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LAMPIRAN

1. Pengujian I-V pada suhu 300 °C

Tegangan (mV)	I (mA)	J(A/cm2)	Pout	efisiensi (%)
50.7	0.0257	0.011422	5.79107E-07	0.104086804
47.9	0.0266	0.011822	5.66284E-07	0.101782178
44.1	0.0274	0.012178	5.3704E-07	0.096525874
40.6	0.0279	0.0124	5.0344E-07	0.090486716
35.8	0.029	0.012889	4.61422E-07	0.082934573
31.5	0.0294	0.013067	4.116E-07	0.073979684
30.2	0.0264	0.011733	3.54347E-07	0.063689151
28.2	0.0251	0.011156	3.14587E-07	0.056542814
26	0.0235	0.010444	2.71556E-07	0.048808538
24.8	0.0228	0.010133	2.51307E-07	0.045169067
23.9	0.0216	0.0096	2.2944E-07	0.041238821

Menghitung efisiensi

Diketahui:

V_{maks} = 50.7 mV
I_{maks} = 0.0257 mA
A = 2.25 cm^2
V_{oc} = 23.9 mV
I_{sc} = 0.0257 mA
P_{in} = 0.000556369 mW/cm^2

Penyelesaian:

$$J_{sc} = \frac{I_{sc}}{A} = \frac{0.0257}{2.25}$$

$$= 0.01142222$$

$$FF = \frac{J_{maks} \cdot V_{maks}}{J_{sc} \cdot V_{oc}} = \frac{(0.0257)(50.7)}{(0.01142222)(43.9)}$$

= 83.68%

$$P_{out} = J_{maks} \cdot V_{maks}$$ = (0.011422) (50.7)

= $5.7910x10^{-7}$ mW/cm^2

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% = \frac{5.7910x10\text{-}7}{0.000556369} \times 100\%$$

= 0.1040 %

Gunakan rumus yang sama untuk variasi suhu 400°C dan 500°C.

2. Pengujian I-V 400°C

Tegangan (mV)	I (mA)	J(A/cm2)	Pout	efisiensi (%)
57.3	0.0291	0.012933	7.4108E-07	0.133199379
54.3	0.0301	0.013378	7.26413E-07	0.130563239
53.4	0.031	0.013778	7.35733E-07	0.132238386
49.4	0.0321	0.014267	7.04773E-07	0.126673733
47.8	0.0329	0.014622	6.98942E-07	0.125625668
34.7	0.0331	0.014711	5.10476E-07	0.091751264
32.6	0.0337	0.014978	4.88276E-07	0.087761106
30.8	0.034	0.015111	4.65422E-07	0.08365352
28.3	0.0345	0.015333	4.33933E-07	0.077993807
25.1	0.0349	0.015511	3.89329E-07	0.069976745
22.1	0.035	0.015556	3.43778E-07	0.061789532

3. Pengujian I-V 500°C

Tegangan (mV)	I (mA)	J(A/cm2)	Pout	efisiensi (%)
94	0.0465	0.020667	1.94267E-06	0.349168772
87.7	0.0487	0.021644	1.89822E-06	0.341179669
81.7	0.0507	0.022533	1.84097E-06	0.330890733
74	0.0511	0.022711	1.68062E-06	0.302069731
65.6	0.0521	0.023156	1.519E-06	0.273021062
52	0.0529	0.023511	1.22258E-06	0.219742269
42	0.054	0.024	0.000001008	0.181174737
39.1	0.0549	0.0244	9.5404E-07	0.171476137
37.4	0.0551	0.024489	9.15884E-07	0.164618178
35.6	0.0557	0.024756	8.81298E-07	0.15840168
33.8	0.0562	0.024978	8.44249E-07	0.151742629

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TENTANG

PENGANGKATAN KOMISI PENASEHAT TESIS BAGI MAHASISWA PROGRAM STUDI MAGISTER A.N. **NUR AULIA** NOMOR INDUK MAHASISWA **H032222002**

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Membaca : Surat usulan Ketua Program Studi Magister Fisika Nomor : 10836/UN4.11.7/TD.05/2024 Tanggal 26 Januari 2024 perihal usulan komisi penasehat dan rencana judul tesis bagi Sdr. (i) Nur Aulia

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2. Prof. Dr. Paulus Lobo Gareso, M.Sc (Anggota)

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Ditetapkan di Makassar
pada Tanggal, 1 Februari 2024
Wakil Dekan Bidang Akademik dan
Kemahasiswaan Fakultas MIPA Unhas,

Dr. Khaeruddin, M.Sc.

Tembusan:
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2. Ketua Program Studi S2 Fisika FMIPA Unhas
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SURAT KEPUTUSAN
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UNIVERSITAS HASANUDDIN
NOMOR : 01019/UN4.11.7/KEP/2024

TENTANG
SURAT KEPUTUSAN PENGANGKATAN PANITIA PENILAI SEMINAR USUL, HASIL DAN UJIAN AKHIR BAGI MAHASISWA PROGRAM MAGISTER A.N. **NUR AULIA**
NOMOR INDUK MAHASISWA **H032222002**

DEKAN FAKULTAS MATEMATIKA DAN ILMU PENGETAHUAN ALAM
UNIVERSITAS HASANUDDIN

Membaca : Surat usulan Ketua Program Studi Magister Fisika Nomor : 10839/UN4.11.7/TD.05/2024 tanggal 26 Januari 2024 Perihal Usulan Panitia Penilai Seminar Usul, Hasil dan Ujian Akhir Magister Sdr. (i) Nur Aulia

Menimbang :
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SURAT KETERANGAN PUBLIKASI ILMIAH

Yang bertanda tangan di bawah ini menerangkan bahwa:

Nama	: Nur Aulia
Nomor Pokok	: H032222002
Judul Publikasi	: Enchanced Efficiency Dye Sensitized solar cell Photoanodes by hybrid rGO (reduced graphene oxide)/TiO_2 (titanium diokside) and its deposition method: A review
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Makassar, 2 Mei 2024

Ketua,

Prof. Dr. Dahlang Tahir, M.Si.

Enhanced the Efficiency of Dye-Sensitized Solar Cell Photoanodes by Hybrid rGO (Reduced Graphene Oxide)/TiO_2 (Titanium Dioxide) and Its Deposition Method

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Abstract: Improving the efficiency of dye sensitized solar cell (DSSC) by applying hybrid materials in the form of rGO combined with TiO_2 on the photoanode. In addition, the optimal TiO_2 deposition method can increase energy conversion efficiency. The hybrid material synthesis method is carried out by integrating rGO into the TiO_2 structure to increase electrical conductivity and improve optoelectronic properties, the material characterization is carried out by various analyses, including spectroscopy and microscopy. This review provides information on the characteristics of TiO_2 as a photoanode, characteristics of (rGO) development of rGO/TiO_2 as a photoanode, methods of deposition TiO_2 on glass substrates. This review will help researchers conduct research in the field of DSSC enhancement using rGO.

Keyword: Efficiency; Reduced Graphene Oxide; Titanium Dioxide.

1. Introduction

Energy is a primary requirement in life activities around the world, with a daily consumption of about 17,4 TW [1]. Rapid population growth and global economy increase energy demand in the mid-21st century, increasing energy demand will lead to energy crisis, climate change, fossil fuel shortages and environmental issues [2]. The source of greenhouse gas emissions comes from the use of fossil fuels that produce carbon dioxide (CO_2), the continuous production of CO_2 will form a blanket, retaining earth's heat nd projecting it into space and will further cause planetary warming [3].

Conventional energy sources are generally obtained from petroleum, coal and natural gas, but their continuous use causes damage to ecosystems and human health, so renewable energy source are required sourced from solar, wind, geothermal, hydropower and biomass [4]. The most promising renewable energy is solar cell because it is obtained from the sun, providing clean energy [5]. The solar energy that can be generated in a year is 3.8 EJ, which is able to convert energy from sunlight into light and warmth that trigger chemical processes in plants and produced energy [6]. Photovoltaic (PV) technology has the advantage of low production costs and no toxic effects on the environment [7].

PV is generally based on inorganic materials which require high cost, difficult fabrication, some toxic materials and little availability in nature [8]. The presence of organic-based PV is the answer to these problems called Dye Sensitized Solar cell. DSSC are the third generation of solar cells that are very attractive because they are semi-transparent, low fabrication cost, and low energy consumption [9], high flexibility, environmental friendliness and abundant material availability [10]. Photoanode, electrolyte and cathode from the DSSC structure. As a contender to silicob-based solar cell, DSSC has demonstrated a very promising photoconversion efficiency 14% [11]

Titanium Dioxide is the most widely used photoanode due to its n-type semiconductor features, wide band gap energy, high transmittance in the range of visible light, environmentally friendly, ease of production and good chemical and thermal, however the conductivity in TiO_2 is low and the nanocrystalline particles in TiO_2 inability to withstand external electric fields has an impact on DSSC performance [12]. To overcome these problems, improving the performance of photoanodes is done by adding various TiO2-based composite materials such as carbon nanotube-TiO_2 [13], [14], Graphene-TiO_2 [15], [16], reduced graphene TiO_2 [17], [18]. Graphene a material with strong electron mobility, a vast surface area and exceptional optical transparency, is the source of rGO [18]. The fusion of rGO to TiO_2, will form a Schottky barrier on the surface of rGO/ TiO_2, which causes electron recombination to be reduced so that the rGO/TiO_2 composite system will include an acceleration of electron transport [19].

Several investigations have revealed in recent years use of graphene in TiO_2 photoanodes including Kumar Subalakshmi et al [20], using rGO/TiO_2 as a photoanode in solar cell fabrication with a resulting efficiency of 6.14% under sunlight with an illumination of 100 mW/cm^2 [20]. Ghasem Habibi et al, also reported the addition of 0.001% rGO was able to increase the current density from 10.18 $mAcm^{-2}$ to 10.79 10.18 $mAcm^{-2}$ [21].

Based on the review of several journals, this review describes the addition of rGO to TiO_2 semiconductor as a photoanode in solar cells. This topic is important to discuss because rGO has the ability to increase electron transfer efficiency and mechanical and thermal stability. This research contributes to the scientific literature and understanding of the addition of rGO in TiO_2 to obtain better efficiency. Through better understanding, this research can be used as a reference for further researchers in developing TiO_2 doped by other materials.

2. Titanium Dioxide (TiO_2) as photoanode material

Because of its larger conduction band gap, ample surface area for loading photosynthetic sensitizers, and effective recombination with holes, defects, and crystal boundaries, TiO2 material is employed in DSSCs with great efficacy [22], [23]. TiO_2 is classified in different crystal forms namely brookite, rutile and anatase shown in Figure 1(a). Anatase TiO_2 polymorphs are more efficient because they support the process of charge transportation and charge separation compared to rutile, this is supported by the nature of anatase, namely higher electrical conductivity so that it is able to transport electrons and energy production [24]. The difference of refractive index in the rutile phase may intensify the dispersion impact, in brookite phase the energy band gap is larger than other phases, brookite phase has the highest open circuit voltage (Voc) evaluation and the most negative conduction band edge. However, the brookite phase hs a small surface and low conductivity, which makes it less effective in collecting charge and dye load at the same time [25].

In terms of the small size of semiconductor nanoparticles, it is capable offering semiconductors with a large surface and high porosity ratio [3]. Figure 1(b) shows a FESEM of a semiconductor film of TiO_2 nanoparticles that has a surface thickness of approximately 10 µm, porosity of about 50% and excellent surface area for dye absorption [26]. The thick mesopores structure offers a high surface area that is useful for attaching dye molecules to the photoanode; thus, the photoanode's morphology which includes its particle size, porosity, pore size, and nanostructure plays a crucial role in controlling the photovoltaic properties [27].

TiO_2 may create a variety of nanoarchitectures as photoanodes, including one-dimensional (1D) structures like nanorods, nanofibers, and nanotubes, zero-dimensional (0D) structures like TiO2 nanoparticles, and three-dimensional (3D) structures like 1D/0D composites and effective 1D/1D composites for DSSC [28]. TiO_2 is generally synthesized by sol-gel, hydrothermal and electrochemical methods, which will form nano-TiO_2 morphologies such as TiO_2 nanotubes (TNTs), TiO_2 nanorods (TNRs), TiO_2 nanosheets (TNSs), hierarchical TiO_2, multi-shelled TiO_2 hollow nanoparticle, ellipsoidal TiO_2, TiO_2 nanoparticle (TNPs), cubic TiO_2, illustrated in Figure 2.

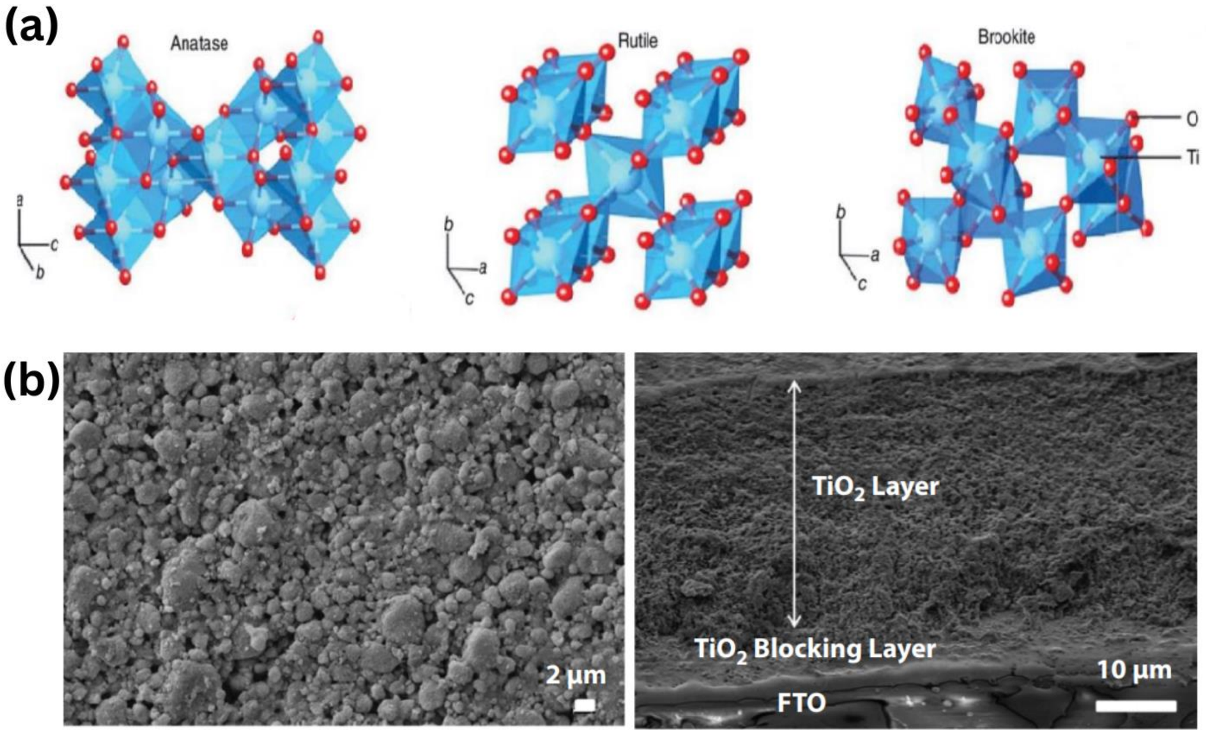


Figure 1. (a) Structure of Anatase, Rutile dan Brookite [29] (b) FESEM images of TiO2 nanoparticles deposition onto FTO glass (a) TiO_2 morphology (b) TiO_2 nanoparticles onto FTO cross-section [26]

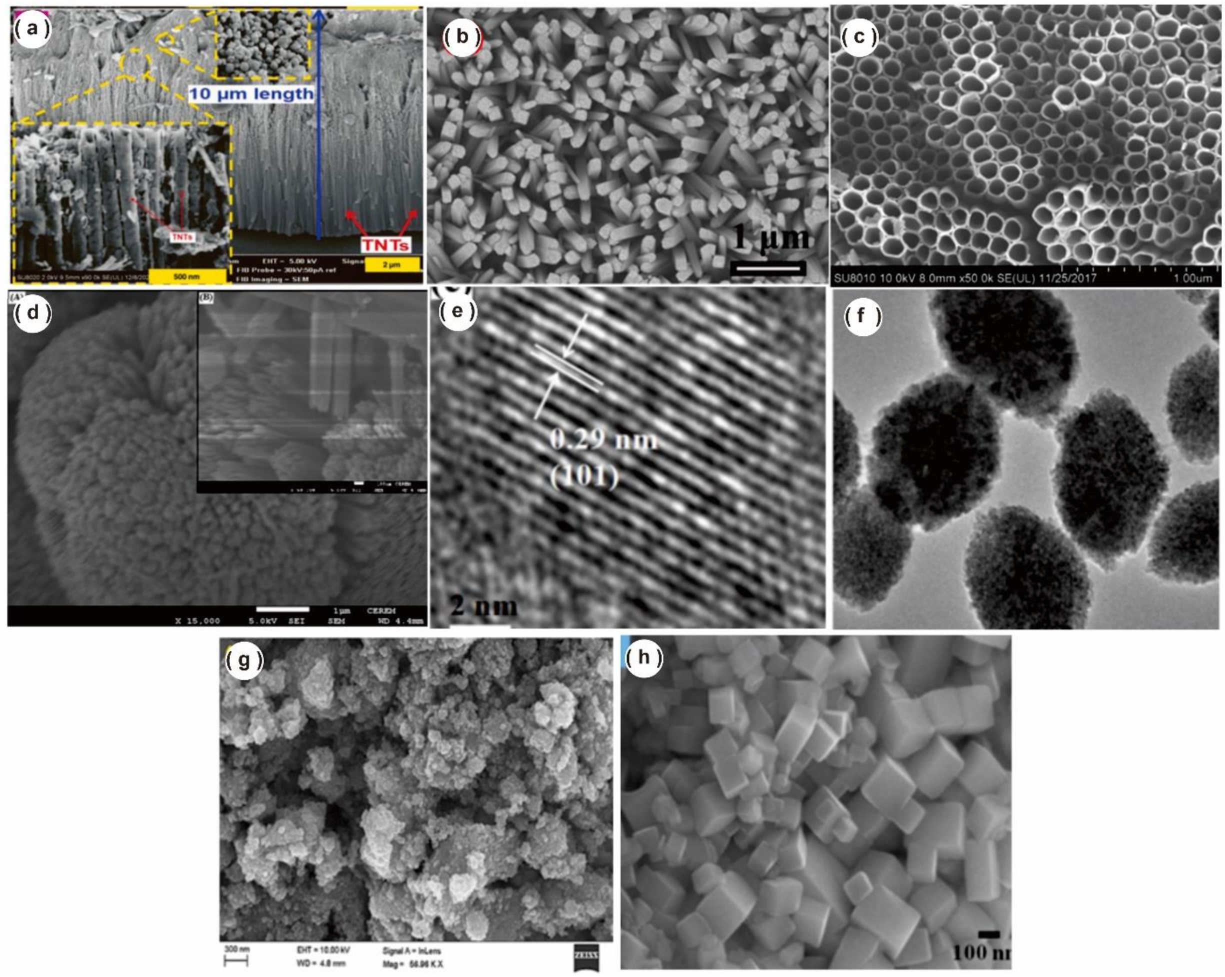


Figure 2. SEM images (a) TNTs[30]–[32] (b) TNRs[33]–[35] (c)TNSs[36], [37] (d) Hierarchical TiO_2[38], [39] (e) Multi shelted-TiO_2 [40], [41](f) Ellipsoidal TiO_2 [42] (g) TNPs [43]–[45](h) Cubic TiO_2 [46], [47].

3. Structure and Properties of reduced graphene oxide (rGO)

According to the international Union of Pure and Applied Chemistry (IUPAC), graphene is a single carbon sheet derived from the graphite structure. It is comparable to a quasi-infinite sized polycyclic aromatic hydrocarbon [48]. Graphene-based materials as affordable price, safety, prosperity, particular area of surface, flexibility, and greater stability, graphene based materials can be used in DSSC [24].

Due to its quicky charge carrier mobility and great light transparency, graphene is an effective photoanode in deep solar cell technology. The carbon material network is shown in figure 3(a), where a single layer of 2D graphene is thought to be the dominating material 1D rolled nanotubes, 3D stacked graphite and 0D folded fulcrums [3] powder based nanomaterials for the development of graphene include graphene oxide (GO), nanowire, nanoparticle plats, and quantum dots, among other forms of pure graphene nanostructure [49]

To produce graphene oxide, GO is generally chemically clamped and reduced to rGO [50]. In rGO, each carbon atom employs three of its four outer orbital electrons to establish three sigma bonds with an angle of 120° with three nearby carbon atoms in the same plane. rGO is a two-dimensional material with a single-layered structure and zero band gap. As seen in figure 3(b), this permits the fourth electron to travel, allowing the electrons in rGO to behave as relativistic particles free from the restrictions of a crystal lattice [12].

Researches have been drawn to rGO because of its mechanical, thermal, electrical and optical qualities. Figure 4 shows some of its physical characteristics. The synthesis of GO into rGO generally uses chemical, microwave, photoreduction, electrochemical and other methods [51], the advantages and disadvantages of the rGO synthesis process are shown in table 1. rGO through chemical techniques, results in rGO that has a wrinkled structure, aggregated sheets, and low hydrophilic properties. These limitations have been overcome with the creation of a new technique. The thermal reduced rGO exhibits a 10:1 C/O ratio and strong electrical conductivity, suggesting a successful reduction [52]. The newly discovered method produces rGO with improved thermal and electrical conductivity and a reduced oxygen content [53].

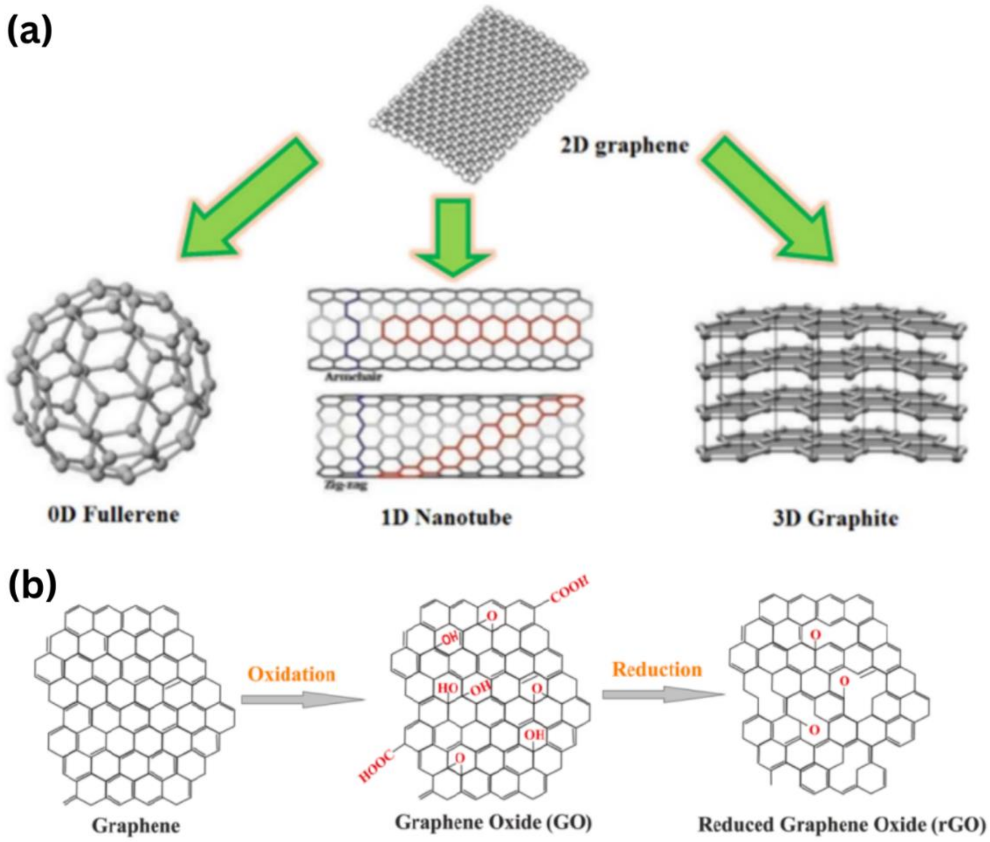


Figure 3. (a) family of carbon networks under 2D graphene [3] (b) Reduction process of graphite to rGO [54]

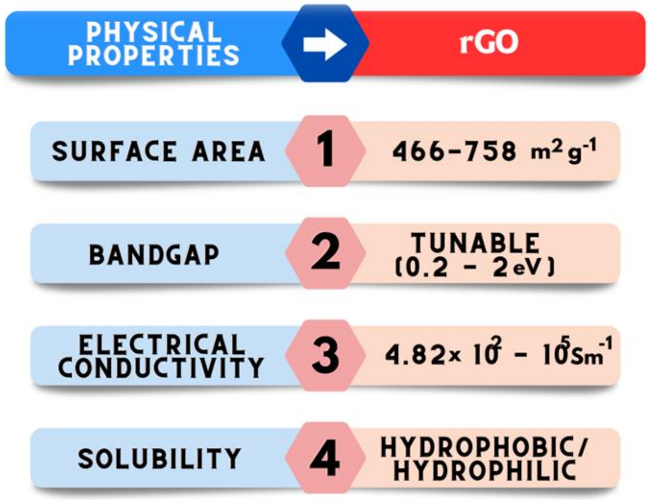
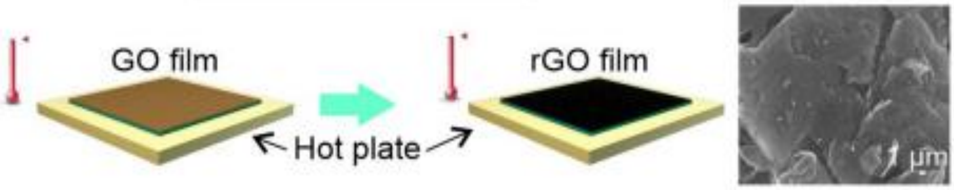


Figure 4. Physical properties rGO

Table 1. Advantages and disadvantages of rGO synthesis methods

<table>
<tr><th>Synthesis Metode</th><th>Advantages</th><th>Disadvantages</th><th>ref</th></tr>
<tr><td>Thermal Reduction</td><td>Easy fabrication, properties and characteristics of rGO.</td><td>High energy consumption, exhaust emissions, defect limitation and control</td><td>[55]</td></tr>
<tr><td colspan="3">
</td><td></td></tr>
<tr><td>Chemical Reduction</td><td>Stabilty, economical</td><td>Difficult fabrication process, toxic to the environment</td><td>[56]</td></tr>
<tr><td colspan="3">
</td><td></td></tr>
<tr><td>Microwave-reduction</td><td>Good effectiveness, saving time and production costs.</td><td>Non-scalable, unsuitable for monitoring the reaction.</td><td>[57]</td></tr>
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4. Development of rGO/TiO_2 as Photoanode

TiO_2 nanomaterial is a good photocatalyst used in DSSC, however weak power conversion efficiency (PCE) is caused by significant electron-hole pair recombination, a possible substance to increase the effectiveness of DSSC, which is typically used as a photocathode, is graphene film [58]. In a DSSC, TiO2 transports electrons from the dye to the conduction band of TiO_2 as well as from the photoanode to the external circuit. However, charge recombination occurs, necessitating the use of techniques to improve electron transport, such as combining charge carriers to direct light-generated electrons in the external circuit, adding doping elements to TiO_2, and combining composite semiconductors with different bandgaps. [59]. TiO_2 nanoparticles can be bonded to rGO, which allows rGO to provide a fast electron transport channel, which accelerates electron transport, reduces recombination losses, and increases light scattering. Therefore, rGO/ TiO_2 nanocomposites can be used in DSSC because of the unique properties of rGO[60]. In accordance with the literature, the synthesis of TiO_2/rGO nanocomposites is currently aimed at various applications, enhancing the functionality of lithium-ion batteries, solar cell, photocatalysts and photodetectors, among other devices. Compared to pure TiO_2, TiO_2/rGO has photocatalytic activity that is many times greater [61]. The purpose of inserting rGO sheets into the TiO2 anode is to decrease resistance and raise chemical capacitance ($C\mu$) [62].

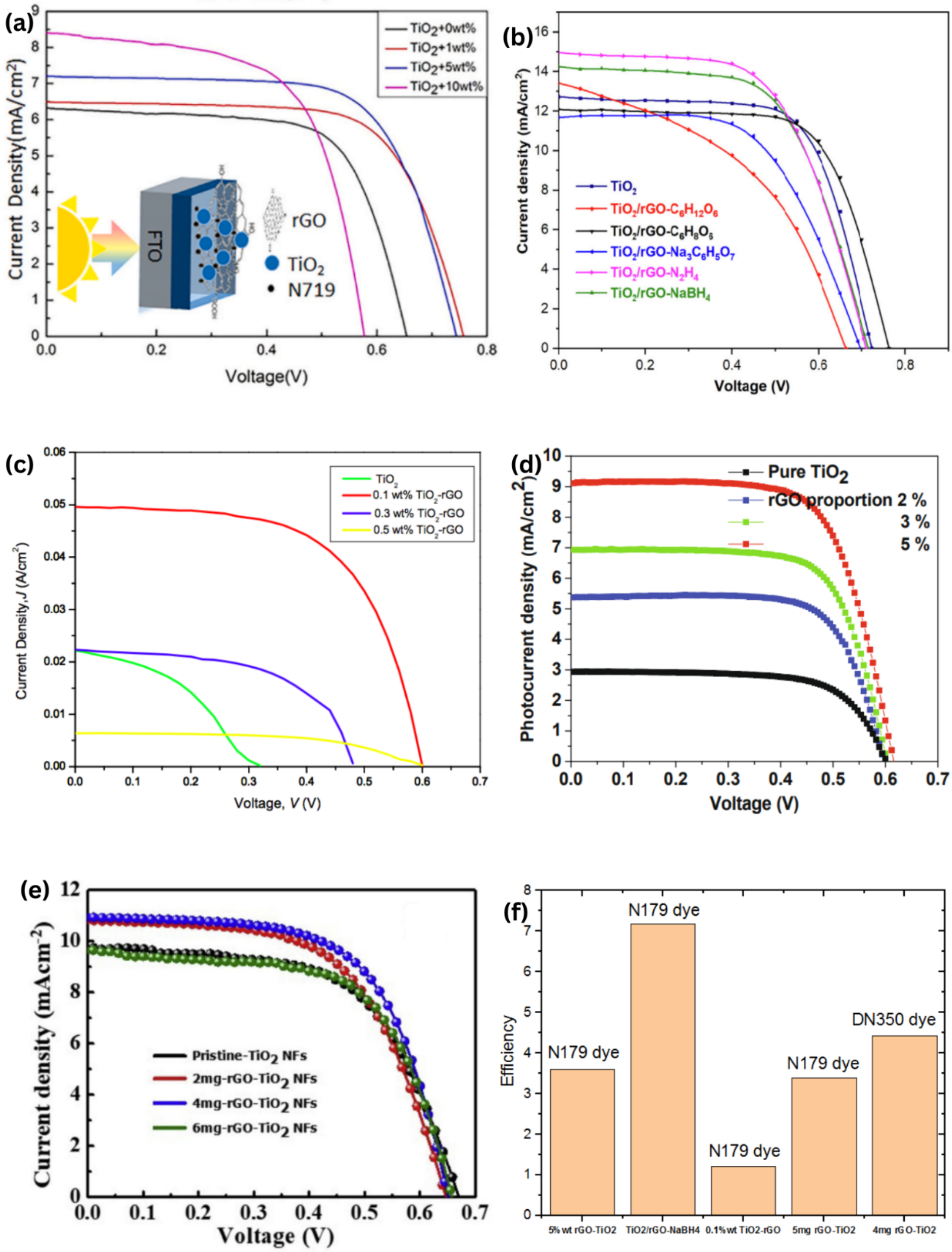

Figure 5. (a)-(e) J-V characteristic DSSC [63] [64] [65] [17] [66], (f) efficiency values from J-V plot of DSSC (a)-(e)

Table 2 shows the parameters efficiency of rGO/TiO_2-based DSSCs from various references. Prior to the deposition of the nanopores TiO_2 film over TCO, rGO was integrated into a thin rGO/TiO_2 interfacial thin layer to reduce recombination of electrons. This layer's potential resistance was shown by a rise in the open-circuit voltage with an unchanged short photon current Jsc. Several subsequent studies showed how to create rGO/TiO_2 composites, which may be used in place of pure TiO_2 in DSSC working electrodes [11].

Merazga et al.[17] was reported also the impact of rGO on DSSC by varying mass fractions of rGO and TiO_2 were combined in distilled water solution, ranging from 0 to 5%. The optical properties of the rGO/TiO_2 composite film are responsible for its photovoltaic features. The effectiveness of DSSC rises linearly as the fraction of rGO increases. The researcher Gao et al. [67] was demonstrated N-doped TiO_2/graphene nanofiber for DSSC photoanode with photo-conversion efficiency (PCE) of 5.01%. In another study, Venkatraman et al. [68] found that a 3% RGO/ TiO_2 composite had a photo-conversion efficiency (PCE) of 6.58%. Figure 5 (a)-(e) shown the J-V characteristic of DSSC use TiO_2 with rGO. Figure 5 (f) shows the efficiency value obtained from Figure 6 (a)-(e) which shows different efficiency values, this is influenced by the addition of different rGO compositions to TiO_2, as in Figure 5 (a) obtained an efficiency value of 3.60 with 5% rGO while in Figure 5 (b) obtained an efficiency value of 7.17 with NaBH4-doped rGO. Figure 5(c) obtained an efficiency value of 1.21% with the addition of 0.1% wt rGO and figure 5(d) shows value of 3.39% with the addition of 6 mg rGO and figure 5(e) is 4.43% with the addition of 5%wt rGO.

Table 2. Some research related to rGO/TiO_2

Material	Deposition Method	J_{sc} (mA/cm^2)	V_{oc} (V)	Fill Factor	η (%)	Ref
rGO/TiO_2	Spin Coating	14.08	0.73	66.35	6.87	[69]
rGO/TiO_2	Doctor Blade	28.36	0.54	0.47	7.20	[70]
rGO/TiO_2	Spin Coating	15.29	0.74	0.66	7.48	[71]

TiO_2-rGO 0.5%	Spin Coating	7.2	0.74	0.67	3.6	[72]
TiO_2-rGO	Doctor Blade	14.68	0.78	0.54	7.68	[73]
TiO_2-rGO	Spin Coating	25.02	0.63	0.54	8.51	[74]
TiO_2-rGO 3%	Doctor Blade	6.95	0.64	0.68	3.09	[75]
TiO_2-rGO 2mg	Doctor Blade	10.82	0.647	58.61	4.10	[66]
rGO/TiO_2	Doctor Blade	10.92	0.65	0.62	4.43	[66]
rGO/TiO_2	Spin Coating	16.27	0.59	0.72	6.90	[76]
0.1 wt% TiO_2-rGO	Spin Coating	0.049	0.600	0.612	1.21	[65]
TiO_2/rGO	Doctor Blade	13.42	0.66	0.47	4.63	[64]

5. TiO_2 deposition method on glass substrate

a. Doctor Blade

Doctor blade known as blade coating is one of the most economical, flexible and simple thin film fabrication methods [58]. This method involves pouring a slurry combination containing nanoparticles onto the substrate and continuously moving it between the blade and the substrate. This modifies the distance between the substrate and the blade, ensuring a thin layer thickness. It is also possible to add thin layers of film or thicken the film by repeating this process. The spread is cleansed and allowed to dry after a consistent coating has developed [77], as shown in figure 6(a).

The doctor blade method has a thickness that varies from 10 to 150 µm [78]. Research conducted by Zhi et al[79], A modest quantity of 3D graphene mixed with nanocrystalline TiO_2 film has been used to study the composition of flexible DSSC photoanodes. Using the doctor blade method, the film was applied on ITO/PET, and N719 dye was utilized as a sensitizer. The results indicate that the maximum rate of 6.41% may be obtained by incorporating 0.85% by weight of 3D graphene into 13 µm-thick TiO_2 nanoparticles.

b. Spin coating

A common and fast procedure known as spin coating is used to coat conductive substrates with a thin and uniform layer. The substrate surface is covered with drops of solution, which are subsequently uniformly distributed by the strong spin action. The coating and spin process factors, such the rotation speed have an impact on the final film thickness, surface tension, solids, viscosity, and drying rate [80]. Fabrication of nanocrystalline thin films using sol-gel spin coating, showing homogeneous and uniform TiO_2 thin films, which are in crystalline anatase phase with a band gap reaching 2.69 eV, shown in Figure 6(b).

c. Screen Printing

Screen printing uses a high-density TiO2 paste during the printing process, which enables the attachment of bigger dye molecules, it is regarded as an effective manufacturing approach. The photoanode paste and the conductive substrate are separated by a mesh, and the paste is pressed into the substrate with a racket to create a pattern depending on the holes in the mesh. [80].

Screen printing is one of the oldest and most commonly used deposition methods [81]. During the screen printing process, paste is forced onto the surface of the wafer through holes in the emulsion layer. This allows the paste to move through the screen in a predetermined pattern, aligned with the pattern to be moved, as shown in figure 6(c)

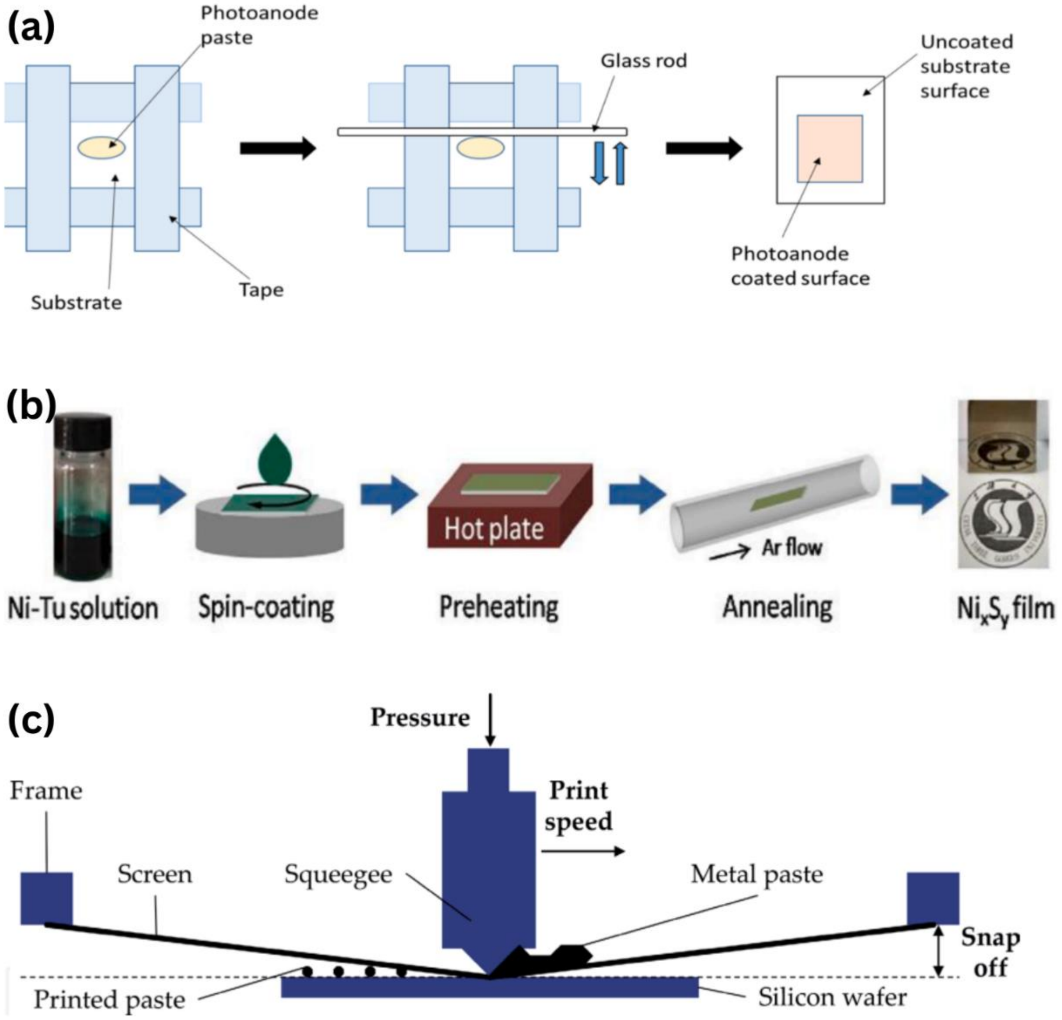

Figure 6. (a) Diagrammatic representation of the doctor blade method [58]. (b) Spin coating method [78] (c) Schematic illustration of screen printing process [82].

d. Electrophoretic Deposition

This deposition technique offers a lot of benefits. The EPD process produces an electric current when an electric current passes through a solution or solvent and charged particles move. Some of these benefits are simple equipment, cheap cost, high deposition rate, enabling the fabrication of suitable conductive substrates, and excellent repeatability [83].

There are two steps in the EPD technique. The particles gravitate toward one of the electrodes when an electric field is added to the solution. The migration process is influenced by the bath's real field strength as well as additional colloidal dispersion properties as bath conductivity, surface charge density, viscosity, size distribution, and particle concentration. Complicated aggregation and electrochemical processes help to advance the deposition phase. The particles must lose charge after being deposited on the electrode in order to create a dense and cohesive deposit [78], shown in figure 7(a).

e. Electrospray Deposition

One drop of sample solution is deposited at a time using the straightforward electrospray deposition technique, which allows for the creation of nano-sized spheres of photoanode nanoparticles and the production of substructures in film [84]. Figure 7(b) shows an example of a spray deposition system configuration design consisting of a sprayer, a pipe connecting the pump to the sprayer, a beaker for the precursor solution, and a pump, either manually or automatically operated [78].

A nozzle that atomizes droplets and a power source that charges the atomized droplets make up an electrospray deposition (ESD) device. The pump applies pressure to the solution. These charged droplets deposition upon reaching the grounded substrate. This method uses less nanoparticles and wastes between 5 and 8% of them [85].

f. Pulse Laser Deposition (PLD)

Thin film production frequently uses PLD, a kind of physical vapor deposition. The material's target surface is diluted, ionized, and evaporated as a result of the laser pulse width's high power density and limited frequency bandwidth. After drying, the substance is applied to the substrate thinly. Furthermore, a heating step of the substrate is necessary to guarantee that the atoms on its surface are thoroughly absorbed. A strong vacuum is also necessary to remove impurities that might degrade the thin layer's quality [86], shown in figure 7(c).

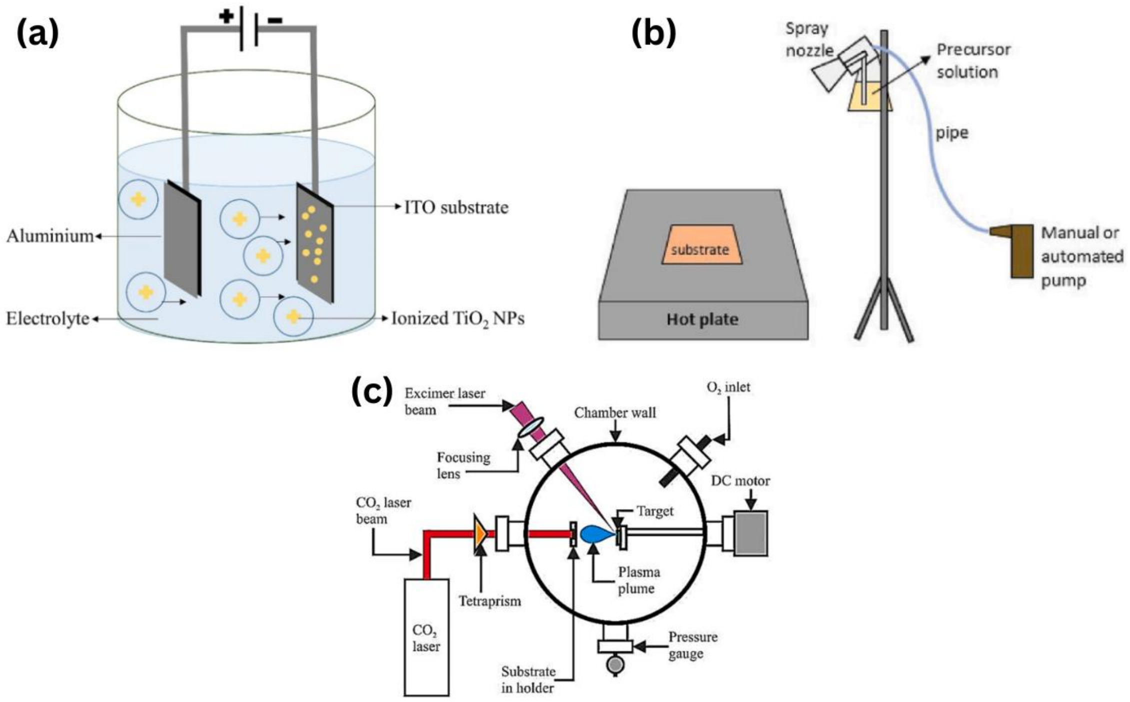

Figure 7. (a) Schematic of the EPD [78], (b) Spray deposition system setup design [78] (c) Schematic presentation of PLD technique [86].]

6. Conclusion, Limitation and Challenges and Future research prospect

Conclusion

Dye sensitized solar cell (DSSC) performance has been effectively increased by the use of hybrid materials on the photoanode, such as rGO with TiO_2. Integration of rGO contributes positively to electrical conductivity and optoelectronic properties, which has a positive impact on energy conversion efficiency. This review places emphasis on developing an optimal TiO_2 deposition method for DSSC photoanodes. This deposition method is intended to ensure the TiO_2 layer has a structure that matches the performance requirements of the solar cell. A deeper understanding of the interaction between materials and deposition methods is key in improving solar cell efficiency. The use of various characterization techniques, such as spectroscopy and microscopy, in this study provides an in-depth understanding of the optical and structural properties of the rGO/

TiO_2 hybrid material. This analysis is important to understand the impact of changes at the microscopic level on DSSC performance. This review makes an important contribution to the development of DSSC technology by integrating hybrid materials and optimizing TiO_2 deposition methods. Improving the performance of dye-sensitive solar cells through this approach could open up wider potential applications in solar energy conversion. This review has significant relevance to the development of renewable energy. Increased energy conversion efficiency from sunlight can support the advancement of solar cell technology as a more sustainable energy source. Thus, the conclusion of this review emphasizes that the incorporation of rGO/ TiO_2 hybrid materials and the optimization of TiO_2 deposition methods can positively affect DSSC performance, opening up the potential for significant improvements in dye-sensitive solar cell technology. Limitations and challenges as well as future research prospects regarding the addition of rGO in TiO_2 as a photoanode are described in detail as follows:

Limitation and Challenges

1. **Recombination:** The efficiency of the solar cell may be decreased by unintended recombination between the injected electrons and the electrolyte on the TiO_2/electrolyte interface, even if rGO can enchance electron transport.
2. **Stability dan Disperse rGO:** The stability and disperse of rGO in the mixture can be challenging. Ensuring that the rGO remains well dispersed and stable in the TiO2 matrix.
3. **Production Price Growth:** If the production process of rGO/TiO_2 is inefficient or the raw materials used are expensive, which can affect the production price and can be an obstacle to mass application.
4. **Electronic Properties rGO:** although rGO improves electron transfer, its electronic properties that are not as optimal as pure graphene may limit overall performance.
5. **Limited Improvement Efficiency:** although rGO can improve the power conversion efficiency of DSSC, the improvement may have certain limits and such challenges need to be overcome to achieve more significant improvements.

Future Research Prospect

1. **Structure and Composition Optimization:** Further research in optimizing the structure and composition of rGO/TiO_2 to improve solar cell performance. Involve variations in rGO to TiO_2 ratio, particle size and distribution, and more efficient synthesis methods.
2. **Stability and Durability:** Focus on improving the stability and durability of rGO/TiO_2 under solar cell operational conditions to ensure long-term performance and address potential issues such as material degradation.
3. **Improved Energy Conversion Efficiency:** Focus on developing new strategies to improve energy conversion efficiency in DSSCs utilizing rGO/TiO_2, such as enhancing the interaction between rGO and TiO_2 to improve electron transfer.
4. **Integration with latest technology:** Exploration of the potential of rGO/TiO_2 with current technologies, such as smart use, renewable energy management, or development of materials for other energy applications.
5. **Other Application Development:** Exploration of the potential of rGO/TiO_2 in applications other than DSSC, such as photocatalysis for water or air treatment, sensors, and energy storage technologies.

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