Citrus fruit peels extracts as light harvesters for efficient ZnO-based dye-sensitized solar cells

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Abstract. Our voracious consumption of fossil fuels at an exponentially increasing rate has led to global warming and climate change. As a result of these problems, it is crucial to explore other sources of clean energy. The natural pigment extraction and the performance determination in Dye-Sensitized Solar Cells (DSSCs) from fruit peels of citrus were presented in this paper. Extraction of natural dye of citrus fruit peels of Citrus paradisi, Citrus sinensis, Citrus limonum and Citrus tangelo were employed as light sensitizers in fabricating ZnO-based DSSCs. The natural pigments extracts characteristics were analyzed by UV-Vis absorption, Fourier transforms infra-red (FTIR) and Photoluminescence spectroscopy techniques. The semiconductor active layer material was synthesized and analyzed. The characteristics of photo-voltaic parameters for the invented DSSCs were studied under simulated sunlight. The presence of chlorophyll derivative in most of the extracted dyes is evident as the core pigments with additional accessory pigments. The conversion efficiencies of sunlight to electrical energy of pheophytin ‘a’ dye ZnO based solar cells are calculated to be 0.028%, 0.013%, 0.004% and 0.022% for Citrus paradisi, Citrus sinensis, Citrus limonum and Citrus tangelo, respectively. Better performance of photo-sensitized was observed for the extracts of Citrus paradisi compared to the other extracts and this may be owing to the better charge transfer between the pigments of Citrus paradisi and surface of ZnO photoactive layer. The conversion of visible light to electricity was produced from natural pigments and ZnO photoactive layer based DSSCs, resulted into superb photo-electric characteristics.

Keywords: Natural dye; citrus fruit peels; chlorophyll derivative, photoactive layer, DSSC, conversion efficiency

1. Introduction
The rapid development of global economy and industrialization in the past century has also brought about grievous problems to the world’s population. Recently high amount of research efforts have concentrated over the years to Dye-Sensitized Solar Cell (DSSC). DSSCs have enticed great recognition because of their low cost of production and environmental friendliness, since its first solar cells development in 1991 [1,2,3]. DSSCs are termed to be favourably low-cost solar cells with comparable sunlight-to-electricity conversion efficiency. In the past years, several photovoltaic cells that guarantee conversion of solar energy from the sun to electrical energy have been discovered. However, two significant problems mitigating against their practical application is restricted by the cost implication and conversion efficiency [2,3,4].
The sensitizer, electrolyte, counter electrode and the porous crystalline wide band gap semiconductor electrode are four main fragments of DSSCs [3,4]. The sensitization of semiconductor photo-anode in DSSC was responsible for the sunlight to electrical energy conversion. However, it was owing to the dye extract light absorption in the visible region, the nature of semiconductor conduction band are relative to the excited dye state in the locality and addition of the dye molecules onto the semiconductor porous layer surface [5,6].

The sensitizer in DSSCs can be broadly categorized according to the structure of dye: polypyridyl complexes of ruthenium (metal complex) and synthetic or natural organic dyes. Synthetic polypyridyl complex of ruthenium dyes have been extensively used as dyes in DSSCs with 11-13% of conversion efficiencies were reported [7,8,9]. However the cost of ruthenium is high, rare, and unwanted due to its effect on the environment [3].

Currently, the natural dyes extraction usage from various parts of plant such as flowers, leaves and various fruits as photo-sensitizer in DSSCs have fascinated a great deal because of their biodegradable and availability characteristics [3,4,6]. Abundant natural occurring pigments like carotenoid [10,11], anthocyanin [12,13,14] and betalains [15] chlorophyll [16,17,18,19] have been effectively used and described as sensitizers for DSSCs. The merit of using natural pigments as sensitizer includes; large absorption coefficient, high efficient light-conversion, low toxicity, environmentally friendliness, fully biodegradable, cheap cost and availability [3,15]. Natural occurring pigments in TiO$_2$ based DSSC using extracts from Citrus paradisi, Citrus sinensis, Citrus limonum and Citrus tangelo fruit peels were used as a dye which resulted into 0.63%, 0.36%, 0.10% and 0.51% efficiencies respectively have been reported [19]. Despite earlier studies, it is imperative to study the performance of other semiconductor anode materials with the extracts from citrus fruit peels.

From this present study, the extraction of natural pigments from fruit peels of Citrus paradisi, Citrus sinensis, Citrus limonum and Citrus tangelo were studied. The optical characterization of the extracted pigments was analyzed. The structural and compositional characterization of Photo-anode ZnO nanoparticle material was also done. The photo-voltaic characteristics of ZnO based DSSCs coupled with the natural dyes from fruit peels of Citrus paradisi, Citrus sinensis, Citrus limon and Citrus tangelo were analyzed.

2. Materials and methods

2.1 Natural Pigments Preparations

Citrus paradisi (grapefruit), Citrus sinensis (orange), Citrus limonum (lemon), and Citrus tangelo (tangerine), were purchased in a market at Ogbomoso, Nigeria. In order to make the weight of the peels from the citrus fruits invariant, the peels were thoroughly washed severally in distilled water and allowed to dry at 60°C in a vacuum oven. The dried peels were pulverized into powder. In this research, the extraction of natural dye photo-sensitizers were obtained by dissolving 5 g of dried peels fine powder in 250 ml of ethanol and aged for 48 hours under ambient temperature undisturbed. The resulting dye solutions were concentrated after it has been filtered and covered from exposure to direct sunlight. Without any further purification, the natural dye photo-sensitizers were analyzed and utilized as sensitizer.

2.2 Construction of Dye Sensitized Solar Cell

Highly conducting film of Fluorine-doped tin oxide (FTO) glass substrate (Solaronix, SA with 8 Ω/sq resistance) was used as supplied. Ultrasonic bath of detergent solution was employed in cleaning the FTO substrates for 30 min and rinsed with the combination of acetone and ethanol for another 30 min to guarantee an impurity free deposition. Doctor Blade technique with 1 cm × 1 cm dimension was employed to deposit a homogenous paste of ZnO powder (May & Baker Ltd Dagenham, England) on the surface of substrate. In order to obtain pre-selected thickness, the sample was repeatedly desiccated at 125°C for 15 min in an oven. At 450°C, the sample was sintered for 1hr inside the furnace and allows cooling to 80°C, before dipping into natural pigment solution at a certain interval to warranty complete
adsorption. Both counter electrode (platinum nanoparticles-coated FTO) and electrolyte (Iodolyte AN-50) were acquired from Solaronix, SA which were used as supplied. The sensitized ZnO electrode and counter electrode was formed together through sandwiching method to couple the constructed DSSCs as it was reported in literature[20]. The characteristics of the constructed cells were later characterized.

2.3 Measurements and Characterization
The absorption characteristics of natural pigments were recorded by scanning along the wavelength of 400-800 nm using UV-Vis-NIR spectrometer (Shimadzu UV-3600). FT-IR spectrometer (NICOLET 380) was used to analyze the natural pigment spectra peaks interval of 400 and 4000 cm⁻¹. A spectrofluorometer (QM-40, Photon Technology International, PTI) was employed to determine the photoluminescence (PL) spectra for natural pigments using an excitation source of Xenon lamp (150 W).

X-ray Diffraction (XRD) characteristics was analysed by X’pert pro MPD PANanalytical with CuαK radiation (λ = 1.5406 Å) and Scanning Electron Microscope, SEM (LEO 430i, Carl Zeiss) were employed to characterize the structural, morphology and compositional characteristics of ZnO powder respectively. The Transmission Electron Microscopy (TEM; Tecnai G2 30ST) was also used to studied microstructure of the ZnO powder.

The characteristic current and voltage data were recorded on measure source unit (Kethley 2400) with solar simulator (Newport model No: 96000) at 100 mW/cm² (1 sun AM1.5). A mask with an active area of the cell 0.5 cm² was used for measurement. The average measurements taken on three repeated experiments for the samples were reported for photo-electrochemical results.

3. Results and Discussion

3.1 Optical absorption analyses of extracted pigments used as photo-sensitizers
UV-Vis optical absorption curve for Citrus paradisi, Citrus sinensis, Citrus limonum and Citrus tangelo, in ethanol as solvent with the inset of the equivalent colour of natural dye extraction are shown in Figure 1. Figure 1(a-d) showed the two main strong absorption peaks of natural extract were aligned around the wavelengths of about 538 nm, 608 nm, 666 nm; 538 nm, 608 nm, 666 nm; 540 nm, 608 nm, 666 nm and 539 nm, 608 nm, 666 nm for Citrus paradisi, Citrus sinensis, Citrus limonum and Citrus tangelo, respectively. It was shown that the absorbance peaks of all the natural dyes were the same. The maximum absorption in the region of 666 nm was recorded for all the four dyes and similarly, two weak bands are observed at 538 nm and 608 nm. The intense Qy band observed at 666 nm, with a weak bands found at 538 nm and 608 nm are in agreement with the described facts for chlorophyll and its derivative [10,21]. It has been reported that many accessory pigments of non-chlorophyll like carotenoid do absorb light with chlorophyll and its derivative [19,21]. However, the prevailing pigment here is pheophytin ‘a’ because major observed peaks correspond to the reported band for pheophytin ‘a’ [14,20,21].

3.2 Studies of photo-luminescence of natural dyes
Photoemission analysis of the pigments extracted is essential in order to establish the potential connection of the presence of emission characteristics for photoelectron with photon to electric conversion of natural photo-sensitizers based DSSC.

The steady-state PL measurements were recorded for all the extracts of natural pigments. The emission spectra of Citrus paradisi, Citrus sinensis, Citrus limonum and Citrus tangelo dye extracts in alcohol are shown in Figure 2. Similar trend of maximum intensity emission located at 495 nm and 675 nm with a small arm at 725 nm is observed. The intensity of photoemission of all pigments at 675 nm with an arm at 725 nm as shown (Figure 2) implies the characteristic response of chlorophyll derivative. In all the spectra, a small red shift compare to that of chlorophyll was observed. The absorption and PL plot show a bathochromic shift as the chlorophyll and its derivative
molecules lean towards the possible aggregation in polar solvents [21,22,23,24]. Intensity of photo-emission of all the dyes at 495 nm shows the presence of non-chlorophyll pigment with emission characteristic.

Figure 1. Plot of absorption against wavelength for light sensitizer achieved from citrus peels (a) *Citrus paradisi*(b) *Citrus sinensis* (c) *Citrus limonum*(d) *Citrus tangelo* alcoholic extracts and inset showing digital photo of natural pigment solution.

Figure 2. Plot of PL intensity against wavelength of the natural dyes.
Figure 3. Plot of transmittance against wavenumber of natural dyes found from citrus fruit peels (a) *Citrus paradisi* (b) *Citrus sinensis* (c) *Citrus limonum* and (d) *Citrus tangelo*.

Figure 4. XRD result with reflection planes of ZnO powder sample.
In agreement with absorption spectra shown in Figure 1, this result shows the presence of other pigments. Basically, bright fluorescence maximumintensity of around 660-700 nm was associated with chlorophylls and pheophytins and with a shoulder of nearly 720-740 nm showing their individualities feedback [21,22]. There is a little red shift in intensity ofemission in all the pigments compare with that of Pheophytin ‘a’. The photoemission spectra are in agreement with the outcome of optical absorption curve, showing typical characteristic feedback of the pheophytin ‘a’, which overshadowed all non-chlorophyll that can be present.

3.3 studies of Fourier Transform-Infrared (FT-IR) analysis of natural dye sensitizers
FTIR spectra of natural pigments from Citrus paradisi, Citrus sinensis, Citrus limonum and Citrus tangelo of citrus peels as shown in Figure 3(a-d) display some of the typical peaks of chlorophyll derivatives [21,23]. The intense and broad bands at 3420-3435 cm\(^{-1}\) are owing to the –OH groups of water and alcohol or N-H band; a band at 1063 cm\(^{-1}\) which belongs to C=O-C mode of vibration of carbohydrate groups; and two points observed at 2924 cm\(^{-1}\) and 2845 cm\(^{-1}\) which belong to asymmetric and symmetric –CH stretching modes respectively. Additionally, the peak at 1618-1638 cm\(^{-1}\) which belongs to double bond (C=C) stretching vibration which is correspondto the stretching of aromatic C=C in chlorophyll, anthocyanin and carotenoid [16,17,18]. The ketone with cyclopentanone ring of pheophytin ‘a’ of the characteristic of C=O band is detectedwithin 1730 cm\(^{-1}\) and 1744 cm\(^{-1}\). The pheophytin ‘a’ presence in the extraction of all the four citrus peels was affirmed by the results of FTIR, which is more allied with the results of UV-Vis and PL spectral.

3.4 X-ray Diffraction (XRD) analysis of ZnO sample
The ZnO powder sample phase evolution was established at room temperature by XRD analysis as shown in Figure 4. The XRD patterns showed coincided with typical structures of wurtzite hexagonal phase of ZnO (JCPDS file 75-0576). The average grain size“D”of 34.2 nm was estimated from the preferred diffraction peak along the <101> plane ofZnO powder sample.

3.5 Studies of microstructural and compositional analysis of ZnO sample
ZnO powder samples of SEM microstructure andEnergy-dispersive X-ray (EDX) spectra are revealed in Figure 5. The morphology of the particle is homogenous and sphericalin nature, with littleassemblage of the particles. Furthermore, the hexagonal structure is also evident from SEM microstructure results. The results from EDX also described matching Zinc (Zn) and Oxygen (O) peaks.

The structural characterization was strengthened by carrying-out TEM analysis on ZnO powder sample. The TEM analysis of the sample dispersed in ethanol is demonstrated as shown in Figure 6. InFigure 6(a),there was aformation of spherical shape nanoparticle. The nanoparticles diameter was in the range of 20 nm to 50 nm. Each individual nanoparticles are single crystalline in nature which was established by High Resolution Transmission Electron Microscopy (HRTEM) image, where their spacing agree with (101) reflection as displayed in Figure 6(b). Figure 6(c) showed the pattern of the Selected Area Electron Diffraction (SAED) which pronounces (101), (102) and (200) planes of ZnO.

3.6 Performance evaluation of Photovoltaic
The photo-electrochemical device performance of natural dyes in solar cell was verified using 100 mW/cm\(^{2}\)radiance (AM 1.5). In Figure 7, the current density-voltage (J-V) curves are displayed for the fabricated DSSCs and photo-electrochemical parameters corresponding to the devices are displayed in Table 1. The results of open-circuit voltage (\(V_{OC}\)) changes from 0.285 to 0.32 V, and the results of short-circuit current density (\(J_{SC}\)) ranges from 0.033 to 0.299 mAcm\(^{-2}\). The efficiencies of 0.028%, 0.013%, 0.004% and 0.022% were recorded for the fabricated DSSCs with natural dyes from Citrus paradisi, Citrus sinensis, Citrus limonum and Citrus tangelo citrus fruit peels respectively. Specifically, fabricated DSSC sensitized by Citrus paradisi extract was found to have a better open-
circuit voltage ($V_{OC} = 0.323$ V), short-circuit current density ($J_{SC} = 0.299$ mAcm$^{-2}$) and highest efficiency of 0.028% compared to the electrical output of the remaining natural dyes sensitizer.

Figure 5. SEM and EDX images of ZnO powder.

Figure 6. ZnO nanoparticles TEM images (a) separated nanoparticles (b) HRTEM image of a single nanoparticle, and (c) SAED pattern.
This study shows an appreciable efficiencies of ZnO based DSSCs fabricated from natural pigments used by other authors [20,25,26,27]. Possibly this may be owing to a wider absorption range of light for natural pigments adsorbed onto the film of ZnO, and better interaction between chlorophyll derivative and a better transfer of charges of ZnO in these extracts[25,26,27]. In addition, the extracts of Citrus paradisi chlorophyll derivative structure in this work might have a shorter distance between the dye skeleton and a point associated to ZnO surface matched to that of other extracts. This could enable transfer of electron from phaeophytins molecules in the extracts to ZnO surface and possibly be justified for an improved performance of Citrus paradisi extract. Based on this result, the interaction between the pigments and film of ZnO is significantly improving the performance of DSSCs. In this work, the natural pigments used may have no or low availability of bonds between ZnO film and the molecules of dye and through which electrons can transport from excited dye molecules to the film of ZnO[25]. The low efficiency obtained from fabricated DSSC using natural dye as photo-sensitizers can be due to non-existence of well interaction between the molecules of dye and ZnO surface through which electrons can transport from the part of molecules of excited dye to film of ZnO compared to synthetic dyes [3,4].

The short-circuit (Jsc) performance controls by dye molecules quality adsorbed into surface of photo-active layer, structure of dye, light harvesting and the injection of electron capacity of dyes into DSSC [6]. The availability of more dye molecules on the surface of ZnO produces further number of photon from sunlight that produces faster injection of electron. Furthermore, the fill factors of around 30% were recorded for most of the fabricated cells. The low conversion efficiency of the fabricated cells may be owing to large resistance in the cell and it probably accountable to low fill factor values. Based on the above results, the extraction of Citrus paradisi can be better alternative for the application of solar cells.

Figure 7. Plot of current density against voltage for ZnO based DSSCs with (a) Citrus paradisi (b) Citrus sinensis (c) Citrus limonum (d) Citrus tangelo alcoholic extracts as sensitizer.
Table 1. Photovoltaic characteristics of natural dye with ZnO as photo-active layer based DSSCs using *Citrus paradisi*, *Citrus sinensis*, *Citrus limonum* and *Citrus tangelo* alcoholic extracts.

| Dye                 | $V_{OC}$ (V) | $J_{SC}$ (mA/cm$^2$) | FF (%) | Conversion efficiency, $\eta$ (%) ± 0.05 |
|---------------------|--------------|----------------------|--------|----------------------------------------|
| *Citrus paradisi*   | 0.323        | 0.299                | 29.18  | 0.028                                  |
| *Citrus sinensis*   | 0.285        | 0.033                | 30.40  | 0.013                                  |
| *Citrus limonum*    | 0.291        | 0.042                | 28.12  | 0.004                                  |
| *Citrus tangelo*    | 0.307        | 0.265                | 26.40  | 0.022                                  |

4. Conclusion
The natural dyes of *Citrus paradisi*, *Citrus sinensis*, *Citrus limonum* and *Citrus tangelo* fruit peels were successfully used as light harvester in DSSCs. The absorption maximum and photoemission intensity are identical to the derivative of chlorophyll (pheophytin ‘a’) along with small identifiable parts which displayed from the spectra of UV-Vis absorption and PL curves of the extracting pigments. The FT-IR results for the natural pigments similar to that of structural properties of derivative chlorophyll (pheophytin ‘a’). The photo-electrochemical parameter shows that the maximum conversion efficiency achieved for the cell constructed with *Citrus paradisi* peels extract is 0.028%, while the conversion efficiencies of cells constructed with *Citrus sinensis*, *Citrus limonum* and *Citrus tangelo* extracts are 0.013%, 0.004% and 0.022%, respectively. The fabricated DSSC of *Citrus paradisi* peels sensitizers with higher efficiency recorded may be due to the proper uptake of dye molecules available to ZnO film and vast hindrance to ZnO-dye-electrolyte interface charge transfer. Therefore the result obtained was heartening and favourable because of their environmental friendliness, ease of preparation and natural abundance. Hence, probe to the constituents of *Citrus paradisi* dye and optimizations of the cell fabrication are recommended.

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References
[1] Liu B Q, Zhao X P and Luo W 2008 The synergistic effect of two photosynthetic pigments in dye-sensitized mesoporous TiO$_2$ solar cells *Dyes pigments* 76 327
[2] O'Regan B. and Gratzel M 1991 A low cost, high efficiency solar cell based on dye-sensitized colloidal TiO$_2$ films *Nature* 353 737
[3] Adedokun O, Titilayo K and Awodugba A O 2016 Review on natural dye-sensitized solar cells (DSSCs) *International Journal of Engineering Technologies* 26
[4] Gratzel M 2003 Review Dye-sensitized solar cells *Journal of Photochemistry and photobiology-photocatalysis Rev.* 4 145
[5] Alhamed M, Issa A S and Dubal A W 2012 Studying of Natural Dyes properties as photosensitizer for Dye-sensitized solar cells (DSSC) *Journal of Electron devices* 16 1370-83
[6] Jose R, ThavasiV and Ramakrishna S 2009 Metal oxides for dye-sensitized solar cells J. Am. Ceram. Soc. 92 289-301

[7] Mathew S, YellaA, GaoP, Humphry-Baker R, Curchedosilaf E, Ashari-AstaniN, TavernelliI, RothlisbergerU, NazerusddinMd K and GratteleM 2014 Dye-sensitized solar cells with 13% efficiency achieved through the molecular engineering of porphyrin sensitizers Nature Chemistry, 6242

[8] BesshoT, ZakereudinnM, YehC -Y, DiauE W –G and GratzelM2010 Highly efficient mesopopicdye-sensitized solar cells based on donor-acceptor-substituted porphyrinsAngew.Chem122 6796-99

[9] Campbell W M, JolleyK W, Wagner P, Wagner K, Walsh P J, Gordon K C, Schmidt-MendelL, NazerusurudinMd K, Officer D L 2007 Highly efficient porphyrin sensitizers for dye-sensitized solar cellsJ. Phys. Chem. C111 11760-62

[10] Shanmugam V, ManoharanS, SharafaliA, AnandanS, MuruganR 2015 Green grasses as light harvesters in dye sensitized solar cellsSpectrochim. Acta Part A: Molecular and Biomolecular spectroscopy13547

[11] Yamazaki E, Murayama M, Nishikawa N, Hashimoto N, ShoyamaM and Kurita O 2007 Utilization of natural carotenoids as photosensitizers for dye-sensitized solar cellsSol. Energy81 512

[12] CherepyN J, SmestadG P, GratzelM and Zhang J Z 1997 Ultrafast electron injection: implications for a photoelectrochemical cell utilizing an anthocyanin dye-sensitized TiO2 nanocrystallineelectrodeJ. Phys. Chem. B101 9342-51

[13] ShanmugamV, ManoharanS, AnandanSandMuruganR 2013 Performance of dye-sensitized solar cells fabricated with extracts from fruits of ivy gourd and flowers of red frangipani as sensitizersSpectrochimicaActa Part A 104 35

[14] GomezOrtiz N M, Vazquez-Maldonado I A, Perez-EspadasA R, Mena-RejonG J, AzamarBarrios J A and OsakmG 2010 Dye-sensitized solar cells with natural dyes extracted from achiotes seedsSol. Energy mater. Sol. Cells94 40

[15] CalogeroG, Yum J -H, SinopoliA, Di Marco G, GratzelM and NazeeruddinMd K 2012 Anthocyanins and betalains as light-harvesting pigments for dye-sensitized solar cells Sol. Energy,861563-75

[16] Kumara G R A, Kaneko S, OkuyaM, Onwona-AgyemanB, Konno A and TennakoneK 2006 Shiso leaf pigments for dye-sensitized solid-state solar cells”, Sol. Energy Mater. Sol. Cells90 1220-26

[17] Wang X -F, Koyama Y, KitaooO, Wada Y, Sasaki S -I, TamiakiH and Zhou H 2010 Significant enhancement in the power-conversion efficiency of chlorophyll co-sensitized solar cells by mimicking the principles of natural photo-synthetic light-harvesting complexes Biosens. Bioelectro251970-76

[18] CalogeroG, Citro I, Di Marco G, ArmeliMinicanteS, MorabitoM and Genovese G 2014 Brown seaweed pigment as a dye source for photoelectrochemical solar cells Spectrochim. Acta Part A117702

[19] AdedokunO, SanusiY K and AwodugbaA O 2017 Pigment Extracts of Citrus Peels as Light Sensitizers for Dye-Sensitized Solar CellsJournal of Materials Sciences and Applications3 1

[20] Chou T P, Zhang Q, Fryxell G E, and Cao G Z 2007 Hierarchically Structured ZnO Film for Dye-Sensitized Solar Cells with Enhanced Energy Conversion Efficiency WILEY Advanced Material192588-92

[21] MilenkovicS M, ZvezdanovicJ B, AndelkovicT D and MarkovicD Z 2012 The identification of chlorophyll and its derivatives in the pigment mixtures: HPLC-chromatography, visible and mass spectroscopy studies Advanced Technology 116

[22] Liu T M, Chu S W, Sun C K, Lin B L, Cheng P C and Johnson I 2001 Multiphoton Confocal Microscopy Using a Femtosecond Cr:Forsterite LaserScanning23 249
[23] Lai W H, Hsun Y, Teoh L G and Hona M H 2008 Commercial and natural dyes as photosensitizers for a water-based dye-sensitized solar cell loaded with gold nanoparticles Journal of Photochemistry and Photobiology A Chemistry 195 307
[24] Furukawa H, Oba T, Tamiaki H and Watanabe T 1999 Diastereoselective Self-Assemblies of Chlorophylls a and a’ Journal of Physical Chemistry B 103 7398
[25] Longyue Z, Songyuan D, Weiwei X, and Kongjia W 2006 Dye-Sensitized Solar Cells Based on ZnO Films”, IOP Science Plasma Science & Technology 8 172
[26] Rani S, Suri P, Shishodia P K and Mehra R M 2008 Synthesis of nanocrystalline ZnO powder via sol-gel route for dye-sensitized solar cells Solar Energy Materials and Solar Cells 92 1639-45
[27] El-Agez T M, El Tayyan A A, Alkahlout A, Taya S A and Abdel-Latif M S 2012 Dye sensitized solar cells based on ZnO films and natural dyes International Journal of Materials and Chemistry 2 105