Reduced graphene oxide-based Transparent Conductive Films: The preliminary review of reductant materials agent

V Iasha1,*, E Wahyudiana1, M S Sumantri1, A Marini1, B Setiawan2 and D Rahmawati3

1 Department of Postgraduate Elementary Education, Universitas Negeri Jakarta, Indonesia
2 Department of Elementary Education Teacher, Universitas PGRI Adi Buana, Indonesia
3 Department of Physics, Institut Teknologi Bandung, Indonesia

*vina.iasha@gmail.com

Abstract. This review aims to present reductant materials that can be used to reduce the oxygen content of graphene oxide which supports the manufacturing of TCF so the development of TCF increases in the future. Reducing agents are separated into two types i.e. toxic materials and green materials. The method that was used to make TCF based on graphene oxide reduction in this paper review was drop-casting, spray coating, vacuum filtration, and spin coating. From the results of the study, it was found that the resistance sheet for each reductant material range from $3.4 \times 10^9$ to $52.2 \ \Omega$ sq. Besides, the use of toxic reductant materials still dominates as a reducing agent because it has a lower sheet resistance than the green reductant materials. Although there are still many challenges in the study of the transparent conductive film based on reduced graphene oxide, the information in this review is expected to contribute to the development of various optoelectronic devices, especially for the development of flexible, portable, and smart device.

1. Introduction

In recent years, the demand for optoelectronic devices, including smart windows [1], Field Effect Transistors (FETs) [2], Solar Cells [3], Organic Light-Emitting Diodes (OLEDs) [4], and others have widely increased. The important part of optoelectronic devices is Transparent Conductive Films (TCFs). However, the market of commercial transparent conductive film was dominated by Fluorine-doped Tin Oxide (FTO), Indium Tin Oxide (ITO), and Aluminum-doped Zinc Oxide [5]. ITO is the most popular in TCF field materials because has a low sheet resistance of 10 $\Omega$ sq-1 and can transmittance of 93% light in visible range [6]. On the other hand, the disadvantages of ITO materials such as poor chemical stability, rare elements, and limited deposition conditions make it possible to find other alternative materials that can be used to develop TCFs.

Graphene is one of the promising materials for TCF that including the kind of two-dimensional nanomaterials and collected from honeycomb shapes with the layers as thin as one atom thick [7]. Besides on the unique structure, graphene has outstanding charge carrier mobility properties that up to $2.0 \times 10^5 \ \text{cm}^2\text{V}^{-1}\text{s}^{-1}$ at room temperature [8], the good thermal conductivity of 5000 W.mK$^{-1}$ [9], and good optical transparency that has an opacity of 2,3% per layer. Moreover, graphene also has remarkable
mechanical flexibility and become one of the strongest material that has Young’s modulus of more than 1 Pascal [10]. Although graphene is one of the promising material due to its properties, the difficulty of material synthesize for mass production is one of a challenge for the researcher to develop it.

Since graphene was founded using the scotch tape method in 2004 [11], many methods were developed to find graphene material such as Chemical Vapor Deposition (CVD) [5], Epitaxial growth [12], and chemical exfoliation graphene [13]. Reduced graphene oxide is a type of chemical exfoliation result to synthesize graphene which is a promising material to use in the manufacture of TCF because it can be produced in mass-produced. Reduced graphene oxide also has similar properties to graphene and has been used in several applications such as batteries [14], Field-Effect Transistors (FETs) [15], Light-Emitting Diodes (LEDs) [16], Solar Cells [17], and others. These similar properties make reduced graphene oxide a suitable material applied in the manufacture of TCF.

The most important aspects of manufacturing TCF in industrial are efficient and economical production. The modified Hummer Method is one of the chemical exfoliation methods that can be used to produce reduced graphene oxide. But this method only produces graphite into graphene oxide material so it takes one step to get reduced graphene oxide where the step in the form of reducing the oxygen content of graphene oxide. The oxygen content graphene oxide gives a poor effect both in electrical conductivity and optical transparency. Reductant materials are needed to reduce oxygen content. This review presents the reductant materials that can be used to reduce graphene oxide, especially in the manufacture of TCF.

As shown in figure 1, the reductant material discussed in this review separated by two groups i.e toxic and green reductant material. This review aims to present a reductant that can be used to reduce the oxygen content of graphene oxide which supports the manufacturing of TCF so the development of TCF increases in the future.

2. Toxic reductant materials
This chapter will explain the reducing agents which have toxic properties to the environment that can be used to reduce graphene oxide, especially in the manufacture of TCF. Table 1 shows a summary of the materials used for the reduction of graphene oxide which supports the manufacturing of TCF.
Table 1. The summary of toxic reductant materials.

| Reductant agent                  | Sheet resistance (Ω/sq) | Transparency (%) | Condition            | Ref. |
|----------------------------------|-------------------------|------------------|----------------------|------|
| Hydrazine                        |                         |                  |                      |      |
| a. Hydrazine                     | 2.197 x 10^4            | 30.7             | - 0-60 minutes       | [18] |
| b. Hydrazine hydrate             | 3.4 x 10^3             | 75               | RT, 1-10 days        | [19] |
| c. Hydrazine monohydrate         | 4.95 x 10^6            | -                | 80°C, 1 hour         | [20] |
| Dopamine Hydrochloride           | 52.2                    | 88.7             | 60°C, 24 hours       | [21] |
| hydroiodic acid                  | 83.86                   | 91.49            | 60°C, 5 minutes      | [22] |
| Sodium Borohydride               | 5 x 10^4                | 56               | 90°C, -              | [25] |
|                                  | 93                      | 78               | 100°C, 24 hours      | [26] |
|                                  | 2.26 x 10^4            | 93.6             | RT, 2 hours          | [27] |
| Lithium aluminum hydride         | -                       | -                | 70°C, 24 hours       | [28] |

RT : room temperature  
- : not available

2.1. Hydrazine

Hydrazine is an inorganic compound from hydrazone with carbonyl groups that has chemical formula N₂H₄. Hydrazine has the appearance of a colorless liquid, flammable, and smells like ammonia. Despite hydrazine is a good reducing agent that used in many industrial and medical applications, hydrazine is a dangerous and highly toxic compound. Although the dangerous and highly toxic compound, there were researchers who used this compound to reduce oxygen content from graphene oxide that support TCF manufacturing.

Liu et. al. in their work using hydrazine hydrate as the reductant agent of reduced graphene oxide via a spray coating, blade coating, and spin coating methods in TCF manufacturing. The 85% Hydrazine hydrate was mixed with GO solution (1 mg/mL) in ratio 3:1-1:3 (w/w) and then the mixture was diluted with water/ethanol in room temperature for 1 until 10 days. The illustration of the spray coating and blade coating method was shown in figure 2(a). The result showed the film that was prepared by spray coating and blade coating method good performance with a sheet resistance of 3.4 kΩ/sq (spray coating) and 3.6 kΩ/sq (blade coating). Moreover, the film has a transparency of 75% and achieved an efficiency of 3.38% when it was applied for the planar perovskite solar cells [19].

![Figure 2](image_url) (a) The illustration of spray coating and blade coating method and (b) Possible reduction GO reaction mechanism by hydrazine hydrate. Illustrations from ref. [13,19].
Eluyemi et al. in their research using hydrazine monohydrate as a reductant agent via spray pyrolysis technique (SPT). Hydrazine monohydrate was diluted in dispersed GO solution (3 mg/mL) and then the solution was placed in an oil bath and stirred about one hour at 80°C. The result showed that the film has a sheet resistance of 4.95 x 10^3 kΩ/sq [20]. Aimon et al. also reported the use of hydrazine to reduced graphene oxide. The 8% hydrazine with a volume of 200µL was put into 150 mL DI water and GO. From the reduction, the result showed that TCF based reduced graphene oxide has a sheet resistance of 21.97 kΩ/sq and 30.37 transmittances [18]. The schematic of hydrazine hydrate reduction to the graphene oxide is shown in figure 2(b) [13].

2.2. Dopamine hydrochloride
Dopamine hydrochloride is a kind of salt form of dopamine that has a molecular formula of C₈H₁₂CINO₂. Although Dopamine hydrochloride is a material that is harmful to the environment, this material can also be used as an option in reducing graphene oxide. Wang et al. in their work used Dopamine Hydrochloride material to reduce graphene oxide in reduced graphene oxide/carbon nanotube/PEDOT: PSS nanocomposites. The use of dopamine hydrochloride also produced PDA-rGO material which increase interfacial adhesion between conductive coating layers and substrate. Reduction process occurs at a temperature of 60°C for 24 hours. The result, using a simple spray coating method was found that the film has a low sheet resistance of 52.2Ω/sq and high optical transmittance of 88.7% [21].

2.3. Hydroiodic acid
Hydroiodic acid is a strong acid solution that has a concentration of 48-57% hydrogen iodide (HI). This solution is generally used as a chemical reagent so it can be used as reducing graphene oxide. Zhang has used this vapor solution to reduce graphene oxide to fabricate rGO/AgNW/PE TCF. The illustration of the reduction method is shown in Figure 3. The result shows that the rGO/AgNW/PE TCF has excellent optical and electric properties (91.49% transmittance and 83.86 Ω/sq) [22]. The reduction method using vapor hydroiodic acid was also used by Tito et al. in the fabrication of PET/rGO given sheet resistance of 3.74 x 10⁻⁶ Ω/s and optical transmittance of 70% in the visible range [23]. Moreover, Nekahi et al. also made TCF based on reduced graphene oxide using hydroiodic acid vapor. Hydroiodic acid that used in this work has a concentration of 57% and the reduction process was maintained at 40°C for 20 minutes. Mekahi reported that the TCF based reduced graphene oxide has a low sheet resistance of 200 Ω/sq and high transparency of up to 70% [24].

![Figure 3](image.png)

Figure 3. The use of a vapor hydroiodic acid solution as a reductant agent. Illustrations from ref. [22].

2.4. Sodium borohydride
Sodium borohydride is an inorganic compound with the chemical formula NaBH₄ which is a corrosive and flammable material. Although included as a toxic material, this material is a versatile reducing agent that can be widely applied in laboratories or mass production. Chang et al. in their work used sodium borohydride to make reduced graphene oxide TCF, and the spin coating method is the method to coat the reduced graphene oxide on the substrate. The result shows that the reduced graphene oxide TCF has transmittance and sheet resistance of 56% T and 50 kΩ/sq [25].
Tien et al., combines reducing NaBH₄ with silver nanoparticles to get well-reduced graphene oxide for TCF. The reduction process is carried out by mixing graphene oxide, AgNO₃, and NaBH₄ in an N₂ atmosphere and a temperature of 100°C for 24 hours. TCF that obtained from the research has a sheet resistance of 93 Ω/sq and optical properties up to 78%. The advantage of silver nanoparticles on the reduction of graphene oxide is shown in figure 4 [26]. Moreover, Shin et al., also used NaBH₄ as a reductant agent. Graphene oxide was placed on a Polyethylene terephthalate (PET) substrate using a spray method and then was dipped in NaBH₄ solution at room temperature with various concentration of NaBH₄ solution. The result showed that the best TCF had a sheet resistance of 22.6 kΩ/sq and optical transmittance of 93.6% [27].

2.5. Lithium aluminum hydride
Lithium aluminum hydride, commonly defined as LAH, is an inorganic compound with the chemical formula LiAlH₄. Although this compound is good to become a reducing agent, this compound is very dangerous because it can be reactive to the water and release hydrogen gas (H₂). Ambrosi et. Al used this material as a reducing agent for graphene oxide. Graphene oxide and LiAlH₄ were dissolved in tetrahydrofuran solution at 70°C for 24 hours. The results of the study showed that graphene oxide reduced using LiAlH₄ had a charge transfer resistance ($R_{ct}$) of 5.9 kΩ [28]. Figure 5 shows the illustration reduction process of graphene oxide using LiAlH₄.

![Reduction by NaBH₄ without AgNO₃](image1)

![Reduction by NaBH₄ with AgNO₃](image2)

**Figure 4.** The advantages of using silver nanoparticles in the reduction of graphene oxide. Illustrations from ref. [26].

**Figure 5.** The illustration reduction process of graphene oxide using LiAlH₄. Illustrations from ref. [28].
3. Green reductant materials
In this chapter, the eco-friendly reducing materials to reduce graphene oxide was explained. Table 2 shows a summary of the materials used for the reduction of graphene oxide which supports the manufacturing of TCF.

| Reductant agent       | Sheet resistance (Ω/sq) | Transparency (%) | Condition               | Ref. |
|-----------------------|-------------------------|------------------|-------------------------|------|
| Oxalic acid           | 28                      | 81.2             | 240°C, 12 hours         | [29] |
|                       | ~1.1 x 10^3             | 71.56            | 110°C, 24 hours         | [30] |
| Ascorbic acid         | 5.3                     | 64.9             | RT, 30 second           | [31] |
|                       | 13.2 x10^3              | 45               | 95°C, -                 | [32] |
| Bacteria (Escherichia coli) | 3.4 x 10^9          | -                | 37°C, 48 hours          | [33] |
| Ginseng               | 5.3 x 10^7              | -                | 80°C, -                 | [35] |
| Green tea             | 1.1 x 10^8              | -                | 80°C, 10 minutes        | [36] |

RT: room temperature
-: not available

3.1. Oxalic acid
Oxalic acid is a chemical compound that has the chemical formula H₂C₂O₄. Oxalic acid is a relatively strong organic acid, 10,000 times stronger than acetic acid which is suitable for use as a reducing agent of graphene oxide. Bai et al. in their work using oxalic acid in manufacturing reduced graphene oxide-based TCF. The reduction process begins by mixing oxalic acid, graphene oxide, polyvinylpyrrolidone, and sodium chloride. After that, the mixture was put into an autoclave and set at 240°C for 12 hours. From the result, TCF has a sheet resistance of 28 Ω/sq and an average transmittance of 81.2% [30]. Moreover, Chamoli et. al. also used oxalic acid in their work. The oxalic acid and graphene oxide were mixed and then transferred into an oil bath at 110°C for 24 hours. The result shows that TCF has a sheet resistance of ~1.10 kΩ and transmittance of 71.56% at 550 nm [30].

3.2. Ascorbic acid
Ascorbic acid is a natural water-soluble vitamin known as vitamin C found in citrus fruits and green vegetables that has a molecular formula of C₆H₈O₆. Ascorbic acid is a reducing agent and antioxidant that can be used as an environmentally friendly graphene oxide reduction material. these properties inspired Kwan et. al to use ascorbic acid as their reduction material agent. To reduce graphene oxide, Kwan et. al. used ascorbic acid that was mixed into the GO solution at a concentration of 10 mg/ml and was shaken violently by hand for 30 seconds. The simple spraying method was chosen by them to deposition the solution into the substrate. The result, TCF has a sheet resistance of 5.3 Ω/sq and an average transmittance of 64.9% [31].

Figure 6. Illustration the reduction of the process using ascorbic acid. Illustrations from ref. [32].
In other work, Tas et. al. also used ascorbic acid to make TCF based reduced graphene oxide. The reduction process began by heating the ascorbic acid solution at a temperature of 95°C and then the TCF film of graphene oxide was immersed in the solution for 15 minutes. Illustration the reduction process that is carried out by Tas et. al. can be seen in figure 6. The result, TCF has a sheet resistance of 13.2 kΩ/sq and an average transmittance of 45% [32].

3.3. Bacteria
Bacteria are a group of organisms that do not have a cell membrane nucleus. although this organism has a small size (microscopic), bacteria have many benefits in the fields of food, medicine, and industry even can be used for the reduction of graphene oxide. Akhavan and Ghanderi used this bacterium as a reducing medium. Graphene oxide on the substrate was dipped in a solution containing Escherichia coli bacteria and incubated for 48 hours at 37°C in a dark room. From the incubation process, the TCF has a sheet resistance of 3.4 x 10⁸ Ω/sq [33]. Moreover, Gurunathan et. al. has a similar process using bacteria in the reduction process. The reduction process was done by mixing the graphene oxide and Escherichia coli bacteria at 37°C for 72 hours [34].

3.4. Ginseng
Ginseng is a perennial plant species that grows in the mountains in East Asia whose roots are widely used by humans, especially in health. On the other hand, ginseng can also be used as a reducing agent. Akhavan et. al. used this plant to reduce graphene oxide in their work. Ginseng extract was obtained by immersing ginseng in DI water at a temperature of 70-80°C for 10 minutes. For the reduction of graphene oxide, ginseng extract and ammonia solution were mixed in a graphene oxide suspension at 80°C. by using extract ginseng, Akhavan et al. got TCF based reduced graphene oxide with sheet resistance of 5.3 x 10⁷ Ω/sq [35].

3.5. Green tea
Green tea is the name of a tea that is made from the leaves of a tea plant. Green tea is a good drink for health because it contains antioxidants. On the other hand, green tea can be used as a reducing agent graphene oxide. Despite using Bacteria and Ginseng, Akhavan et. al. also try to used green tea as reduction agent. Polyphenol content that functions as a reducing agent in green tea was obtained through the process of immersion of green tea in DI water at a temperature of 80-86°C for 10 minutes. Then the extract was mixed with a suspension of graphene oxide at 80°C for 10 minutes. The result, reduced graphene oxide has sheet resistance of 1.1 x 10⁸ Ω/sq [36].

4. Conclusion
In this review, the toxic and green materials reductant agent have been used successfully to reduce graphene oxide, especially in the manufacture of transparent conductive films (TCFs). the properties of graphene that have outstanding electrical conductivity, good in chemical and thermal stability, high optical transparency, and remarkable mechanical flexibility are all part of the success in using this material. All the studies mentioned above focus on the reducing sheet resistance and increasing the transmittance in manufacturing TCF based reduced graphene oxide to meet the requirements that can be used in the device. Although there are still many challenges to go through, transparent conductive films based on graphene oxide reduction have good prospects in the future due to its natural properties of graphene and will contribute to the development of optoelectronic devices especially for the development of flexible, portable, and smart devices.

Acknowledgement
The author would like to thank all those who have helped complete this review.
References

[1] Behera M K, Williams L C, Pradhan S K and Bahoura M 2020 Reduced transition temperature in Al: ZnO/VO 2 based multi-layered device for low powered smart window application Sci. Rep. 10 1–11

[2] Ahn S R, An J H, Lee S H, Song H S, Jang J and Park T H 2020 Peptide hormone sensors using human hormone receptor-carrying nanovesicles and graphene FETs Sci. Rep. 10 1–8

[3] Hu M, Chen M, Guo P, Zhou H, Deng J, Yao Y, Jiang Y, Gong J, Dai Z and Zhou Y 2020 Sub-1.4 eV bandgap inorganic perovskite solar cells with long-term stability Nat. Commun. 11 1–10

[4] Guan H-M, Hu Y-X, Xiao G-Y, He W-Z, Chi H-J, Lv Y-L, Li X, Zhang D-Y and Hu Z-Z 2020 Novel adamantane-bridged phenanthroimidazole molecule for highly efficient full-color organic light-emitting diodes Dye. Pigment. 177 108273

[5] Ma Y and Zhi L 2019 Graphene- Based Transparent Conductive Films: Material Systems, Preparation and Applications Small Methods 3 1800199

[6] Morales- Masis M, De Wolf S, Woods- Robinson R, Ager J W and Ballif C 2017 Transparent electrodes for efficient optoelectronics Adv. Electron. Mater. 3 1600529

[7] Na Y, Song Y Il, Kim S W and Sub S-J 2017 Study on properties of eco-friendly reduction agents for the reduced graphene oxide method Carbon Lett. (Carbon Lett.) 24 1–9

[8] Mayorov A S, Gorbachev R V, Morozov S V, Britnell L, Jalil R, Ponomarenko L A, Blake P, Novoselov K S, Watanabe K and Taniguchi T 2011 Micrometer-scale ballistic transport in encapsulated graphene at room temperature Nano Lett. 11 2396–9

[9] Balandin A A, Ghosh S, Bao W, Calizo I, Teweldebrhan D, Miao F and Lau C N 2008 Superior thermal conductivity of single-layer graphene Nano Lett. 8 902–7

[10] Lee C, Wei X, Kysar J W and Hone J 2008 Measurement of the elastic properties and intrinsic strength of monolayer graphene Science (80-. ). 321 385–8

[11] Novoselov K S, Geim A K, Morozov S V, Jiang D, Zhang Y, Dubonos S V, Grigorieva I V and Firsov A A 2004 Electric field effect in atomically thin carbon films Science (80-. ). 306 666–9

[12] Yu X Z, Hwang C G, Jozwiak C M, Köhl A, Schmid A K and Lanzara A 2011 New synthesis method for the growth of epitaxial graphene J. Electron Spectros. Relat. Phenomena 184 100–6

[13] Iskandar F, Hikmah U, Stavila E and Aimon A H 2017 Microwave-assisted reduction method under nitrogen atmosphere for synthesis and electrical conductivity improvement of reduced graphene oxide (rGO) RSC Adv. 7 52391–7

[14] Iskandar F, Setiawan B, Mayangarsi T R, Maharsi R, Purwanto A and Aimon A H 2018 Electrochemical impedance analysis of polyvinylpyrrolidone-coated sulfur/reduced graphene oxide (S/rGO) electrode Mater. Res. Express 6 25514

[15] Masoumi S, Haghshem H, Erfanian A, Molaei A and Rajipour M 2017 Design and manufacture of field-effect transistor based on Reduced Graphene Oxide (RGO-FETs) 2017 Iranian Conference on Electrical Engineering (ICEE) (IEEE) pp 445–50

[16] Jiang G, Tian H, Wang X-F, Hirtz T, Wu F, Qiao Y-C, Gou G-Y, Wei Y-H, Yang J-M and Yang S 2019 An efficient flexible graphene-based light-emitting device Nanoscale Adv. 1 4745–54

[17] Milić J V, Arora N, Dar M I, Zakeeruddin S M and Grätzel M 2018 Reduced graphene oxide as a stabilizing agent in perovskite solar cells Adv. Mater. Interfaces 5 1800416

[18] Aimon A H, Hidayat R, Rahmawati D, Sutarto R, Permatasari F A and Iskandar F 2019 Facile deposition of reduced graphene oxide-based transparent conductive film with microwave assisted method Thin Solid Films 692 137618

[19] Liu Z, Xie Y, Zhao J, Wu S, Zhou Z, Wen M, Cheng Y-B and Zhong J 2018 Rapid preparation of conductive transparent films via solution printing of graphene precursor Thin Solid Films 657 24–31

[20] Eluyemi M S, Eleruja M A, Adedeji A V, Olofinjana B, Fasakin O, Akinwunmi O O, Ilori O O,
Famojuro A T, Ayinde S A and Ajayi E O B 2016 Synthesis and characterization of graphene oxide and reduced graphene oxide thin films deposited by spray pyrolysis method \textit{Graphene} \textbf{5} 143–54

[21] Wang T, Jing L-C, Zhu Q, Ethira J A S, Tian Y, Zhao H, Yuan X-T, Wen J-G, Li L-K and Geng H-Z 2020 Fabrication of architectural structured polydopamine-functionalized reduced graphene oxide/carbon nanotube/PEDOT: PSS nanocomposites as flexible transparent electrodes for OLEDs \textit{Appl. Surf. Sci.} \textbf{500} 143997

[22] Zhang R, Liao Y, Zhou Y and Qian J 2020 A facile and economical process for high-performance and flexible transparent conductive film based on reduced graphene oxides and silver nanowires \textit{J. Nanoparticle Res.} \textbf{22} 39

[23] Tito H A R, Habermehl A, Müller C, Beck S, Nieto C R, Sosa G H and Caceda M E Q 2017 Electrical and optical properties of reduced graphene oxide thin film deposited onto polyethylene terephthalate by spin coating technique \textit{Appl. Opt.} \textbf{56} 7774–80

[24] Nekahi A, Marashi P H and Haghshenas D 2014 Transparent conductive thin film of ultra large reduced graphene oxide monolayers \textit{Appl. Surf. Sci.} \textbf{295} 59–65

[25] Chang C-W, Hon M-H and Leu C 2019 The transmittance and sheet resistance of chemically and heat reduced graphene oxide film \textit{Opt. Quantum Electron.} \textbf{51} 4

[26] Tien H-W, Huang Y-L, Yang S-Y, Wang J-Y and Ma C-C M 2011 The production of graphene nanosheets decorated with silver nanoparticles for use in transparent, conductive films \textit{Carbon N. Y.} \textbf{49} 1550–60

[27] Shin H, Kim K K, Benayad A, Yoon S, Park H K, Jung I, Jin M H, Jeong H, Kim J M and Choi J 2009 Efficient reduction of graphite oxide by sodium borohydride and its effect on electrical conductance \textit{Adv. Funct. Mater.} \textbf{19} 1987–92

[28] Ambrosi A, Chua C K, Bonanni A and Pumera M 2012 Lithium aluminum hydride as reducing agent for chemically reduced graphene oxides \textit{Chem. Mater.} \textbf{24} 2292–8

[29] Bai M, Wu W, Liu L, Chen J, Ma X and Meng Y 2019 NaCl and oxalic acid–assisted solvothermal exfoliation of edge-oxidized graphite to produce organic graphene dispersion for transparent conductive film application \textit{J. Nanoparticle Res.} \textbf{21} 145

[30] Chamoli P, Das M K and Kar K K 2017 Structural, optical, and electrical characteristics of graphene nanosheets synthesized from microwave-assisted exfoliated graphite \textit{J. Appl. Phys.} \textbf{122} 185105

[31] Kwan Y C G, Le Q L and Huan C H A 2016 Time to failure modeling of silver nanowire transparent conducting electrodes and effects of a reduced graphene oxide over layer \textit{Sol. Energy Mater. Sol. Cells} \textbf{144} 102–8

[32] Tas M, Altin Y and Bedeloglu A C 2019 Reduction of graphene oxide thin films using a stepwise thermal annealing assisted by l-ascorbic acid \textit{Diam. Relat. Mater.} \textbf{92} 242–7

[33] Akhavan O and Ghaderi E 2012 Escherichia coli bacteria reduce graphene oxide to bactericidal graphene in a self-limiting manner \textit{Carbon N. Y.} \textbf{50} 1853–60

[34] Gurunathan S, Han J W, Eppakayala V and Kim J-H 2013 Microbial reduction of graphene oxide by Escherichia coli: a green chemistry approach \textit{Colloids Surfaces B Biointerfaces} \textbf{102} 772–7

[35] Akhavan O, Ghaderi E, Abouei E, Hatamie S and Ghasemi E 2014 Accelerated differentiation of neural stem cells into neurons on ginseng-reduced graphene oxide sheets \textit{Carbon N. Y.} \textbf{66} 395–406

[36] Akhavan O, Kalaei M, Alavi Z S, Ghiasi S M A and Esfandiar A 2012 Increasing the antioxidant activity of green tea polyphenols in the presence of iron for the reduction of graphene oxide \textit{Carbon N. Y.} \textbf{50} 3015–25