat treatment SEM micrograph shows that the average grain size of the $CdCl_2$ heat-treated sample is much larger than that of the as-deposited sample. In principle, $CdCl_2$ heat-treatment re-crystallizes the CdTe layer as mention by M. Rami et al. [18].The re-crystallization action can be explained by The chloride ions from $CdCl_2$ diffuse in the CdTe electrodeposited layer and substitute the Te ions causing the production of $CdCl_2$ which with heat treatment dissociate leaving cadmium vacancy. Smaller grains coalesce together, whereas, some of the bigger grains divide into smaller grains and reorient themselves, which affects the overall microstructure. The SEM image also shows that roughness is reduced after $CdCl_2$ heat-treatment as indicated by M. Rami et al. [18]. Also the SEM micrograph of the $CdCl_2$ heat treated sample has better appearance compared to that before treatment. This is due to enhancing the electrical conductivity after $CdCl_2$ heat treatment.

Figure (10) presents the EDX spectra of the CdTe films which display the effect of the $CdCl_2$ heat treatment on the composition of the CdTe films. The atomic percents of Cd/Te for the $CdCl_2$ heat treated sample is 47.67/52.33. The peaks of Sn and Si because we are using FTO glass substrate.

3.5 Effect of $CdCl_2$ heat treatment of CdTe films electrodeposited onto CdS/FTO glass substrate

Figure (11) shows the morphology of CdTe films deposited onto CdS/FTO glass substrates before and after $CdCl_2$ heat treatment. As expected the grain size is enhanced and the appearance is improved.

Figure (12) presents the EDX spectra of the CdTe films which display the effect of the $CdCl_2$ heat treatment on the composition of the CdTe films. The atomic percents of Cd/Te for as deposited and the $CdCl_2$ heat treated samples were 53.63/46.37 and 49.34/50.66 respectively. The EDX data indicates the presence of Cd vacancy film. The peaks of Sn and Si because we are using FTO glass substrate and the peak of S is due to CdS layer.

3.6 Thickness measurement

Figure (13) is the SEM for the cross section of CdTe electrodeposited layer deposited over CdS/ FTO glass substrate for 4 hrs with heat treatment at 350ºC. The composition analysis of this sample is shown in Figure (12b). The SEM shows that the thickness of CdTe film is equal to 4 μm. A. A. Ojo and I. M. Dharmadasa et al. [19] studied the deposition of cadmium telluride (CdTe) film from $CdCl_2$ and tellurium oxide by electroplating technique using two-electrode configuration at cathodic voltage between 1.33 and 1.4 V. The CdTe thickness of the prepared films was estimated using both experimental and theoretical methods against cathodic voltage for CdTe layers grown for 2 hrs duration. The thickness of the layers had a maximum of 1.2 μm. Chandan Bhardwaj [20,21]. prepared CdTe thin film by the electrodeposition on glass/FTO substrates. A standard three-electrode system was used. Different potential ranges were used ranging from -0.6 V to -0.3 V. The deposition was performed for 2 hours and the CdTe films have a thickness of 1 μm. In this study the deposition time was extended to 4 hrs which enhanced the thickness to be 4 μm.

Figure (12b) shows EDX analysis of the $CdCl_2$ heat treated layer. The composition analysis indicated the Cd and Te with atomic percent (At %) of Cd/Te was 49.34/50.66. The EDX data indicates the presence of Cd vacancy film.

3.7 X-Ray diffraction analysis for prepared electrodeposited CdTe films

Figure (14a) shows the XRD for standard CdTe cubic crystalline sample According to JCPDS reference (card 15-0770) [19-20]. Figure (14b) shows the XRD of as deposited sample, where the count per second was low indicating poor crystallinity structure. Figure (14c) shows the XRD for $CdCl_2$ heat treated sample. The seven peaks correspond to the reflection from (111), (220), (311), (400), (331) (422) and (511) planes corresponding to the cubic phase zinc blend CdTe. Deposited films crystallize in cubic phase with preferred orientation (111). The intensity of preferred planes (111) revealed the good crystallinity. The films are highly ordered with a strong reflection along the (111) plane of the cubic phase and the intensities of the (220) and (311) planes are low in comparison to those of the standard. This results with good agreement with results obtained by Y. V. Znamenshchykov et al. [22]. These data indicates that these films can be used for preparing heterojunction that can be used as X-ray detectors. The XRD shows another peaks because the CdTe film is deposited onto CdS/FTO glass substrate, where there are 6 peaks of CdS hexagonal structure and another 5 peaks correspond to FTO.

3.8 Optical properties of the prepared CdTe films

The optical transmission spectrum of the CdTe film between 350 to 800 nm was used to determine the band gap of the prepared CdTe films. The thickness, refractive index and the absorption coefficient α of thin films were calculated by the Swanepoel model, using the following equations [23,24]:

$$n = \left[N + (N^2 + n_s^2)^{1/2}\right]^{1/2} \tag{1}$$

$$N = 2n_s \frac{T_M - T_m}{T_M T_m} + \frac{n_s^2 + 1}{2} \tag{2}$$

$$d = \frac{\lambda_1 \lambda_2}{2(\lambda_1 n_2 - \lambda_2 n_1)} \tag{3}$$

$$\alpha = \frac{1}{d} ln \frac{(n-1)(n-n_s)\left(\frac{T_M}{T_m}+1\right)^{1/2}}{(n+1)(n+n_s)\left(\frac{T_M}{T_m}-1\right)^{1/2}} \tag{4}$$

where n is the refraction index at various wavelengths, T_M and T_m are the maximum and minimum transmissions at specific wavelength λ and n_s is the refractive index of the substrate (n_s=1.52 for glass).n_1 and n_2 are the refractive indices at two adjacent max or min at λ_1 and λ_2, h is Planck constant and υ is the photon's frequency. The values are closed to these published by Kim Mitchell et al. and Jesus Rangel et al. [25,26].

Figure (15) illustrates the plot of $(\alpha h\upsilon)^2$ vs. $h\upsilon$ of the deposited CdTe film. It has been observed that the plot of $(\alpha h\upsilon)^2$ versus $h\upsilon$ is linear over a wide range of photon energy. The intercept (extrapolation) of the plot (straight line) on the energy axis reflects the energy band gap. The band gap E_g can be extrapolated to be 1.41 eV.

.

3.9 Performance measurement

Figures (16 a,b,c) show output signal from FTO/CdS/CdTe/Mo sensor exposed to X-ray of 21, 27 and 30 keV at 0.05 mA intensity. It is observed that the maximum amplitudes of the pulse formed due to the exposure of FTO/CdS/CdTe/Mo sensor to X-ray are 0.41, 0.65 and 0.72V for the accelerated voltage 21, 27 and 30 kV respectively.

Figures (17 a,b,c) show output signal from FTO/CdS/CdTe/Mo sensor exposed to X-ray of 21, 27 and 33 keV at 1mA intensity. It is observed that the maximum amplitudes of the pulse formed due to the exposure of FTO/CdS/CdTe/Mo sensor to X-ray are 0.64, 0.86 and 1.03V respectively.

The produced peaks with X-ray exposure can be explained by using the equivalent electrical circuit of the detector. The circuit resistance of the FTO/CdS/CdTe/Mo sensor and the measuring circuit is assumed to be R, while the total capacitance assumed to be C. The voltage V(t) across the load resistance as a function of time is the main output signal voltage. The time constant of the circuit could be simply calculated by RC. Assume that the time separate pulses is large enough, so the discharge of the charged capacitance will be performed via the resistance as mention by Knoll [27]. After discharge the voltage return to zero across the load resistance. In this case the main factor which determine the time required for the signal pulse to reach its maximum value is the charge collection time in the FTO/CdS/CdTe/Mo sensor. Although the time required to retain the signal voltage to zero is affected by the time constant of the load circuit. We can calculate the pulse amplitude by dividing the total charge created in the detector during one interaction by the capacitance of load circuit. Assuming that the capacitance of the load circuit is constant as indicated by Knoll [27], so the amplitude of the signal pulse is only proportional to the total collected charge Q. The signal formation can be explained through three steps [27]. The first step, the formation of depletion region or junction prevents the passing of the free charges from the bulk. X-ray passes through the FTO/CdS/CdTe/Mo sensor. X-ray photons disappeared, and a photoelectron ejected from one of the inner electron shells of the absorber CdS/CdTe sensor. The ejected electron will hold kinetic energy equals to the incident photon energy minus the binding energy of the electron in its original shell. The second step, The vacancy that is formed in the electron shell as a result of the photoelectron ejection is refilled very fast in an electron rearrangement inside the atom, this rearrangement will cause a characteristic X-ray is produced. The third step, X-rays reabsorbed again through photoelectric interactions with less tightly bound electron shells of the CdS/CdTe junction. the produced electrons make collisions in its path with the absorber electrons causing the appearance of a given amount of electric charge within the detector. These created charges flow in the opposite directions and collected at the electrodes causing electrical pulses. The obtained results is with good agreement with the result obtained by J. Abramovitch [28].

Figure (18) shows the output signal of FTO/CdS/CdTe/Mo sensor versus X-ray energy at different intensities. The amplitude is linearly increased with energy of X-ray where we can predict three regions. Region one from 21 to 27 KeV where there is high sensitivity to increase in X-ray energy due to increase in number of electron-hole pair produced. Region two from 27 to 36 KeV, which there is equilibrium between electron-hole pair production and recombination, so the rate of increase in amplitude is reduced. Region three from 36 to 42 KeV, where saturation occur. The increase in amplitude not significant. The electron-hole pairs produced from high energy X-ray are far from the junction of the detector and consequently the recombination process of electron-hole pairs is dominant [25]. We can see that the linearity of the FTO/CdS/CdTe/Mo sensor is better at lower intensity of X-ray than that at higher intensity. In this work we used the energy range from 21 to 42 KeV because the maximum obtained thickness for CdS/CdTe junction is of range 4 μm. The stacked four CdS/CdTe junction connected in series increases the area of the sensor. As the area increases, the number of interactions of X-ray with CdS/CdTe junction is enhanced resulting in the increase of the collected charges and the signal amplitude.

4 Conclusion

CdTe was electrodeposited onto the prepared CdS/FTO substrates. The cyclic voltammetry was used to provide the optimum applied voltage for CdTe deposition onto CdS/FTO glass substrate, where -1.3 V was found suitable for CdTe film deposition. By growing CdTe layer onto CdS/FTO at constant voltage a homogeneous good distribution layer was established with maximum thickness 4μm. Mo metal as a back contact was deposited on CdTe/CdS/FTO hetero junction samples by DC magnetron sputtering system. The performance of the FTO/CdS/CdTe/Mo X-ray detector was measured by computerized oscilloscope. The output electric were measured at 21, 27 and 30 keV and 0.05 mA intensity and were found to be 0.41, 065 and 0.72V respectively, while the peak amplitude at 21, 27 and 33 keV and 1mA intensity were found to be 0.64, 0.86 and 1.03V respectively, which indicating good performance, response and sensitivity to different X-ray energy and intensity. By utilizing peak amplitude obtained from the detector, we demonstrate a new method to measure X-ray. with the 4 detector stacked in series. Stacked FTO/CdS/CdTe/Mo X-ray detector have been developed, demonstrating room-temperature semiconductor radiation detectors. The used fabrication method intended to be simple, low cost and available to reduce the production cost of the detector. This new sensor technology is useful for many applications requiring direct, high sensitive imaging of X-rays at room-temperature.

References:

1- Laxmidhar Besra, Meilin Liu, "A Review on Fundamentals and Applications of Electrophoretic Deposition (EPD)", Progress in Materials Science 52 (2007) 1–61, (2007), doi:10.1016/j.pmatsci.2006.07.001, 2007.

2- I. M. Dharmadasa, P. A. Bingham, O. K. Echendu, H. I. Salim, T. Druffel, R. Dharmadasa , G. U. Sumanasekera, R. R. Dharmasena, M. B. Dergacheva, K. A. Mit, K. A. Urazov, L. Bowen, M. Walls and A. Abbas, "Fabrication of CdS/CdTe-Based Thin Film Solar Cells Using an Electrochemical Technique", Coatings 2014, 4, pp. 380-415, ISSN 2079-6412, (2014), doi:10.3390/coatings4030380, 2014.

3- F. Lisco, A. Abbas, J.W. Bowers, G. Claudio, P.M. Kaminski, J.M. Walls, "Electrodeposition of CdTe Films on CdS Layers Deposited Using Magnetron Sputtering and Chemical Bath Deposition", Proceedings of the 10th Photovoltaic Science, Applications and Technology Conference C96 (PVSAT-10), Holywell Park, Loughborough university, Loughborough, pp. 145 – 148, 2014.

4- Gennadiy Khrypunov, Natalja Klochko, Neonila Volkova1, Viktor Lyubov, and Tatyana Li, "Single-Phase Cadmium Telluride Thin Films Deposited by Electroless Electrodeposition", Japanese Journal of Applied Physics 50 (2011) 05FH04, doi: 10.1143/JJAP.50.05FH04, 2011.

5- C. Lepillera, P. Cowachea, J. F. Guillemolesa, N. Gibsonb, E. OE zsanc, D. Lincota, "Fast Electrodeposition Route for Cadmium Telluride Solar Cells", Thin Solid Films 361-362 (2000) 118-122, 2000. https://doi.org/10.1063/1.4895925.

6- Jun Wanga, Qian Lib, Yannan Mua,c, Xiaoming Zhoud, Lihua Yange, Pin Lva, Shi Sua, Jiasheng Niua, Wuyou Fua and Haibin Yanga, "Effect of Sodium Chloride on the Electrochemistry Activity of

Electrodeposited CdTe films with various morphologies", The Royal Society of Chemistry, doi: 10.1039/C5RA05885F, 2015.

7- J. Wang, Q. Li, Y. Mu, S. Li, L. Yang, P. Lv, S. Su, T. Liu, W. Fu, H. Yang, "Fabrication of CdTe Thin Films Grown by the Two-Step Electrodeposition Technique on Ni Foils", Journal of Alloys and Compounds (2015), doi.org/10.1016/j.jallcom.2015.02.094, 2015.

8- Utpal Madhu, Nillohit Mukherjee, Nil Ratan Bandyopadhyay and Anup Mondal, "Properties of CdS and CdTe Thin Films Deposited by an Electrochemical Technique", Indian Journal of Pure and Applied Physics, vol. 45, March 2007, pp. 226-230, 2007.

9- Qian Li, Yufen Yang, Meiling Sun, Yannan Mu, Wuyou Fu, Haibin Yang and Lecheng Tian, "Electrodeposition of a Novel CdTe Array on Ni foils and Photoelectrochemical Performance", CrystEngComm, 2013, 15, 6911, (2013), doi:10.1039/c3ce40900g, 2013.

10- O. K. Echendu, K. B. Okeoma, C. I. Oriaku, and I.M. Dharmadasa, "Electrochemical Deposition of CdTe Semiconductor Thin Films for Solar Cell Application Using Two-Electrode and Three-Electrode Configurations: A Comparative Study"', Article ID 3581725, 8 pages, doi.org/10.1155/2016/3581725, 2016.

11- N. Dhara, P. Chelvanathana, M. Zamanb, K. Sopiana, N. Amina,b,c, "An Investigation on Structural and Electrical Properties of RF-Sputtered Molybdenum Thin Film Deposited on different Substrates", Energy Procedia, 33 (2013), pp. 186 – 197, doi: 10.1016/j.egypro.2013.05.057, 2013.

12- X-Ray Generator Geratogram Roentgen generate instrument 42kV Manual.

13- O. K. Echendu, K. B. Okeoma, C. I. Oriaku, and I.M. Dharmadasa, "Electrochemical Deposition of CdTe Semiconductor Thin Films for Solar Cell Application using two-Electrode and Three-electrode Configurations: a Comparative Study", Advances in Materials Science and Engineering Vol. 2016, 3581725, doi: org/10.1155/2016/3581725.

14- D. G. Diso1, F. Fauzi, O. K. Echendu, O. I. Olusola, I. M. Dharmadasa, "Optimization of CdTe Electrodeposition Voltage for Development of CdS/CdTe Solar Cells", Journal of Materials Science Materials in Electronics, doi: 10.1007/s10854-016-4844-3, 2016.

15- Imyhamy M. Dharmadasa, Mohammad L. Madugu, Olajide I. Olusola, Obi K. Echendu, Fijay Fauzi, Dahiru G. Diso, Ajith R. Weerasinghe, Thad Druffel, Ruvini Dharmadasa, Brandon Lavery, Jacek B. Jasinski, Tatiana A. Krentsel and Gamini Sumanasekera, "Electroplating of CdTe Thin Films from Cadmium Sulfate Precursor and Comparison of Layers Grown by 3-Electrode and 2-Electrode Systems", Coatings 2017, 7, 17; doi:10.3390/coatings7020017, 2017.

16- Catherine Lepillera, and Daniel Lincota, "New Facets of CdTe Electrodeposition in Acidic Solutions with Higher Tellurium Concentrations", Journal of The Electrochemical Society, 151 (5) C348-C357 , 2004.

17- Azam Mayabadi, Kavoos Mirabbaszadeh, Amit Pawbake, Sachin Rondiya, Avinash Rokade, Ravindra, Waykar, Rupali Kulkarni, Habib Pathan, Sandesh Jadkar, " Electrochemical Deposition of p-CdTe Nanoparticle Thin Films for Solar Cell Applications", J Mater Sci: Mater Electron (2017) 28:18745–18754, doi:10.1007/s10854-017-7823-4, 2017.

18- M. Rami, E. Benamar, M. Fahoume, F. Chraibi, and A. Ennaoui, " Effect of Heat Treatment with $CdCl_2$ on the Electrodeposited CdTe/CdS Heterojunction", M.J. Condensed Matter VOL. 3, Number 1, 1 July 2000.

19- A. A. Ojo · I. M. Dharmadasa, "Analysis of Electrodeposited CdTe Thin Films Grown Using Cadmium Chloride Precursor for Applications in Solar Cells", J Mater Sci:

Mater Electron, doi:10.1007/s10854-017-7264-0, 2017.

20- Chandan Bhardwaj, " Studies on optimisation of processing parameters for ultra-thin CdTe solar cell", for the degree of Master of Philosophy, Heriot-Watt University, School of Engineering and Physical Sciences, September 2015, http://hdl.handle.net/10399/3027, access on 1/9/2015.

21- Atef Y. Shenouda, El Sayed M. El Sayed, "Electrodeposition, Characterization and Photoelectrochemical Properties of CdSe and CdTe", Ain Shams Engineering Journal, (2014), doi.org/10.1016/j.asej.2014.07.010, 2014.

22- Y. V. Znamenshchykov, V. V. Kosyak, A. S. Opanasyuk, M. M. Kolesnyk, V. V. Grinenko, P. M. Fochuk, "Structural Properties of $Cd_{1-x}Zn_xTe$ Films Deposited by Close Spaced Vacuum Sublimation", Functional Materials, 23, No. 1 (2016), pp. 32-39, ISSN 1027-5495, doi:org/10.15407/fm23.01.032, 2016.

23- J. C. Manifacier, J. Gasiot and J. P. Fillard, "A Simple Method for the Determination of the Optical Constants n, h and the Thickness of a Weakly Absorbing Thin Film", (1976) doi: 10.1088/0022-3735/9/11/032, 1976.

24- S. Ilican, M. Caglar, and Y. Caglar, "Determination of the Thickness and Optical Constants of Transparent Indium-Doped ZnO Thin Films by the Envelope Method", Material Science-Poland, 0137-1339, 3 ,2007.

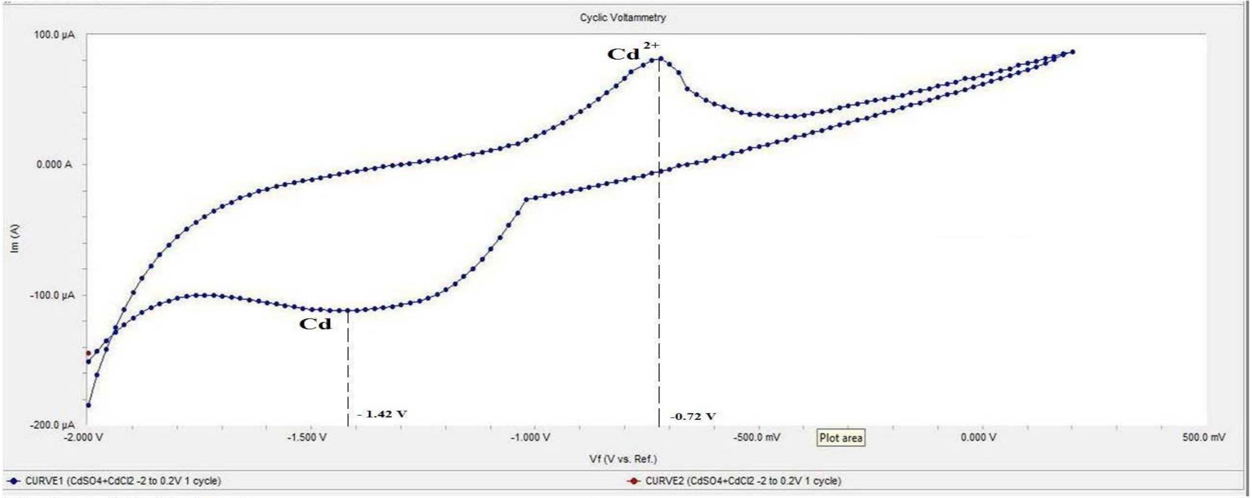
25- Kim Mitchell, Alan L. Fahrenbruch and Richard H. Bube, "Photovoltaic Determination of Optical Absorption Coefficient in CdTe", Journal of Applied Physics, 48, 829 (1977), doi: 10.1063/1.323636, 1977.

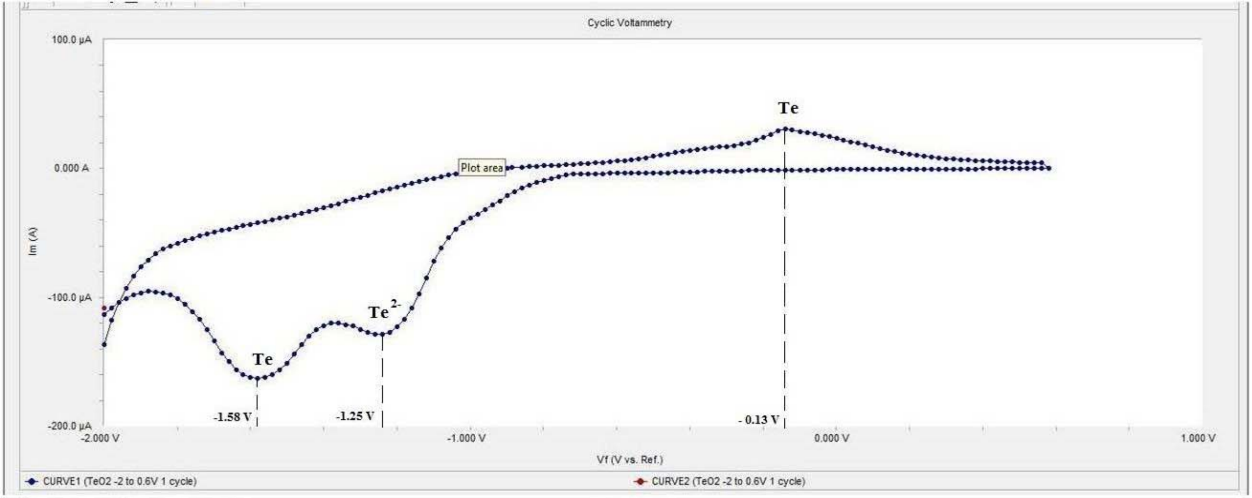
26- Jesus Rangel-Cardenas and Hugo Sobral, "Optical Absorption Enhancement in CdTe Thin Films by Microstructuration of the Silicon Substrate ", Materials 2017, 10, 607; doi:10.3390/ma10060607, 2017.

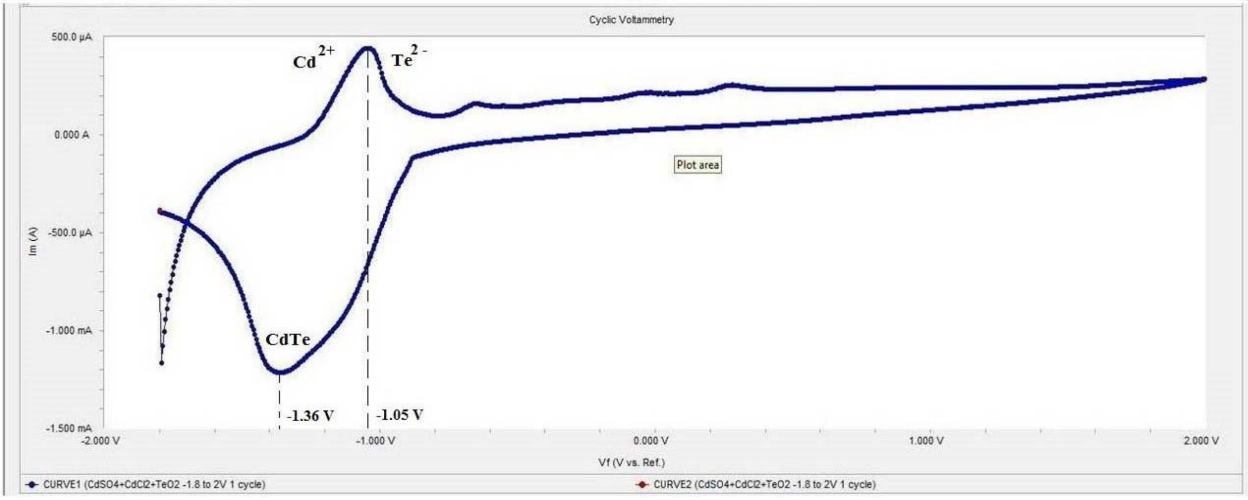
27- G. E. Knoll. Radiation Detection and Measurement 3rd edn., John Wiley and Sons, New York, PP. 48:53, 103:111, 308:317, 2000.

28- J. Abramovitch, Engaged learning at SMUD digital repository, Development of a Silicon PIN Diode X-Ray Detector (2014),http://digitalrepository.smu.edu/upjournal_research/32, 2014.

Appendix







Figures 2, 3, 4

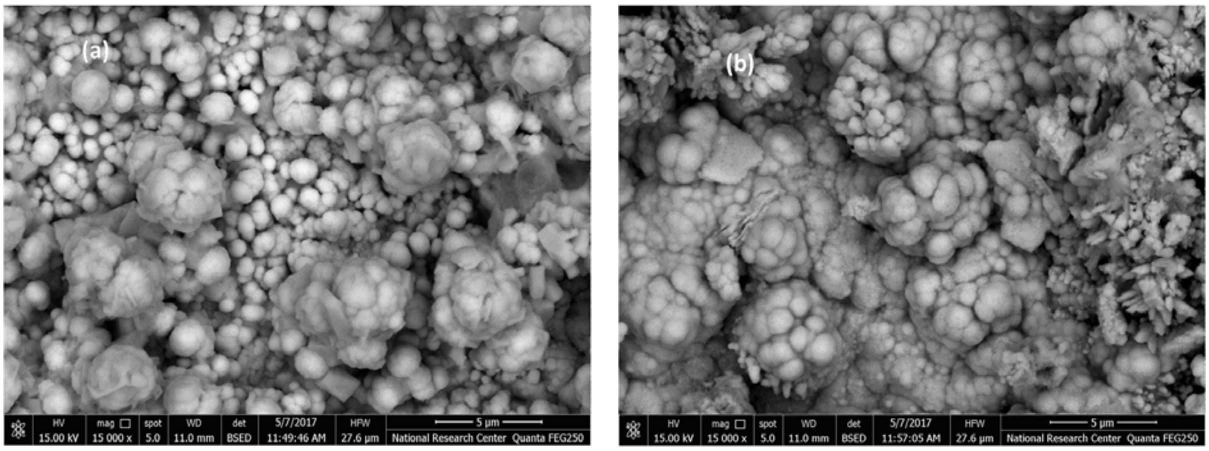
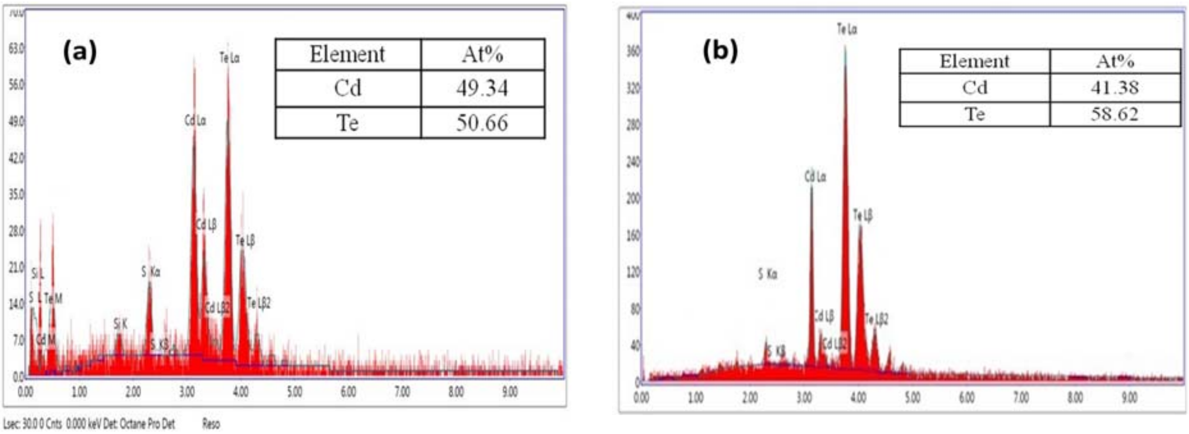


Figure 5: (a), (b).



Element	At%
Cd	49.34
Te	50.66

Element	At%
Cd	41.38
Te	58.62

Figure 6: (a), (b)

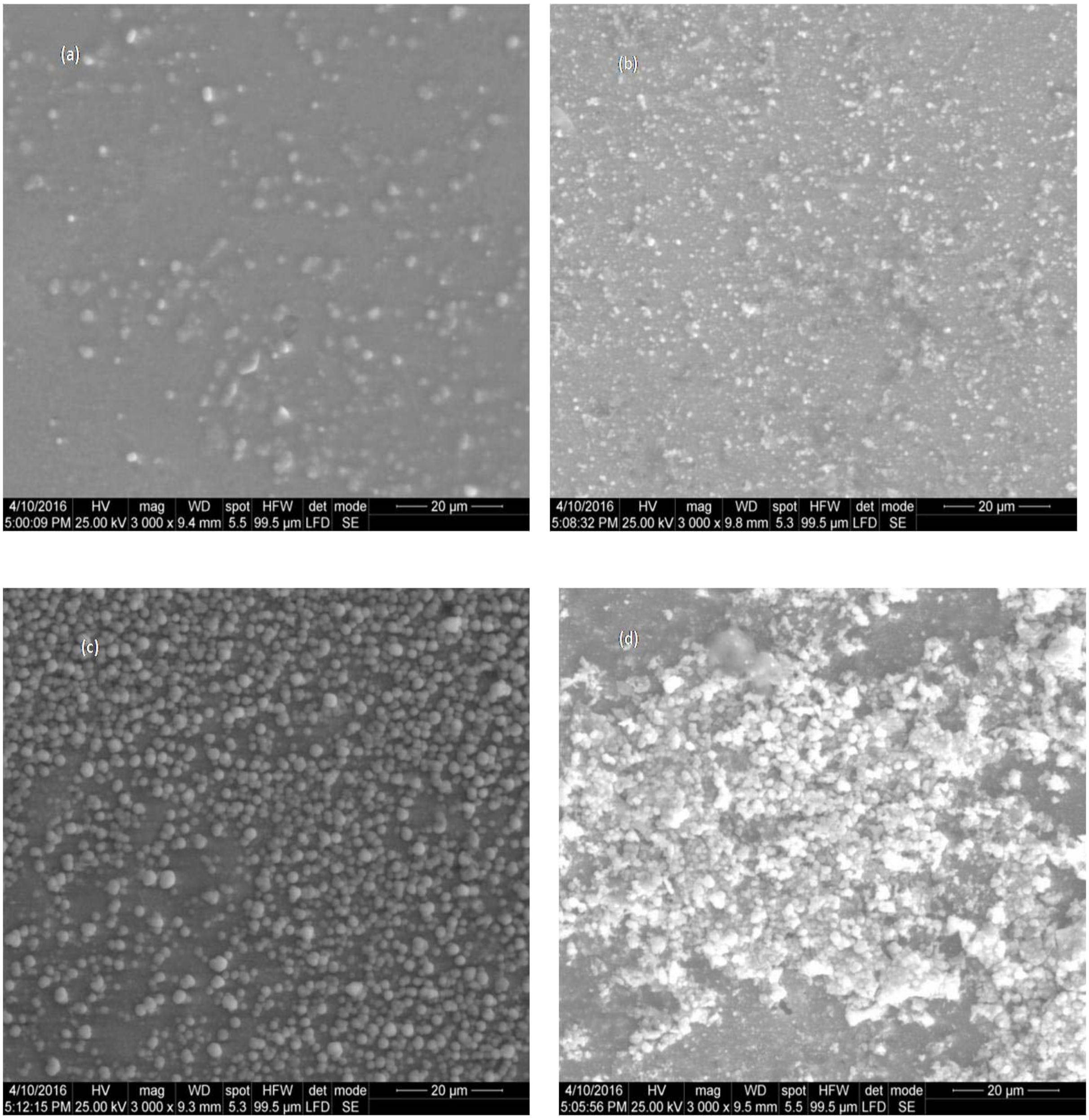
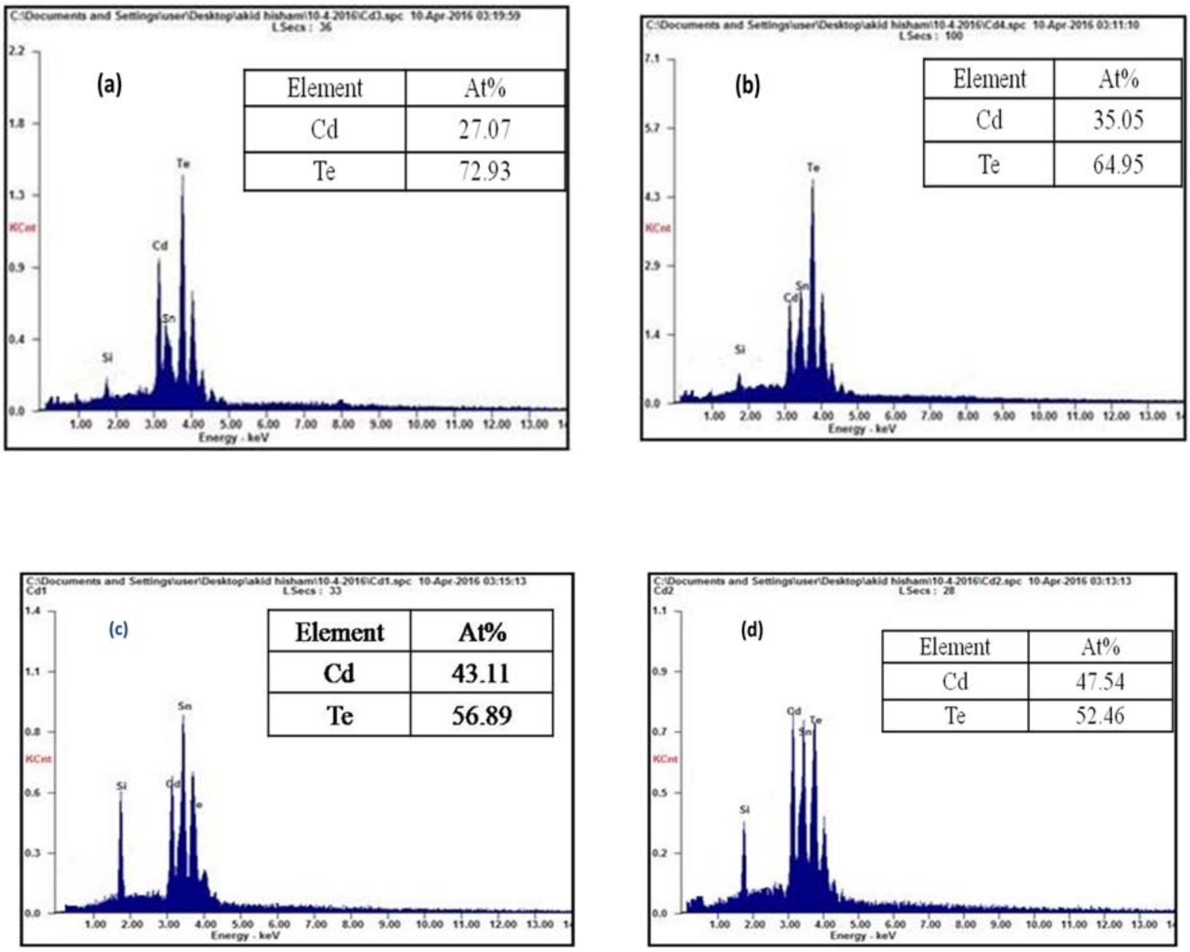


Figure 7: (a), (b), (c), (d)



(a)

Element	At%
Cd	27.07
Te	72.93

(b)

Element	At%
Cd	35.05
Te	64.95

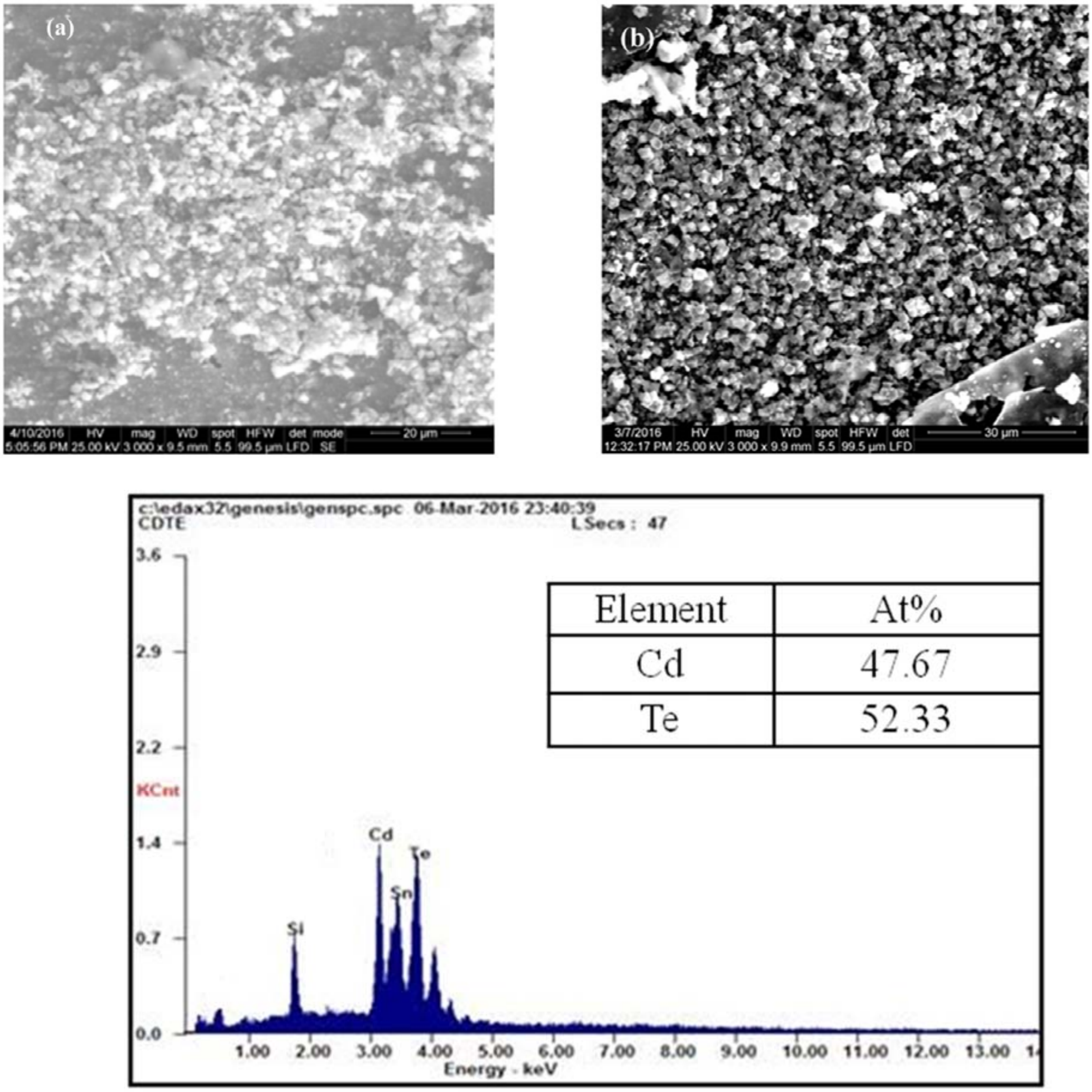
(c)

Element	**At%**
Cd	**43.11**
Te	**56.89**

(d)

Element	At%
Cd	47.54
Te	52.46

Figure 8: (a), (b), (c), (d)



Element	At%
Cd	47.67
Te	52.33

Figure 9: (a), (b), Figure 6.10

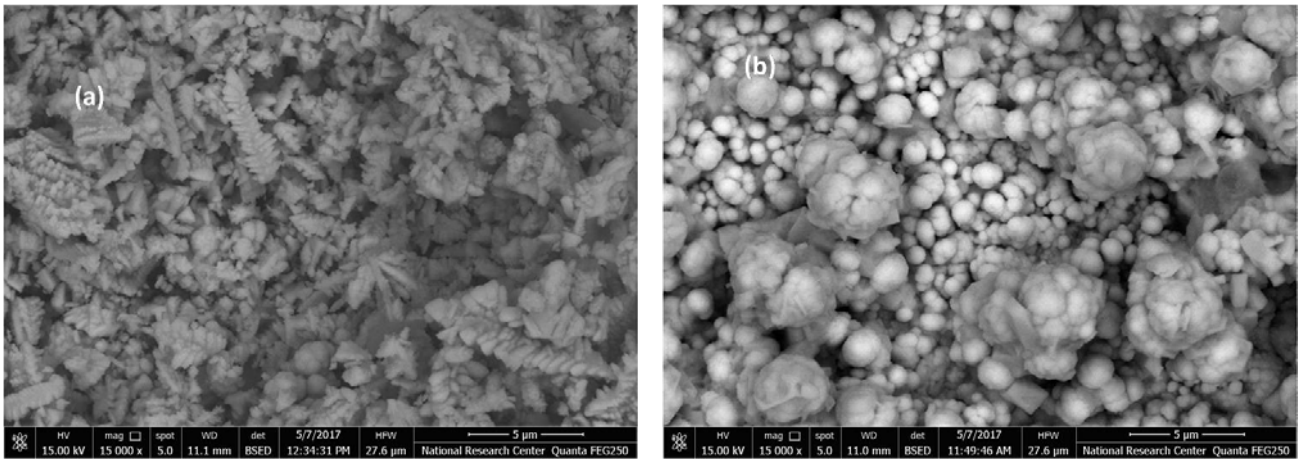
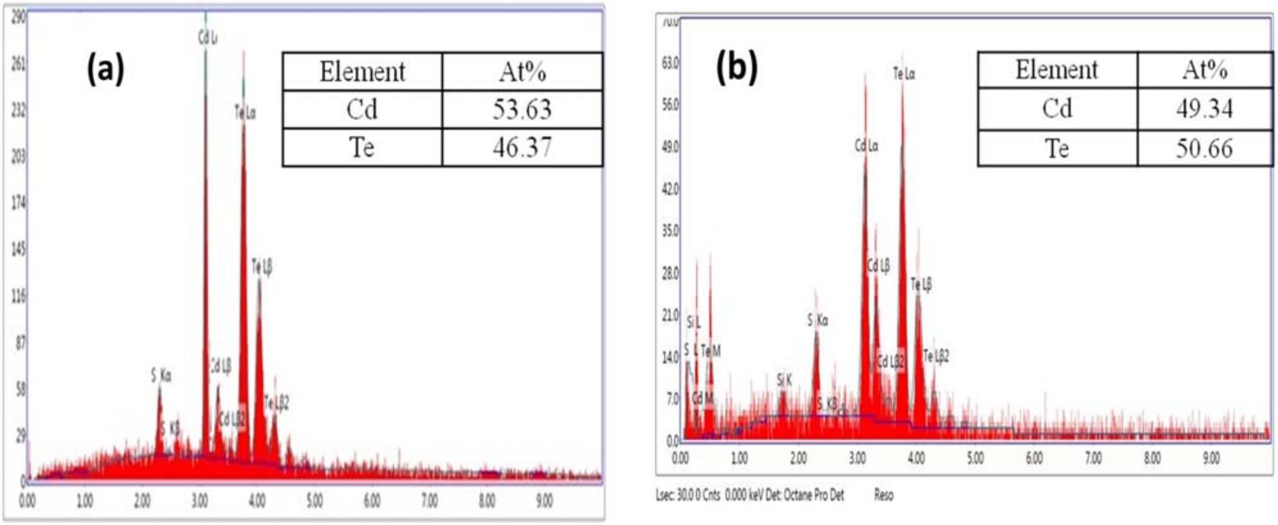


Figure 11



(a)

Element	At%
Cd	53.63
Te	46.37

(b)

Element	At%
Cd	49.34
Te	50.66

Figure 12

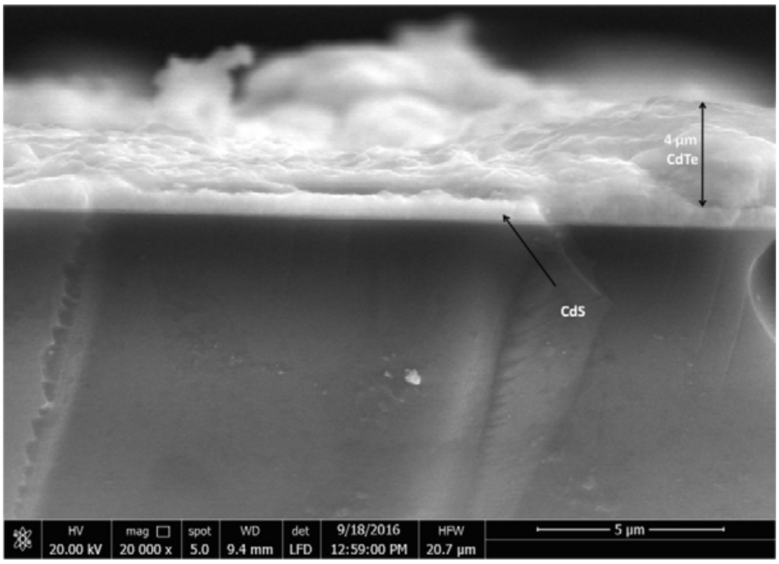
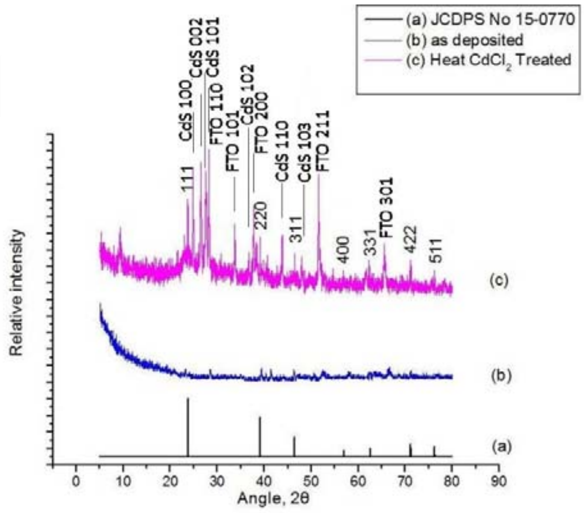


Figure 13



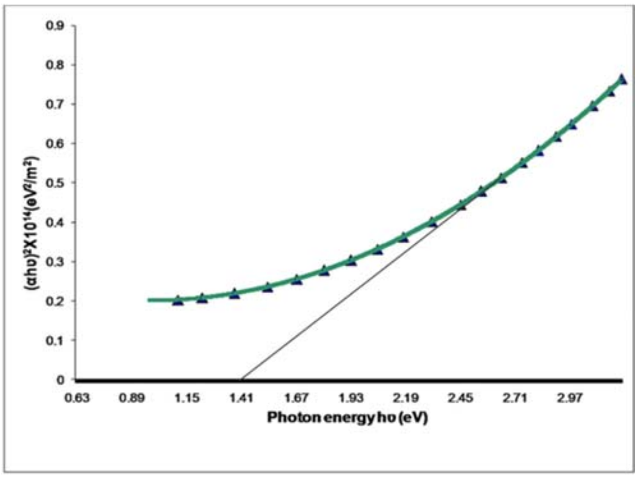


Figure 14

Figure 15

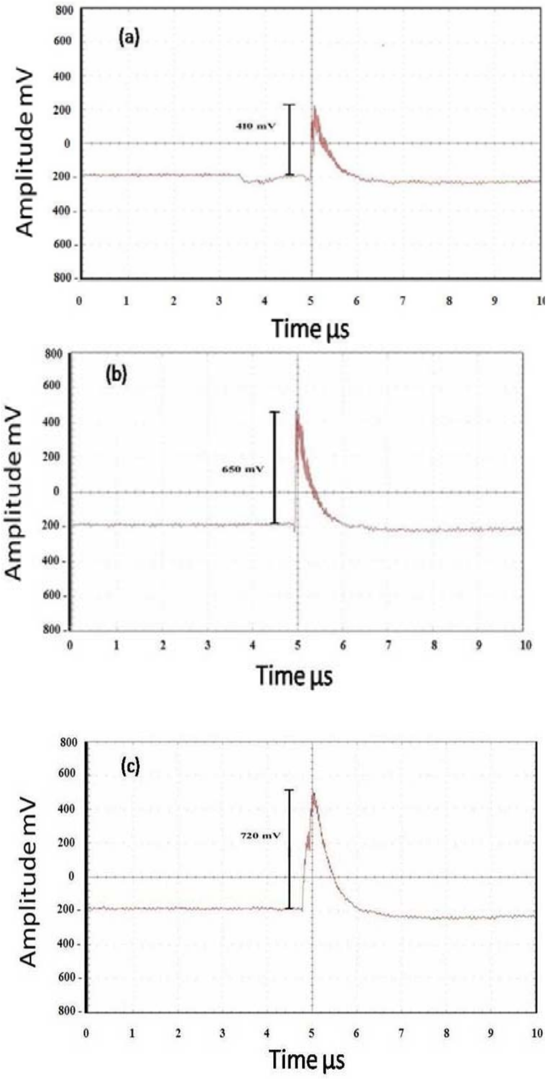


Figure 16

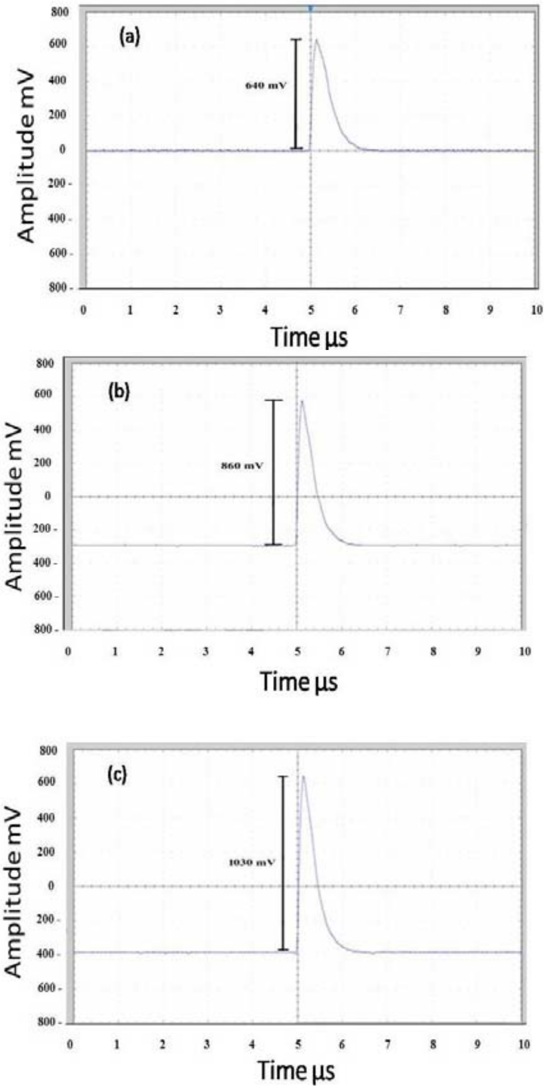


Figure 17

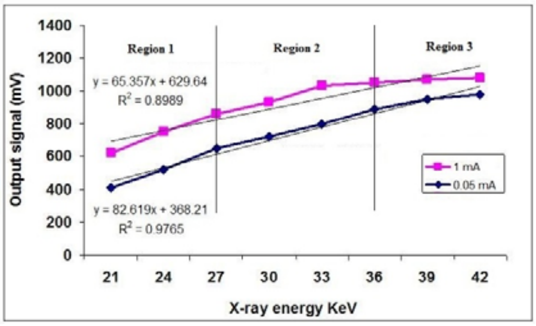


Figure 18