Graphene : An Out Standing Material

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Abstract: In photovoltaics, research is aiming to investigate new materials able to push the efficiency limit for solar cells towards the highest values without increasing the fabrication cost.

This paper presents a review about graphene material and its potential use in all technological fields. Due to its high conductivity, transparency and amazing properties. It seems that it has an important place in the next generation of solar cells instead of silicon or thin film based solar cells, researchers found diverse applications for graphene in nanoelectronics, aviation, industry, transport, biomedecine and others.

This paper present a review about the state of art about the graphene material in photovoltaic solar cells where very interesting efficiencies were recorded.

Keywords: Graphene, 2D material, Solar cell, Conversion efficiency.

1. INTRODUCTION

What is Graphene

Carbon is a nonmetallic element that belongs to column IV in the Mendeleev table of elements. It is widely distributed in the Earth and all living creatures [1].

Carbon may crystallize in diamond structure to be the most expensive material in the world [2], graphite in hexagonal structure [3], and in diamond-hexagonal as synthetized firstly by F.P. Bundy *et al*. [4]. This was possible by applying a temperature of 1000 °C and pressure 130 kbar. They obtained an hexagonal crystalline structure with c = 4.12 A°, a = 2.52 A° but with keeping the same density than diamond = 3.51 g/cm^3 [4].

Graphene is an amazing material [5] that was firstly discovered by Nobel Prize scientists; Andre Geim [6] and Konstantin Novoselov [7] in 2004. It is a carbon 2D material with one layer thickness [8-10] and seems to be useful in elaboration of nanoelectronic devices owing to its transport properties [5, 11-13].

Graphene is the most resistant material so far with elastic stiffness values (340 N/m: 2nd order; -690 N/m: 3rd order) [14]. It is considered as a semi-metal without a bandgap [15] with a carrier mobility equal to 10^5 cm^2/V which is greater than the value of silicon. This is why it is the most suitable to replace silicon in electronic devices [16]. Due to this behavior, it can be employed for all metallic contacts in solar cells and electronic devices [17-18]. It has also the advantage to have an elevated transparency [19] and thermal conductivity [20].

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Graphene in Solar Cells

- The window layer in a solar cell has the key role to be conductive and transparent at the same time. The most commonly used materials for the window layer are indium tin oxide ITO and fluorine doped tin oxide FTO due to their high transparency and large bandgap [21-22]. However, they present the disadvantage of lack of transparency in the near infrared region in addition to the expensive cost of indium [21-22].

  Here appears graphene as an alternative material for electrode contacts owing to its high transparency in the whole spectral range [23]. Graphene is then obtained by graphite oxide exfoliation and thermal reduction. It presents 550 S/cm conductivity with 10 nm thickness. The transparency ranges around 70% in the interval 1000 nm to 3000 nm. It is also interesting to mention that transparency may be increased to 80% just by reducing the thickness [23].

  As example: The dye sensitized solar cell with TiO_2 (electron transport) and spiro-OMeTAD ([2,20,7,70-tetrakis(N,N-di-p-methoxyphenyl-amine)9,90-spirobifluorene] (hole transport) with electrodes: graphene (anode) and gold

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(cathode). Its performance: Jsc = 1.01 mA/cm^2, Voc = 0.7 V, FF =36% and η = 0.26% [23]. Compared to the same structure by replacing graphene with FTO: Jsc = 3.02 mA/cm^2, Voc = 0.76 V, FF =36% and η = 0.84%.

The work function of graphene is 4.42 eV [24] is closest to that of FTO electrode 4.40 eV [25].

- The structure graphene/n-Si schottky junction acheived a conversion efficiency equal to 8.6% just by doping the graphene with

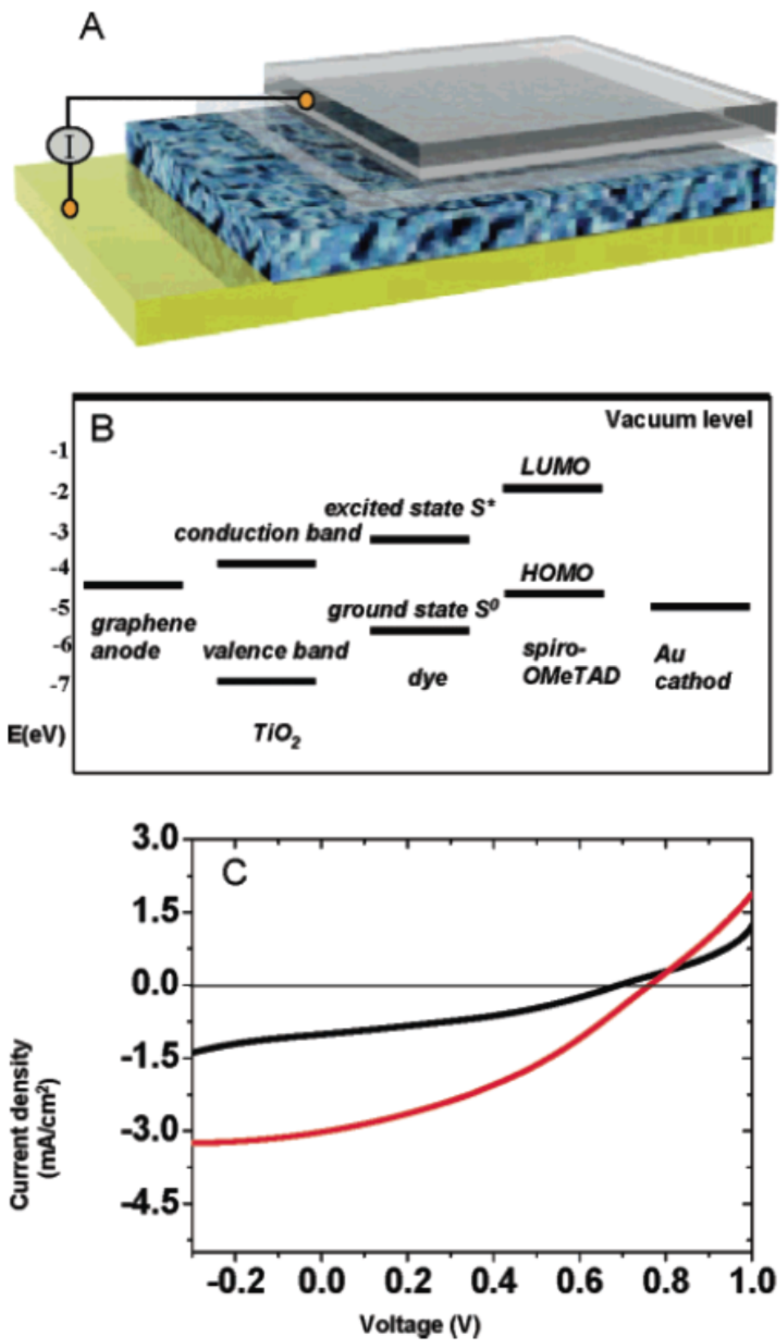

Figure 1: Illustration and performance of solar cell based on graphene electrodes. (**A**) Illustration of dye-sensitized solar cell using graphene film as electrode, the four layers from bottom to top are Au, dye-sensitized heterojunction, compact TiO2, and graphene film. (**B**) The energy level diagram of graphene/TiO2/dye/spiro-OMeTAD/Au device. (**C**) I-V curve of graphene-based cell (black) and the FTO-based cell (red), illuminated under AM solar light (1 sun). **Reprinted with permission from (Xuan Wang, Linjie Zhi, and Klauss Müllen, "Transparent, conductive graphene electrodes for dye-sensitezed solar cells", Nanoletters, vol 8 n° 1, 2008, 232-327) copyright (2008) American Chemical Society [23].**

bis(trifluoromethane sulfonyl) amide. It is mentioned that the structure without doping had conversion efficiency η=1.9% [26]. The efficiency enhancement can be explained by the built-in voltage increase with doping.

There was other studies with the structures graphene on silicon, on cadmium sulfide and cadmium selenide [27-28, 18].

The corresponding efficiencies are presented in the table below:

- Grätzel dye sensitized solar cells with graphene as counter electrode, Pt free, exhibit a conversion efficiency of 7.59% [29].
- D.W. Zhang *et al*. used graphene nanosheets (GNs) to replace platinum in dye-synthetized solar cells **[30].** They obtained very interesting results: With platinum: Jsc = 18.507 mA/cm^2, Voc = 0.714 V, FF =57.51% and η = 7.59%.

  With GNs-annealed at 400°C: Jsc = 16.988 mA/cm^2, Voc = 0.747 V, FF =53.62% and η = 6.81% [30].

  H. Choi *et al*. followed many steps to process the dye sensitized solar cell device and found the parameters: Jsc = 5.6 mA/cm^2, Voc = 0.76 V, FF =70% and η = 3.0 % [31].

2. DEPOSITION TECHNIQUES OF GRAPHENE

The simplest and cheapest way to obtain graphene increase its attractivity to use it in all technological fields [32]. Graphene can be deposited by many techniques such as CVD (Chemical Vapor Deposition) [28] for transparent electrodes applications like in touch screens for example [20], or mechanically onto silicon as carried out by C.C. Chen *et al*. but only after removing the native silicon oxide following the wet and dry etching [27], or by chemical exfoliation [33], organic elaboration of graphene molecule [34], epitaxy [35], thermal exfoliation where graphite pellets were oxidized and exfoliated in a liquid phase solution [36-37], Laser ablation method [38] and spray-coating method [39].

3. APPLICATIONS OF GRAPHENE

Biomedecine

There are diverse applications of graphene such as biomedecine [40]: as we know, the materials based on carbon are biologically friendly compared to non organic materials. Biosensors based on Graphene Field Effect Transistor FET were successfully carried out [40] electrochemical double layer capacitors [41], smart windows [42].

Energy Storage and Nanoelectronics

Due to the fact that graphene presents an elevated fracture strain (σ_c= 9.51 GPa), it is really suitable for flexible devices like organic electronics [39, 43]. In addition, the thermal conductivity of graphene provide the opportunity to the material to be employed for thermal dissipation in electronics.

Photodetectors

The high carrier mobility of graphene lead to quick photogenerated carriers with a bandwidth of 1.5 THz making the material useful in photodetectors [44-45].

Nanocomposite and Coatings

It was found that the incorporation of graphene in composite materials enhance considerably their properties [20]. As example, one can avoid the rust deterioration of transport means such as cars and ships, just by inserting graphene into paint [32].

CONCLUSION

Graphene is a material that is making its way into all areas of technology. Thanks to its great properties, it is the ideal candidate for future electronic devices and materials used in painting, aviation, transportation, biomedicine and others.

The abundance of carbon and the ease of graphene's manufacture give it a place of choice to replace old materials. However, further research remains to be done to refine the conversion efficiency of solar cells based on graphene.

Table 1: Conversion Efficiency for Solar Cells Containing Graphene

Structure	Graphene-CdSe Nanobelt Solar Cells [18]	Graphene-CdS Nanowire Solar Cells [28]	Graphene-Silicon Schottky Diodes [27]
Conversion efficiency	0.1%	1.65%	2.86%

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