DYE – SENSITIZED SOLAR CELLS:

USING OVER 100 NATURAL DYSES AS SENSITIZERS

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ABSTRACT

Over 100 natural dyestuffs extracted from fruits, leaves, flowers, stems, bark and roots of plants growing in Sri Lanka were used as sensitizers to fabricate dye-sensitized solar cells (DSSC’s).

Preliminary investigations on the identification of natural pigments in the dye-sensitization of nanocrystalline n-type TiO2 were carried out. Fresh extracts of various fruits and vegetables were employed as sensitizers in thin layer sandwich type photo electrochemical dye – sensitized solar cells (DSSC’s).

After electrical and electronic analysis, of several natural dyestuffs of local plants, it was observed that many useful dyestuffs which could be extracted from natural products by simple procedure could be used as photo sensitizers for DSSC’s. It was also observed that dye extracts of Mangoosteen yielded better results.

The current-voltage curves obtained with solar cells employing the photo anode with TiO2 sensitized by different dyestuffs were observed. The values of short circuit current density (Jsc), open circuit voltage (Voc), fill factor (ff), and efficiency (η) obtained for solar cells employing photo anodes with TiO2 sensitized with different fruit / vegetable extracts were noted. The dye extracts of Mangoosteen fruit were found to be superior to those obtained from other dyestuffs, and were Jsc = 2.56mAcm−2, Voc 685.3 mV, ff = 60.02 %, η = 1.053 %. Also Ekkiriya wood, Egg Plant, Karawilla kabilla yielded Jsc, Voc, ff and η of 2.32 mA.cm−2, 414.2mV, 56.86%, 0.547% respectively; 2.096 mA.cm−2, 410.4mV, 56.42%, 0.485%; 1.395 mA.cm−2, 443.5mV, 58.58% and 0.362%; 4.128mA.cm−2, 405.1mV, 47.97% and 0.802% respectively.

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1. INTRODUCTION

With oil, petrol, diesel, kerosene prices increasing due to the dwindling of these scarce fossil fuel resources in the world market, vast amounts of renewable energy sources like wind, hydro, solar, geothermal, tidal and wave power have been identified as being most suitable alternative energy sources for Sri Lanka.

Amongst renewable energy sources in Sri Lanka, Photovoltaics (PV's) have been indentified to be a technically suitable and economically viable power source for solar energy to electricity conversion in future. The material platforms for PV are:

a. PV Technology
b. Thin Film PV Technology
c. Organic PV's
d. Dye-Sensitized Solar Cells (DSSC's)
e. Quantum Dot – Enhanced DSSC's

Technological achievements in the clean energy system infrastructure are a fundamental issue for world economy and environmental improvements. Therefore, in this 21st century, energy based non-renewable sources has to be converted into new energy systems by incorporating novel technologies derived from advancements in science [1], [2].

Among several new energy technologies Die-Sensitized Solar Cells (DSSC's) constituting third generation solar cells which mimics the natural photosynthetic process of green plants are one of the most promising new energy generation systems of photovoltaic technology. It has emerged as one of renewable energy sources as a result of exploiting several new concepts and materials, such as nanotechnology and molecular devices.

DSSC's differ from conventional semiconductor PV devices in that they separate the function of light absorption from charge carrier transport. Dye sensitiser absorb the incident sunlight and exploits the light energy to induce vectorial electron transfer reaction.

A DSSC is generally composed of a photoactive semiconductor working electrode of nanocrystalline Titanium dioxide with adsorbed dye molecules and counter electrode made of either metal like Platinum or semiconductors. Both electrodes are immersed in the electrolyte containing suitable redox couple (e.g. Iodine/tri Iodide). If the semiconductor – electrolyte
interface is illuminated with light having energy greater the bandgap energy of the semiconductor, photogenerated electrons/holes are separated. The photogenerated minority carriers arrive at the interface of the semiconductor – electrolyte. Photogenerated majority carriers accumulate at the backside of the semiconductor. With the help of a charge – collecting substrate, photogenerated majority carriers are transported via a load to the counter electrode where these carriers electrochemically react with the redox electrolyte. Sustained conversion of light energy is facilitated by regeneration of the reduced dye sensitizers via the reversible redox couple.

It has been observed that in nature, the fruit, flower, root, stem, bark and leaf of plants show various colours of the visible electromagnetic spectrum from red, orange, yellow, green, blue, indigo to purple and contains various natural dyes which can be extracted by simple procedure. Therefore, it has been emphasized by many researchers to obtain useful dyes as photo sensitizers for DSSC's from natural products, because of the simple preparation techniques, widely available sources, and low cost [3], [5] - [9]. Due to these reasons the importance of work done by the authors to develop low-cost solar energy to electricity conversion units in principal is emphasized.

2. EXPERIMENTAL

2.1 Extraction of dyes

The extracts of dyes from various fruits and vegetables were obtained from fresh fruits and vegetables. The clean fresh fruits and vegetables were crushed and added to Ethanol (Merk). Where necessary, the mixtures were centrifuged and all solutions were protected from direct light exposure.

2.2 Preparation of nanocrystalline TiO2 films

TiO2 paste was prepared by blending 200mg TiO2 powder (P25- Degussa), 1 drop of Triton X100, and 12 drops of Acetic acid in an agate mortar. Then the mixture was ground for 30min, finally 3ml of Ethanol was slowly added whilst grinding continuously for another 30min. Paste was then applied to Fluorine –doped Tin oxide coated transparent conducting glass substrate (resistance 10 - 15 ohm.cm2) which has been cleaned with Teepol detergent solution using an ultrasonic bath for 15min, rinsed with water and Ethanol and then dried, by the Doctor Blade method to obtain approximately 10 micrometer thick TiO2 film of 0.25cm2. Films were then heat treated at 500°C for 30min. and naturally cooled down to room temperature. Then they were immersed separately in alcoholic dye solutions for 12 hours.
Fabrication and Characterization of Solar Cells

Photo electrochemical solar cells were then fabricated by sandwiching a Platinum sputtered conducting Tin oxide (CTO) glass plate with dyed TiO2 film. A redox electrolyte containing I3/I redox couple was then introduced to the solar cells. The I-V Characteristics of the solar cells at 100mW.cm-2 (AM 1.5) were measured using a home made I-V curve measuring set up coupled to a Keithley 2000 Electronic Multimeter with a Potentiostat via a computer controlled software available at the Institute of Fundamental Studies (IFS), Kandy, Sri Lanka. Xenon 500 lamp was also used with AM 1.5 filters to obtain simulated sunlight with an intensity of 100mW.cm-2. The intensity of light was calibrated using an Eko Pyronometer and Silicon photodiode.

3. RESULTS AND DISCUSSION

3.1 Absorption Spectra obtained from various fruits and vegetables

The Absorption spectra of various natural dye solutions were also obtained with UV 2450 SHIMADZU UV-VIS Spectrophotometer available at the IFS, Sri Lanka.

Figures 1, 2 and 3 depicts the Absorption Spectra of a few natural dyes of plants grown in Sri Lanka in ethanolic dye solutions. It can be seen that, the dye solutions obtained from Turmeric and Mangoostein absorb more in the blue and red side of the electromagnetic spectrum than the other dyes. Absorbance peaks at 220 nm, 250 nm, 325 nm have been obtained for Mangoostin; 210nm, 280 nm, 330 nm, 430 nm for Turmeric; 205 nm for Ekkiriya wood, and 205 nm for Fire Fern.

The I-V curves were used to calculate that short circuit photocurrent density (Jsc), the open circuit voltage (Voc), the fill factor (ff), and the conversion efficiency (η) of DSSC's.

The I-V characteristics of DSSC's sensitized with extracts of Mangoostein, Fire fern, Ekkiriya wood, Egg Plant, Karawala kabilla, Banana flower Inflorescence, Beetroot and Turmeric are shown in Figure 4. From this Figure the values of short circuit current (Jsc) and open circuit voltage can be obtained directly using the I- V data corresponding to 100mW.cm-2 simulated sunlight luminance. The highest Jsc value is obtained from the DSSC's sensitized with Fire fern, whilst the highest Voc value is obtained from the DSSC sensitized with Mangoostein.

The I-V characteristics of a total of 145 natural dyes from plants grown in Sri Lanka were analyzed at the IFS using the equipment mentioned at paragraph 2.3 and the best 27 natural dyes
identified are at Table 1 (Table of Results). From this Table it is observed that extracts of Mangoostein fruit rind (dark purple) yielded better results amongst these dyes tested. It has been observed from these results that darker the colour of these dyes, greater would be their conversion efficiencies. Also the addition of trace amounts of concentrated Acetic acid, Hydrochloric acid etc to these natural dyes have been observed during recent tests to alter the pH to < 1 and possibly change their chemical structures, and hence to make them appear darker in colour and to increase their conversion efficiencies.

The most probable target conversion efficiencies of these natural dyes suitable for use in DSSC’s would be around 2%. The Authors of this paper have recently obtained a practical conversion efficiency of 1.053% for Mangoostein fruit rind extract (after purification with Chloroform), 0.802% for Fire Fern leaf of garden plant endemic to Ecuador, Venezuela and Colombia in Central America. Also conversion efficiencies of 0.547% for Ekkiriya wood, 0.485% for Egg Plant fruit skin, 0.362% for Karawala Kabilla (Purple fruit), 0.357% for Banana Flower Inflorescence, 0.32% for Beetroot and 0.264% for Turmeric were also obtained. Even though the efficiency values obtained in this study are not significant with the values obtained in the system with very expensive Ruthenium complexes, the straight forward preparation of photo anodes with semiconductor oxides sensitized by natural dyes still enables, a much cheaper and easy environmentally friendly production of solar cells. Further it provides an interesting and cheap alternative to commonly used expensive and rare synthetic dyes. Therefore, investigations are being carried out in searching for efficient natural dyes which can have potential use in these DSSC’s [5].

Good photo-to-electric conversion ability in a DSSC is strongly dependent on available bonds between the dye molecules and TiO₂ particles, through which electrons can transport from excited dye molecules to the TiO₂ film.

This work done incorporate the foundation on which research is to be done to develop low cost, high efficiency solar energy to electricity conversion units for use especially in rural areas of Sri Lanka where access to the national grid electricity supply is not available. This would also enable to alleviate poverty and to improve living standards amongst rural communities.
Figure 1. Absorbance of Dye Solutions extracted from (a) Mangoostein (b) Daun purple fruit (Karawela Kabili) (c) Turmeric (d) Red Plum (e) Australian Orange fruit rind (f) Red Cabbage (g) Croton leaf (h) Red Globular Chilli fruit (i) Beet Root (j) Red Onion
Absorption Spectra obtained from various Fruits & Vegetables

Figure 2. Absorbance of Spectra dye solutions extracted from (a) Mangoostein + HCL (b) Mangoostein (c) Turmeric + HCL (d) Turmeric (e) Ekiriya + HCL (f) Ekiriya (g) Purple Fruit + HCL (h) Purple Fruit (i) Red Plum (j) Red Plum + HCL (k) Black Grape (l) Beetroot (m) Eggplant (n) Spinach
Figure 3. Absorption of Spectra of dye solutions extracted from (a) Mangoosetin + Acetic acid (b) Mangoostein + HCL (c) Mangoostein (d) Turmeric + HCL (e) Turmeric (f) Fire Fern + HCL (g) Fire Fern (h) Begonia (i) Red Hart (j) Anthurium
Current-Voltage Characteristics of Dye-Sensitized Solar Cells

Figure 4. Current Voltage Characteristics of Dye Sensitized Solar Cells (a) Mangoostein (b) Fire Fern + HCL (c) Fire Fern (d) Ekkiriya wood (e) Egg Plant (f) Karawala kabilla (g) Fire Fern + Acetic acid (h) Beet root (i) Banana inflorescence (j) Turmeric (k) Black grapes (l) Black grapes (m) Black grapes (l) Croton (m) Begonia (n) Walmadata (o) Venival

Figure 4 depicts the Current Density Vs. Open Circuit Voltage characteristics of some DSSC cells tested. It is observed that Ethanol extracts of Mangoostein, Fire Fern, Ekkiriya, Egg plant, Karawila Kabilla, Beetroot, Banana, Turmeric gave fairly good Current Densities and Open Circuit Voltages amongst all natural dyes analyzed.
<table>
<thead>
<tr>
<th>Serial No</th>
<th>Dye</th>
<th>Open Circuit Voltage Voc (mV)</th>
<th>Short Circuit Current Isc (mA)</th>
<th>Current Density $I_d$ (mA/cm²)</th>
<th>Fill Factor (ff)</th>
<th>Efficiency ($\eta$)</th>
<th>Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mangoostein</td>
<td>685.3</td>
<td>0.640</td>
<td>2.56</td>
<td>60.02</td>
<td>1.053</td>
<td>Ethanol purified with Chloroform</td>
</tr>
<tr>
<td>2</td>
<td>Fire Fern + HCL</td>
<td>405.1</td>
<td>1.032</td>
<td>4.128</td>
<td>47.97</td>
<td>0.802</td>
<td>Ethanol</td>
</tr>
<tr>
<td>3</td>
<td>Ekkiriya Wood</td>
<td>414.2</td>
<td>0.58</td>
<td>2.32</td>
<td>56.86</td>
<td>0.547</td>
<td>Ethanol</td>
</tr>
<tr>
<td>4</td>
<td>Egg Plant</td>
<td>410.4</td>
<td>0.524</td>
<td>2.096</td>
<td>56.42</td>
<td>0.485</td>
<td>Ethanol</td>
</tr>
<tr>
<td>5</td>
<td>Fire Fern</td>
<td>365.7</td>
<td>0.584</td>
<td>2.336</td>
<td>51.77</td>
<td>0.442</td>
<td>Ethanol</td>
</tr>
<tr>
<td>6</td>
<td>Purple Fruit (Karawala Kabilla)</td>
<td>443.5</td>
<td>0.348</td>
<td>1.395</td>
<td>58.58</td>
<td>0.362</td>
<td>Ethanol</td>
</tr>
<tr>
<td>7</td>
<td>Banana Flower Inflorescence</td>
<td>414</td>
<td>0.477</td>
<td>0.763</td>
<td>45.2</td>
<td>0.357</td>
<td>Ethanol</td>
</tr>
<tr>
<td>8</td>
<td>Fire Fern + Acetic Acid</td>
<td>442.2</td>
<td>0.333</td>
<td>1.332</td>
<td>55.03</td>
<td>0.325</td>
<td>Ethanol</td>
</tr>
<tr>
<td>9</td>
<td>Beetroot</td>
<td>441.2</td>
<td>0.328</td>
<td>1.312</td>
<td>55.36</td>
<td>0.32</td>
<td>Ethanol</td>
</tr>
<tr>
<td>10</td>
<td>Fire Fern (1 hour)</td>
<td>335.6</td>
<td>0.459</td>
<td>1.836</td>
<td>50.13</td>
<td>0.309</td>
<td>Ethanol</td>
</tr>
<tr>
<td>11</td>
<td>Turmeric</td>
<td>601.9</td>
<td>0.16</td>
<td>0.64</td>
<td>68.31</td>
<td>0.264</td>
<td>Ethanol</td>
</tr>
<tr>
<td>12</td>
<td>Turmeric (1 hour)</td>
<td>542.6</td>
<td>0.26</td>
<td>1.04</td>
<td>45.61</td>
<td>0.257</td>
<td>Ethanol</td>
</tr>
<tr>
<td>13</td>
<td>Mangoostin + HCL</td>
<td>609.2</td>
<td>0.131</td>
<td>0.527</td>
<td>72.98</td>
<td>0.234</td>
<td>Ethanol</td>
</tr>
<tr>
<td>14</td>
<td>Mangoostin (14 days)</td>
<td>308.9</td>
<td>0.557</td>
<td>2.228</td>
<td>31.86</td>
<td>0.219</td>
<td>Ethanol</td>
</tr>
<tr>
<td>15</td>
<td>Mangoostin + HCL (14 days)</td>
<td>499.9</td>
<td>0.263</td>
<td>1.052</td>
<td>40.26</td>
<td>0.211</td>
<td>Ethanol</td>
</tr>
<tr>
<td>16</td>
<td>Mangoostin (3 hrs)</td>
<td>576.9</td>
<td>0.136</td>
<td>0.544</td>
<td>65.18</td>
<td>0.204</td>
<td>Ethanol</td>
</tr>
<tr>
<td>17</td>
<td>Fire Fern + HCL (14 days)</td>
<td>606</td>
<td>0.11</td>
<td>0.44</td>
<td>64.33</td>
<td>0.171</td>
<td>Ethanol</td>
</tr>
<tr>
<td>18</td>
<td>Mangoostin (1 hour)</td>
<td>600.7</td>
<td>0.088</td>
<td>0.352</td>
<td>70.08</td>
<td>0.147</td>
<td>Ethanol</td>
</tr>
<tr>
<td>19</td>
<td>Black Grape</td>
<td>416.5</td>
<td>0.161</td>
<td>0.644</td>
<td>54.87</td>
<td>0.147</td>
<td>Ethanol</td>
</tr>
<tr>
<td>20</td>
<td>Croton Leaf</td>
<td>416.3</td>
<td>0.137</td>
<td>0.548</td>
<td>56.62</td>
<td>0.13</td>
<td>Ethanol</td>
</tr>
<tr>
<td>21</td>
<td>Begonia Black Velvet Leaf (15hrs)</td>
<td>442.8</td>
<td>0.125</td>
<td>0.5</td>
<td>57.66</td>
<td>0.128</td>
<td>Ethanol</td>
</tr>
<tr>
<td>22</td>
<td>Walmadata</td>
<td>520.7</td>
<td>0.084</td>
<td>0.336</td>
<td>68.54</td>
<td>0.12</td>
<td>Ethanol</td>
</tr>
<tr>
<td>23</td>
<td>Purple Fruit</td>
<td>479.1</td>
<td>0.088</td>
<td>0.352</td>
<td>65.51</td>
<td>0.111</td>
<td>Ethanol</td>
</tr>
<tr>
<td>24</td>
<td>Red Hart</td>
<td>500.7</td>
<td>0.82</td>
<td>0.028</td>
<td>64.81</td>
<td>0.106</td>
<td>Ethanol</td>
</tr>
<tr>
<td>25</td>
<td>Begonia Black Velvet</td>
<td>608</td>
<td>0.058</td>
<td>0.232</td>
<td>68.9</td>
<td>0.098</td>
<td>Ethanol</td>
</tr>
<tr>
<td>26</td>
<td>Venivel</td>
<td>529.9</td>
<td>0.079</td>
<td>0.316</td>
<td>57.59</td>
<td>0.097</td>
<td>Ethanol</td>
</tr>
<tr>
<td>27</td>
<td>Orange</td>
<td>627.5</td>
<td>0.05</td>
<td>0.2</td>
<td>73.1</td>
<td>0.091</td>
<td>Ethanol</td>
</tr>
</tbody>
</table>
Figure 1, 2 and 3 depicts the Absorbance Spectra of various fruits and vegetables in Ethanolic dye solutions. It can be seen that the dye solution of Fire fern and Mangoostin absorb more in the red side of the solar spectrum than the other dyes tested.

This work done incorporate the foundation on which research is to be done to develop low cost, high efficiency solar energy to electricity conversion units for use especially in rural areas of Sri Lanka where access to the national grid electricity supply is not available. This would also enable to alleviate poverty and to improve living standards amongst rural communities.

4. CHEMICAL STRUCTURE OF MOST SUITABLE NATURAL DYE SENSITIZERS IDENTIFIED

4.1 Mangoosteen (Garcinia Mangostana)

Mangoosteen fruit is endemic to South East Asia (including Sri Lanka), and produces a fruit with a white sweet purple covered by a reddish brown colour pericarp (rind). The rind is rich in antioxidants of 39 different Xanthones. These consist of Alpha – Mangoosteen (brown red), Beta – Mangoosteen, Gamma – Mangoosteen, Mangoostinone, Smeathxanthone A, Rutin, 3-Isomagoosteen, 8 - Desoxygatanin, Gertanin and 9 – Hydroxycolaboxanthene, and is considered nature's most abundant source of Xanthones.

As well as the most potent source of Xanthones in any single fruit, the whole fruit of Mangoosteen is also an excellent source of other flavanoids. These include Rutin (reddish brown), Pyroanthocyanidins and EGEC Catechins.

\[
\text{Mangoosteen} \quad \text{Molecular formula } C_{24}H_{26}O_6
\]

\[
\text{Rutin} \quad \text{Molecular formula } C_{27}H_{36}O_{16}
\]
It is believed that the presence of Rutin is responsible for the good sensitization of Mangoostein DSSC; s.

**Mangoosteen trihamnasid**

4.2 **Fire fern leaf (Oxalis hedyscaroides)**

Fire fern a rare exotic garden plant which grows to a height of about 1 foot and is a native of Colombia, Venezuela and Ecuador in Central America. It thrives in bright sunny areas with hot and humid temperatures. A few plants have been recently brought to the Royal Botanical Gardens, Peradeniya, Sri Lanka, and the Author fortunately managed to gain access to this plant. It has prominent maroon-red leaves with a deterrent sour taste to animals and humans due to its Oxalic acid. These leaves also contain chlorophyll (green) essential for photosynthesis, even though the colour of its leaves is masked by the excessive maroon-red Anthrocyanins and yellow Xanthophylls. It also consists of Carotenoids comprising Carotene (yellow) and Lycopene (orange red).

Anthrocyanins are water soluble vacuole pigments and they appear red, blue, purple or magenta depending on PH.

- Red at PH < 3
- Violet at PH = 7 - 8
- Blue at PH > 7 - 8

**Cynodin Anthrocyanin**

Xanthophylls of this plant leaves consist of Flavonoids comprising Flavone (deep yellow), Flavol (yellow)
4.3 **Ekkiriya Wood**

The essential chemical components of Ekkiriya Wood are its dark reddish brown Tannins which are astringent, bitter plant phenolic compounds. These are considered to be responsible for the relative good sensitization in DSSC; s.

<table>
<thead>
<tr>
<th>Base Unit</th>
<th>Gallic acid</th>
<th>Flavone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class/Polymer</td>
<td>Hydrolysable Tannins</td>
<td>Non Hydrolysable or Condensed Tannins</td>
</tr>
</tbody>
</table>

4.5 **Egg Plant (Solanum melongenol)**

The black/purple colored Anthrocyanins and Glycoalkaloid pigments in Egg Plant fruit peel are considered to contribute to their good sensitization.

Common Glycoalkoid aglycones in Eggplant fruit peel.

4.6 **Karawala kabilla (B. Ceylonious)**

The reddish/purple colored Tannin polyphenol compounds along with Anthrocyanins present in its ripe fruit is considered responsible for fairly good sensitization when use in DSSC; s.
4.7 *Turmeric (Curcuma longa)*

Turmeric rhizome root contain upto 5% essential oils and upto 3% Curcumin, a polyphenol. Curcumin is the active ingredient of Turmeric. It exists at least in two tautomeric forms, Keto and Enol. The Keto form in preferred in solid phase and the Enol form in solution. Curcumin is a pH indicator and in acidic solutions (pH > 7.4) it turns yellow where as in basic (pH >8.6) solution it turns bright red. The extract of Turmeric root yields, a deep orange yellow dye.
5. CONCLUSIONS

This paper describes an investigation on the use of natural dyes of plants grown in Sri Lanka as natural photo sensitizers for DSSC’s. Extracts of Mangoostein fruit rind, Fire Fern leaf, Ekkriya wood, Karawala kabilla, Banana Flower Inflorescence, Beetroot and Turmeric root have achieved solar energy conversion efficiencies of 1.053%, 0.802%, 0.547%, 0.485%, 0.362%, 0.357%, 0.32% and 0.264% respectively.

Natural dyes based solar cells appear to be limited by low Voc and Isc. The way forward would be to find different additives such as conc. Acetic acid, Hydrochloric acid etc which when doped in trace amounts would cause alteration of the pH to < 1, and the chemical structure of these natural dyes hence to darken their colours and possibly to result in larger conversion efficiencies. Although natural dyes are still below the present requirements, the results are encouraging and may boost additional studies oriented to the search of new natural dye sensitizers.

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REFERENCES


solar cells. Solar Energy 80, 209-214

Materials of Solar Cells, 73, 103 (2002).


9. Senadheera G.K.R., Fernando J.M.R.C., Natural Anthocyanins as Photosensitizes for
DSSC's, Current Science, Vol.95, No. 5 (2008).