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FABRICATION OF DYE-SENSITIZED SOLAR CELLS USING NITROGEN DOPED CARBON QUANTUM DOTS AND ORGANIC DYE EXTRACTED FROM PURPLE CABBAGE.

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ABSTRACT

The emergence of Nitrogen Doped Carbon Quantum Dots and natural dyes as sensitizers for fabricating, Dye sensitized solar cells, have provided an environmental friendly alternative means for generating clean energy. In this research, three monolithic dye sensitized solar cells were fabricated from NCQDT and natural dye extracted from purple cabbage, using Doctor blade technique. The optical properties of the dyes and NCQDT were investigated using UV-Spectrometer. The results of the band gap energy is 2.00 ev, 1.20ev, and 1.75ev respectively. The Scanning Electron Microscope (SEM) and X-ray Diffractometer, were used to study the structures of the samples and the result shows that they are polycrystalline in nature with average crystalline size of 1-9 nm. The electrical properties as demonstrated by I–V curves, show that the conversion efficiency (7) of the NCQDT, purple cabbage and NCQDT +purple cabbage is 4.17%, 1.06% and 3.63% respectively.

Keywords: Nitrogen doped carbon quantum dots (NCQDT), Photosensitizers, DSSCs TiO_2, ZrO_2

INTRODUCTION

One of the resources of clean and renewable energy, is the solar energy. The photovoltaic cell (Pv), converts radiation from the sun into electricity. These solar cells, have gone through different development called generations. The dye-sensitized solar cells (DSSCs) and carbon quantum dots are examples of third generation solar cells [1-2]. O' Regan and Gratzel, were the first scientists to developed dye sensitized solar cell in 1991 [3]. The major components of the DSSC, include; photoanode (Semiconductor), sensitizer (dye), radox electrolyte and a counter electrode [4-5]. The sensitizer plays one of the major roles because it promotes overall efficiency performance of the solar cell. The sensitizer absorbs radiation from the sun and in the process electrons are excited from the Highest occupied molecular orbital (HOMO) to the Lowest Unoccupied Molecular Orbital (LUMO) of the semiconductor interface [6-7]. This principle is based on the photo – injection of electrons from the sensitizer molecules into conducting band, thereby creating holes transport in the semiconductor, with the help of redox mediator [8 – 11]. The porous electrode in the DSSCs component helps in enhancement of the recombination activities by decreasing all the cell parameter and the photo conversion efficiency [12 – 14]. Recently, scientists have developed interest on carbon quantum dots (CQDs) in the fabrication of DSSCs. CQDs have shown excellent photo induced electron transfer ability, low cytotoxity, good biocompability e.t.c. The Nitrogen doped carbon quantum dot (green quantum), is an environmental friendly sensitizer, used in fabrication of DSSCs [15]. Synthetic and organic dyes are sensitizers used for fabrication of option due to the facts that, it is cheaper, abundant in nature and affordable [16 – 17]. Numerous studies have been reported on natural dyes. But most of the cells have low efficiencies due to poor binding energy of the sensitizers molecules to the surfaces of the semiconductor. In this research, green quantum dot and natural dye, were used as sensitizers to fabricate DSSCs, the results of the photo conversion efficiencies are high, after characterization.

MATERIALS AND METHOD

Experimental Procedure

This work is an experimental research and some of the materials and machines used include; titanium dioxide (iv) (TiO_2), Fluorine Doped Tin Oxide (FTO), Zirconium dioxide (ZrO_2), propanol, ammonia, purple cabbage, Ultraviolet Visible Spectrometer (750 Series), Scanning Electron Microscope (MARA3 TESCAN), Solar simulator (ORILE S013A) and X-ray diffractometer (BRUKER AXS D8 Advance) e.t.c.

Extraction of Dye

6 g of purple cabbage was washed with distilled water for several times and chopped into a container containing clean water. Then the mixture was heated up to 100 ^oC for about 12 hours. After cooling, the solution was filtered to get clean dye and stored in a dark room

Synthesis of NCQDT

5 g of citric acid and 4 g of ammonium were added to a beaker containing 15 ml of distilled water. The solution was stirred for about 20 minutes and transferred into a porcelain boat that was placed on hot magnetic plate. It was heated up to about 300 ^oC for 4 hours until the solution becomes carbongenic product. Then, the product is grinded inside mortor into power and 3 ml of methanol was added and filtered to get Nitrogen doped carbon quantum dot (NCQDT).

Preparation of TiO_2 Paste

Mesoporous TiO_2 was prepared by adding 3g of titania into 5 ml of tempineol-etyl cellulose. Then 0.3 ml of acetic acide was added slowly to the solution while grinding continuously for about 10 munites. 6 ml of Isopropanol was added while still grinding, until the solution becomes homogenous paste.

Fabrication of Monolithic DSSCs

Glass substrate (FTO) was cut into 20 by 12 mm. The glass was washed with isopropanol and distilled water for several times. After drying, the conducting surface was placed upward and etched. Then, a blacking layer was created on the surface by spin coating of TiO_2. Mesoporous layer was created by adding TiO_2 paste on the surface of the FTO using Doctor blade technique and annealed for 400 ^oC for about 20 minutes. A photosensitizer (Dye/NCQDT) and electrolyte were introduced on the surface and annealed at 450^oC for about 15 minutes. Zirconium dioxide layer was created by screen printing ZrO_2 paste on the surface of the cell. Counter electrode layer was deposited on the cell, using graphite, plastisol and electrolyte (iodine) and annealed at 450^oC for about 30 munities. The cell was finally sandwiched with another FTO glass.

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RESULTS AND DISCUSSION
Optical Properties

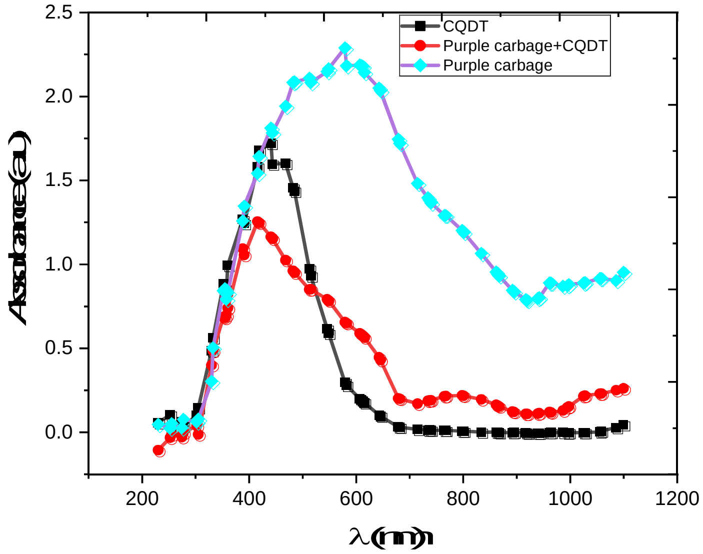

Figure 1: plot of absorbance Vs wavelength

The absorbance of CQDT, purple carbage and purple carbage and CQDT is shown in Figure 1. According to the plot, the absorbance of the synthesized cell rises as the wavelength increases, with purple carbage having the maximum absorbance in the region. Additionally, it demonstrates how crucial a role dyes play in enhancing CQDT solar cells. The absorption is typically making a strong choice for solar applications. The lowest absorption is shown by purple cabbage + CQDT

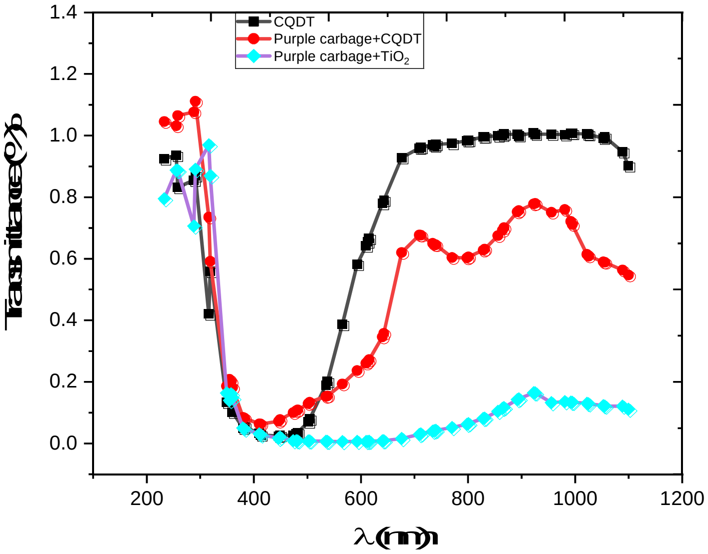

Figure 2: plot of transmittance Vs wavelength

Figure 2 displays the transmittance of CQDT, purple carbage, CQDT+ purple carbage. The plot indicates that as wavelength increases, the transmittance of the synthesized cell increases, with CQDT having the transmittance while CQDT + purple carbage having the lowest transmittance in the visible region. Additionally, it shows how important dyes are in improving CQDT solar cells. For solar applications, transmittance is often a wise choice.

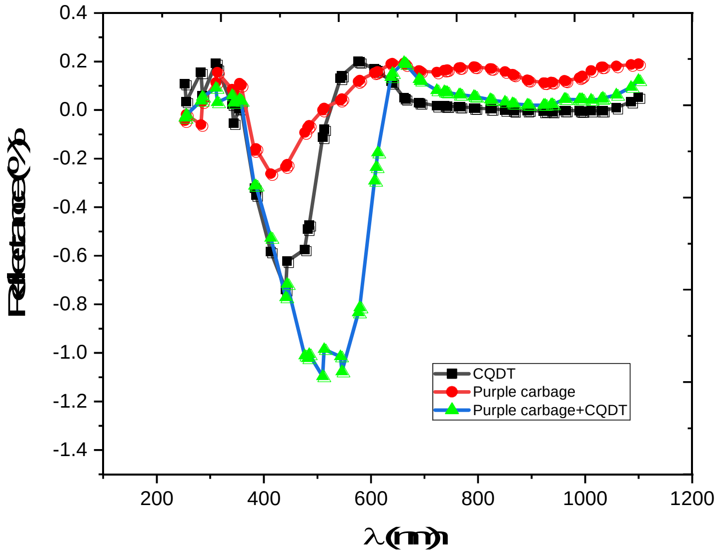

Figure 3: plot of reflectance Vs wavelength

The reflectance of CQDT, purple carbage, purple carbage and CQDT are shown in Figure 3. The plot shows that the reflectance of the synthesized cell increases with wavelength, with purple carbage+CQDT having the lowest reflectance in the area. It also demonstrates how crucial dyes are to enhancing CQDT solar cells. Reflectance is frequently a sensible choice for solar applications. Maximum reflectance is shown by carbon quantum dots.

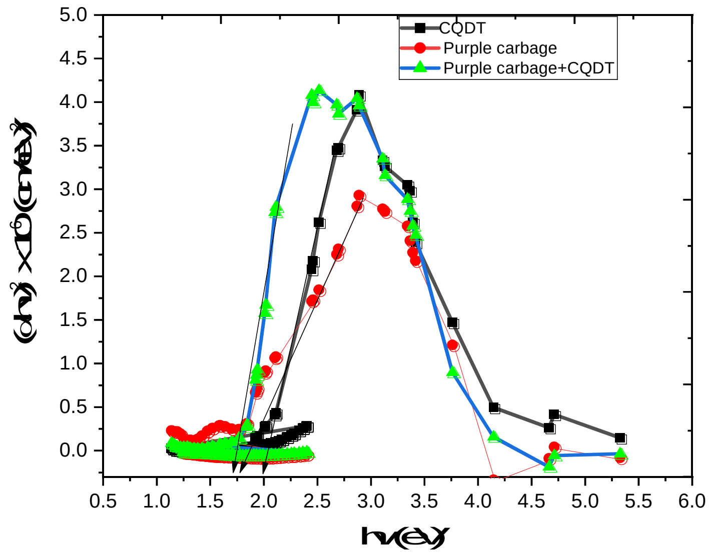

Figure 4: plot of absorption coefficient square Vs photon energy

The band gap energy plots were estimated from Tauc equation and the energies were gotten by extrapolating the linear portion of the graph. The obtained band gap energies are seen in Figure 4 and give increasing band gap energies upon introduction of purple cabbage. The energies increase upon introduction of the dye because the host electrons gain more energy for band transition. The bandgap energy of the CQDT is 2.00 eV while purple cabbage + CQDT is 1.75 eV and purple cabbage is 1.70 eV.

Structural analysis with the use of Xray diffractometer

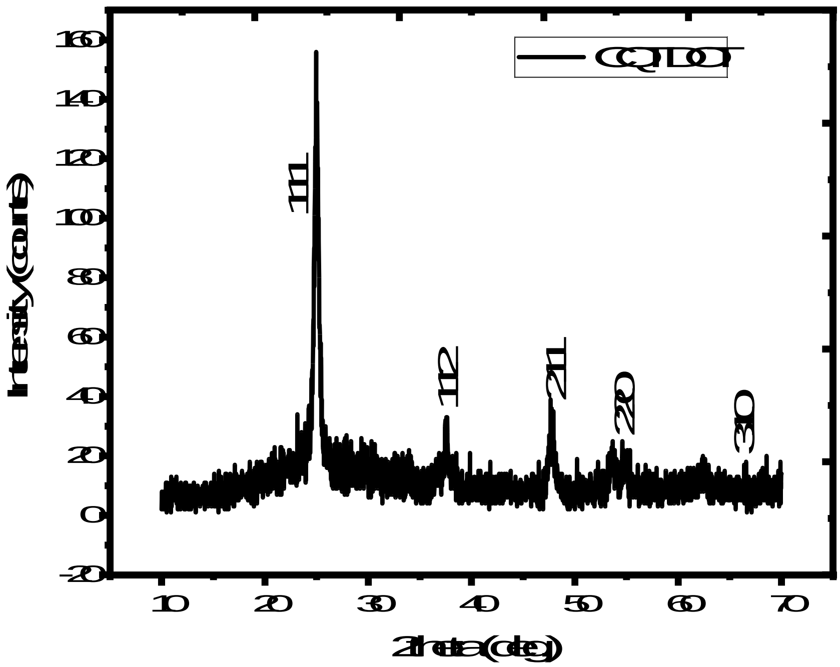

Figure 5: XRD spectrum of CQDT

The X-ray diffractometer was use to study the lattice structure of CQT DOT in Figure5. The spectrum is polycrystalline with hexagonal structure and a prominent peak at (111) orientation. The crystal lattice is notice by a drop in peak intensity with 2theta degree values; the appearance of an unindexed peak is caused by the substrate utilized for the deposition. Because of their nature, polycrystalline materials are continuously better for making optoelectronic devices. The spectrum suggests that the glass substrate use for the synthesis reduce peaks intensities of the synthesized CQDT which increases the available surface area for photovoltaic and solar cell activities. Table 1 includes additional characteristics and the average crystallite size of the films in addition to the computed crystallite or grain sizes, and dislocation density.

Table 1: structural parameters of CQDT

Film	2θ (deg.)	d (spacing) Å	Lattice constant (Å)	(β) FWHM	(hkl)	Grain Size(D) nm	Dislocation density, **σ** lines/m^2
CQDT	25.38	3.506	6.072	0.1765	111	8.052	4.697
	37.72	2.382	4.765	0.1745	112	8.396	4.320
	47.56	1.910	3.820	0.1734	211	8.738	3.989
	54.82	1.673	3.741	0.1759	220	8.879	3.863
	66.38	1.406	3.446	0.1734	310	9.555	3.336

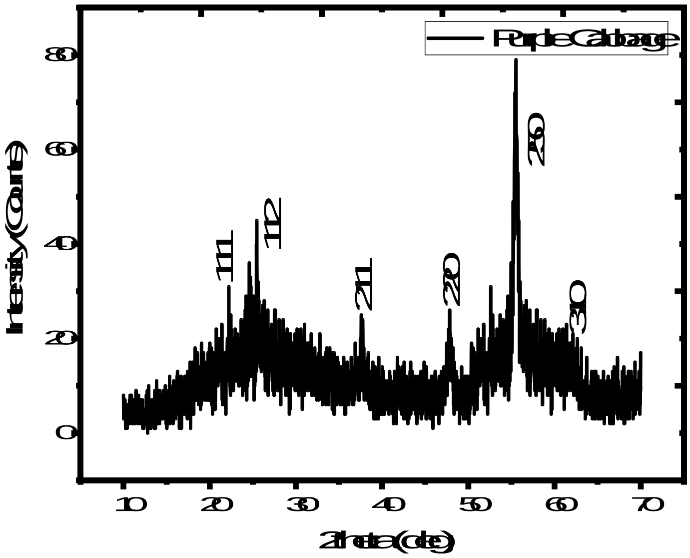

Figure 6: XRD spectrum of purple cabbage

The XRD spectrum of purple cabbage in Figure 6 showed prominent crystalline peaks at angles of 22.44°,25.63°,37.76°,47.96°,52.96 and 63.08° with corresponding diffraction planes (111), (112), (211), (220), (250), and (310). However, the diffraction pattern shows that the peak intensity decreases as a result of the *purple cabbage* dye concentration. Important factors like crystallite size and d-spacing are summarized in Table 2. Due to the restriction of crystallite motion at the interface between the dye and glass substrate the crystallite brought on by stress generation.

Table 2: structural parameters of beet root

Film	2θ (deg.)	d (spacing) Å	Lattice constant (Å)	(β) FWHM	(hkl)	Grain Size(D) nm	Dislocation density, **σ** lines/m^2
Purple cabbage	22.44	3.958	6.856	0.211	111	6.699	6.787
	25.63	3.472	6.944	0.212	112	6.707	6.770
	37.76	2.380	4.760	0.198	211	7.401	5.561
	47.96	1.895	4.237	0.265	220	5.726	9.289
	56.96	3.472	6.944	0.212	250	6.707	9.289
	63.08	1.472	3.606	0.213	310	7.638	5.221

The X-ray diffraction spectrum of purple cabbage + CQDT and is polycrystalline in nature as indicated in the spectrum in Figure 6. The film had a strong peak at (182) which corresponds to 2theta values of 31.82°, and a perfect crystalline peak with a hexagonal phase indexed at (111), (112), (211), (220), (250), and (310) orientations which correspond to 2theta angle of 20.91°, 25.34°, 31.82°, 37.56°, 47.62°, and 53.88°. The crystal lattice is shown by drop in peak intensity with higher 2theta degree values; the appearance of an unindexed peak is caused by the substrate utilized for the deposition. Because of their nature, polycrystalline materials are continuously better for making optoelectronic devices. The spectrum suggests that the higher peaks may result from the film's increased in concentration of the purple cabbage+CQDT, which increases the available surface area for photovoltaic and solar cell activities. Table 4.8 includes additional characteristics and the average crystallite size of the films in addition to the computed crystallite or grain sizes, dislocation density, and concentration of the purple cabbage+CQDT for the films deposited for optoelectronic application.

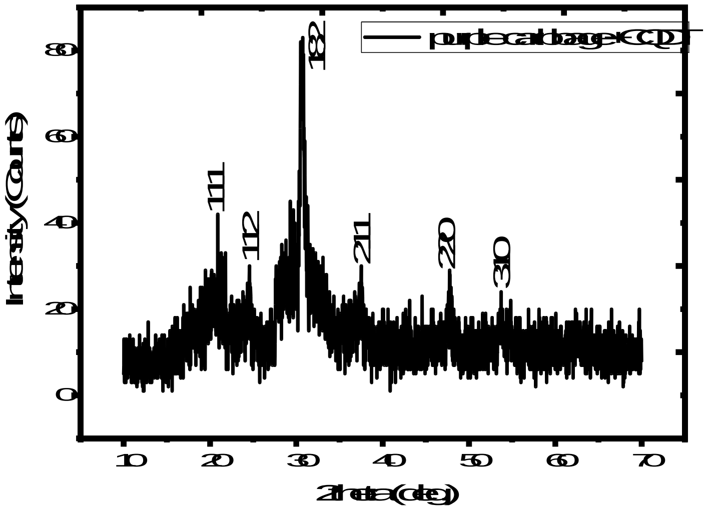

Figure 7: XRD spectrum of purple cabbage+CQDT

Table 3: structural parameters of purple carbbage +CQDT

Film	2θ (deg.)	d (spacing) Å	Lattice constant (Å)	(β) FWHM	(hkl)	Grain Size(D) nm	Dislocation density, **σ** lines/m^2
Purple carbbage + CQDT	20.91	4.244	7.351	0.189	111	7.460	5.473
	25.34	3.511	7.023	0.188	112	7.559	5.330
	31.82	2.851	5.144	0.187	182	7.721	5.011
	37.56	2.392	4.784	0.187	211	7.831	4.966
	47.62	1.907	4.266	0.187	220	8.104	4.637
	53.88	1.700	4.164	0.186	310	8.362	4.356

Surface Morphology

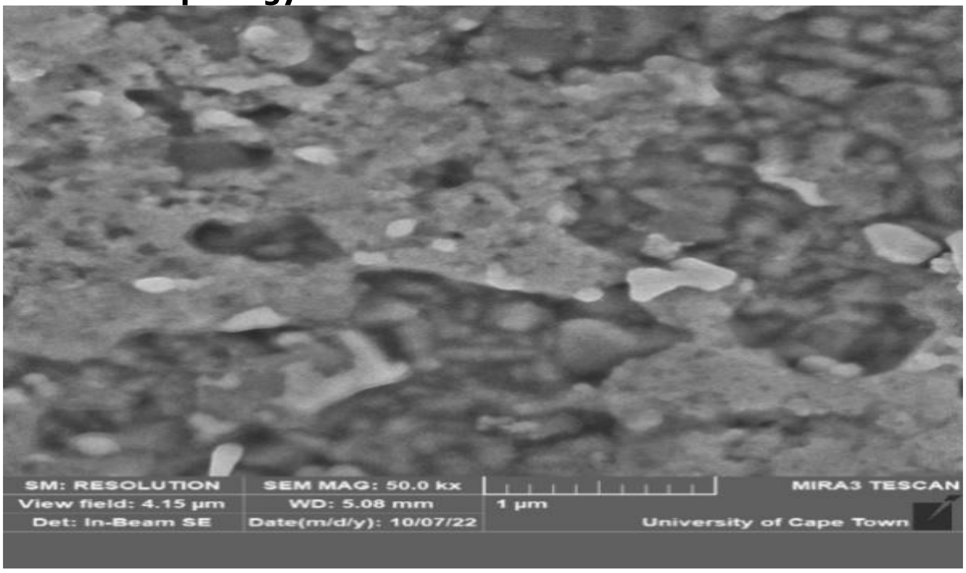

Figure 8: SEM of CQDTFigure

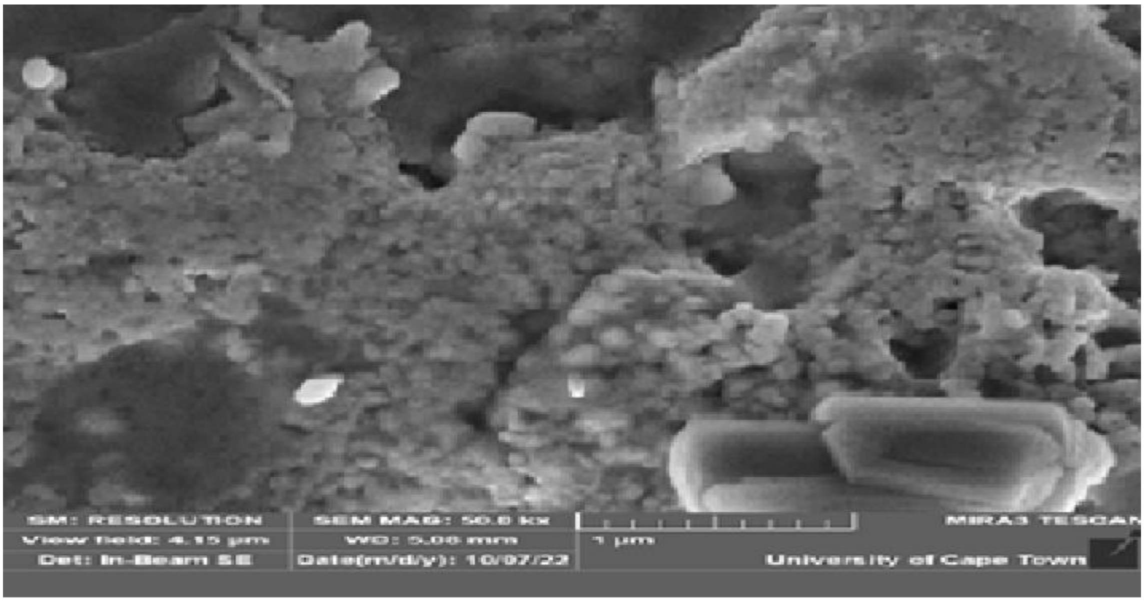

Figure 9: SEM of PURPLE CARBBAGE

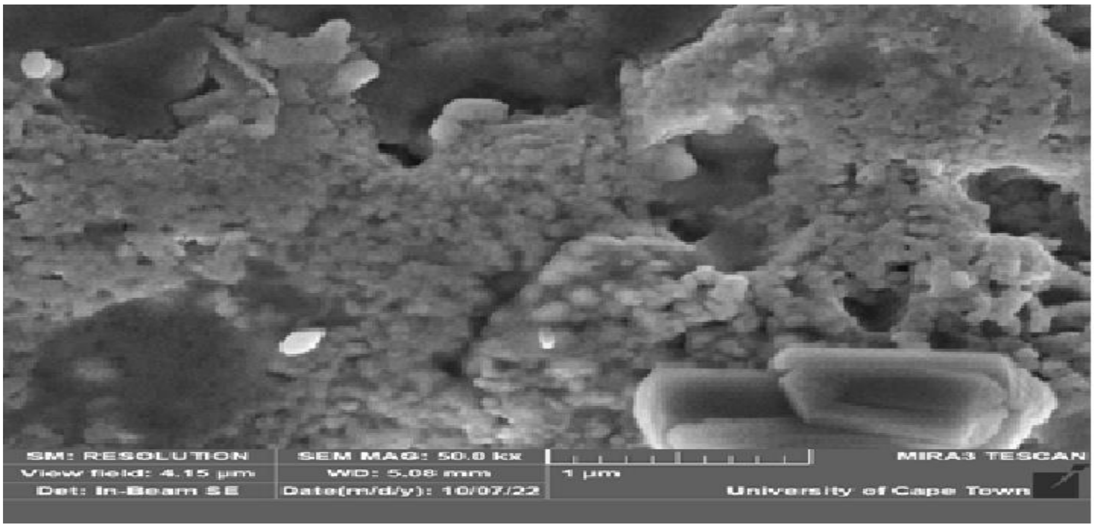

Figure 10: SEM of PURPLE CARBBAGE+CQDT

Figure 8, 9 and 10 is the surface morphology of CQDT, purple cabbage and Purple cabbage + CQDT. The SEM images show nanograins spread throughout the substrate surface which show a stacked like agglomeration due to glass substrate use for the synthesis. The morphology also corresponds to the random orientation obtained from their structural result. Average crystallite size of about 1 to 9 nm was obtained from the XRD data. Incorporating different dye also gave rise to rough surfaces which would facilitate optical and photovoltaic activities

Photoelectrical properties of CQDT, purple carbage, and purple carbage+CQDT

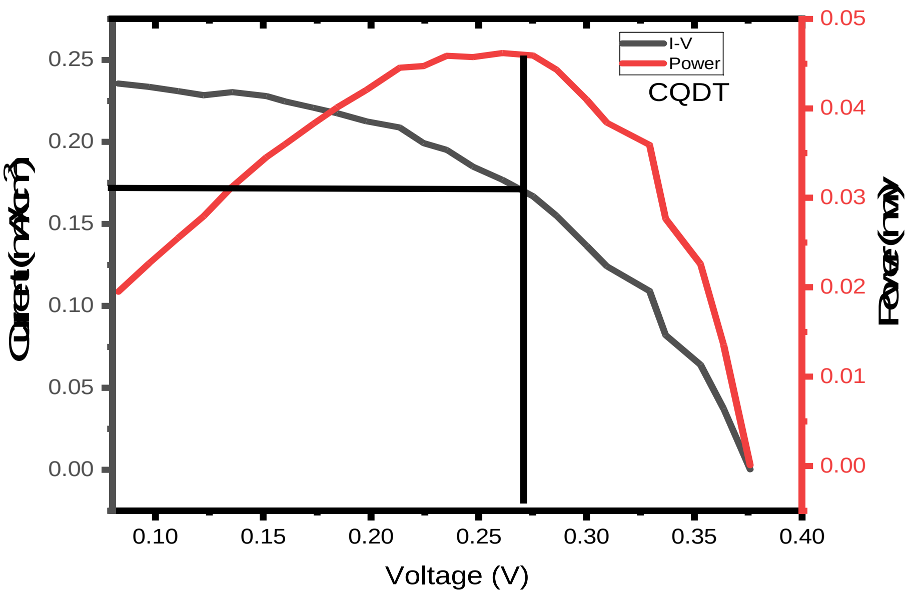

Figure 11: I-V curve of CQDT

Figure 11 is a graph of voltage vs current, as the voltage increases, there was a corresponding decrease of the current. Consequently, there was a corresponding increase in power as the voltage and current increase, the maximum power attained was 0.047 mw but further increase of the volt lead to decrease in the power.

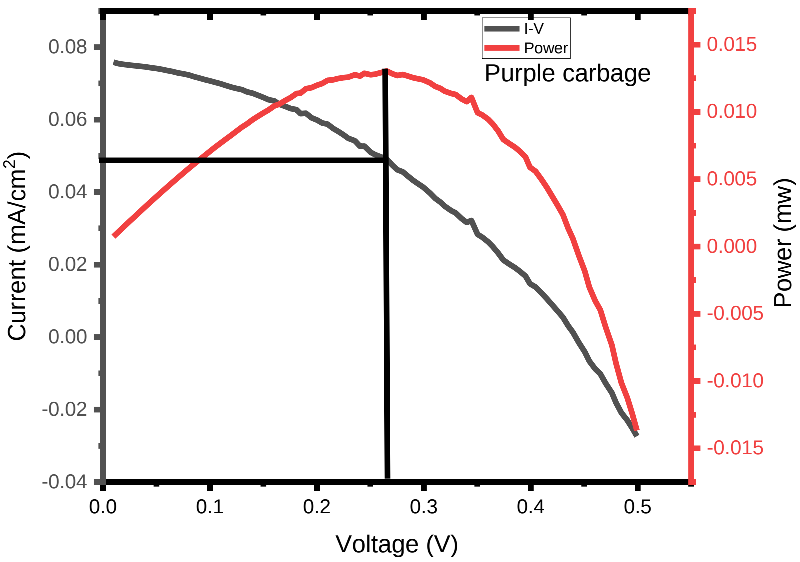

Figure 12: I-V curve of purple carbage

Figure 12 is a graph of purple carbbage voltage vs current, as the voltage increases, there was a corresponding decrease of the current. Consequently, there was a corresponding increase in power as the voltage and current increase, the maximum power attained was 0.012 mw but further increase of the volt lead to a corresponding decrease in the current and also the power respectively

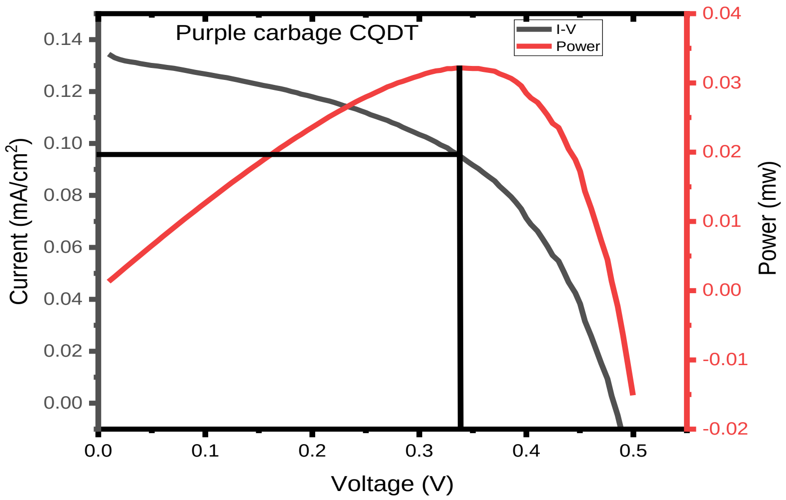

Figure 13: -V curve of purple carbage +CQDT

Figure 13 is a graph of purple carbbage +CQDT voltage vs current, as the voltage increases, there was a corresponding decrease of the current. Consequently, there was a corresponding increase in power as the voltage and current increase, the maximum power attained was 0.032 mw but further increase of the volt lead to a corresponding decrease in the current and also the power respectively

Table 4: Photovoltaic performance of CQDT, purple carbage, and purple carbage+CQDT.

Sample	J_{sc}(mA/cm^2)	V_{oc} (v)	V_{mp}(v)	J_{mp}(mA/cm^2)	**FF**	**η (%)**
CQDT	0.21	1.54	0.27	0.17	0.14	4.17
Purple Carbage	0.30	2.91	0.26	0.05	0.015	1.06
Carbage + CQDT	0.49	2.68	0.34	0.10	0.025	3.63

Table 4: the summary of the electrical parameters of CQDT, Purple cabbage and purple carbage+CQDT.
From the table, the values the efficiency of the fabricated cells are 4.17, 1.06 and 3.63 % respectively. Showing that the CQDT has the highest efficiency closely followed by the hybrid fabricated solar cells (CQDT+Purple cabbage dye).

CONCLUSION
Dye-sensitized solar cells were fabricated from NCQDT and natural dyes extracted from purple cabbage, using doctor blade method. The optical properties as demonstrated by the Uv spectrometer, shows that the incorporating sensitizer (dye/NCQDT) on the surface of the semiconductor, enhances the binding energy of the dye molecules on the semiconductor, thereby increasing the performance of absorbance, reflectance, transmittance and bandgap energy. The structural characteristics, revealed by XRD and SEM, show the cells are polycrystalline in nature. The electrical properties of the cells, shows that the NCQDT cell has the highest conversion efficiency of 4.17%.

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