Performance Of Organic Photovoltaic Cells Fabricated Using Reduced Graphene Oxide/PEDOT:PSS Composites As Transparent Electrodes

B V R S Subramanyam[1], J Raiguru[2], P C Mahakul[1], K Sa[1], I Alam[1], S Das[1], S Subudhi[1], M Mandal[1], S Saha[1], B Das[3], and P Mahanandia[1]

[1]Department of Physics & Astronomy, National Institute of Technology, Rourkela
[2]Department of Electrical Engineering, National Institute of Technology, Rourkela
[3]Center for Atomic Scale Electromagnetism, Seoul National University

Introduction

- **Photovoltaic technology - The best solution to face the current global energy crisis.**
- **Third generations photovoltaic technology amalgamates the benefits of both the first and second generations.**
- **Organic photovoltaic cells (OPVCs)**
  - ❖ Advantages of transparency, flexibility, easy processing on substrates with standard printing or coating techniques along with economic benefits
  - ❖ Disadvantages of low power conversion efficiency (PCE) and less stability.
- **Application of composites prepared by reduced graphene oxide (RGO) and poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) as transparent electrodes in fabrication of OPVCs can enhance their performance due to high work function, and hole affinity of PEDOT:PSS and almost graphene like physical properties of RGO.**

$$PCE = (J_{sc}.V_{oc}.FF)/P_{in}$$

J_{sc} : Short-circuit current
V_{oc} : Open-circuit voltage
FF : Fill factor
P_{in} : Input power density

Experimental section

Synthesis of graphene oxide (GO) from graphite by modified Hummer's method

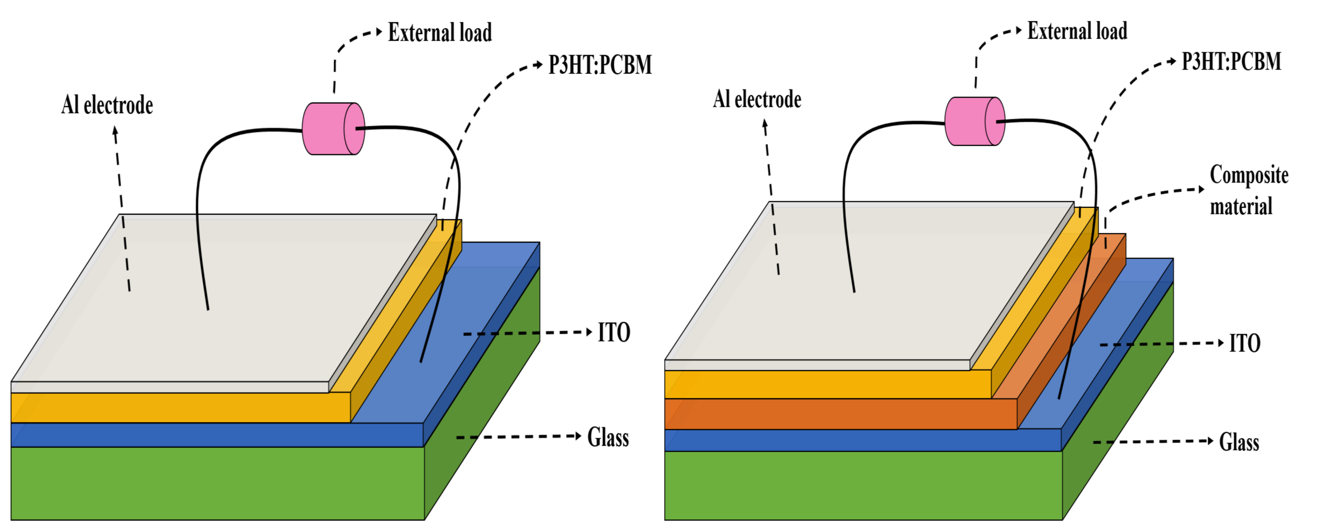
Synthesis of RGO by reducing GO using Hydrazine hydrate

Preparation of RGO/PEDOT:PSS composites

Fabrication of thin film OPVCs using RGO/PEDOT:PSS composites

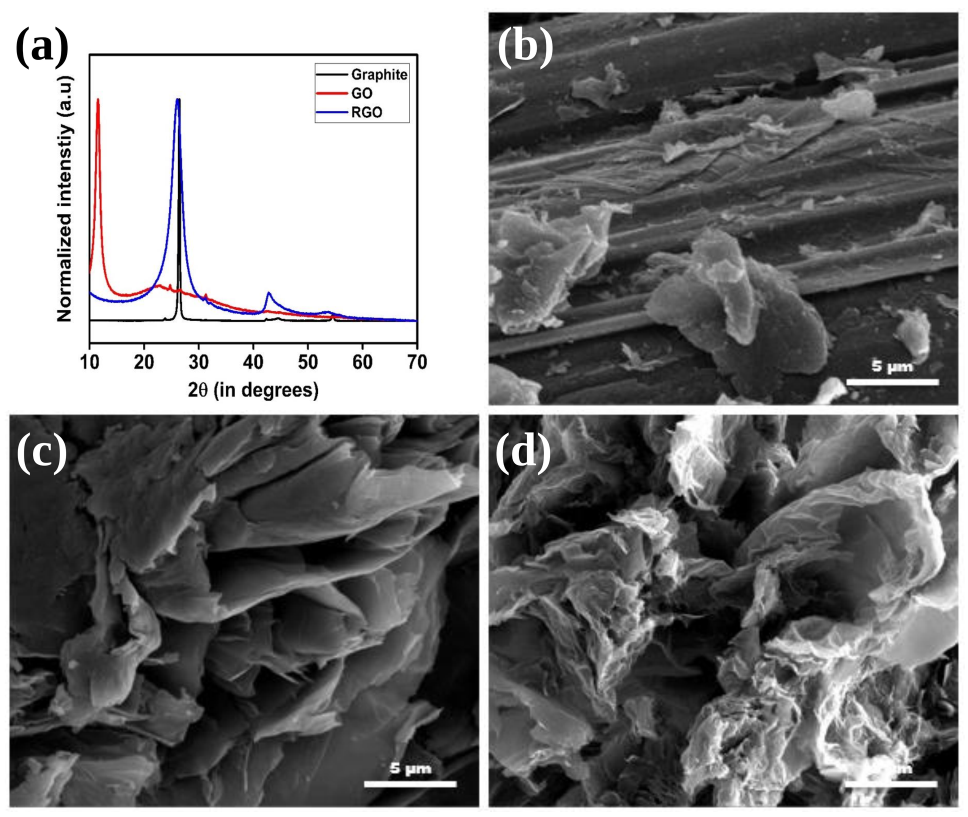
Name of the composite	Weight % of RGO in PEDOT:PSS
PP	0
C1	1
C2	2
C3	3
C4	4
C5	5

Name of the OPVC	Composite used
ITO	No composite used
PP	PP
C1	C1
C2	C2
C3	C3
C4	C4
C5	C5



Designs of OPVCs fabricated without the composite (left), and with the composite (right)

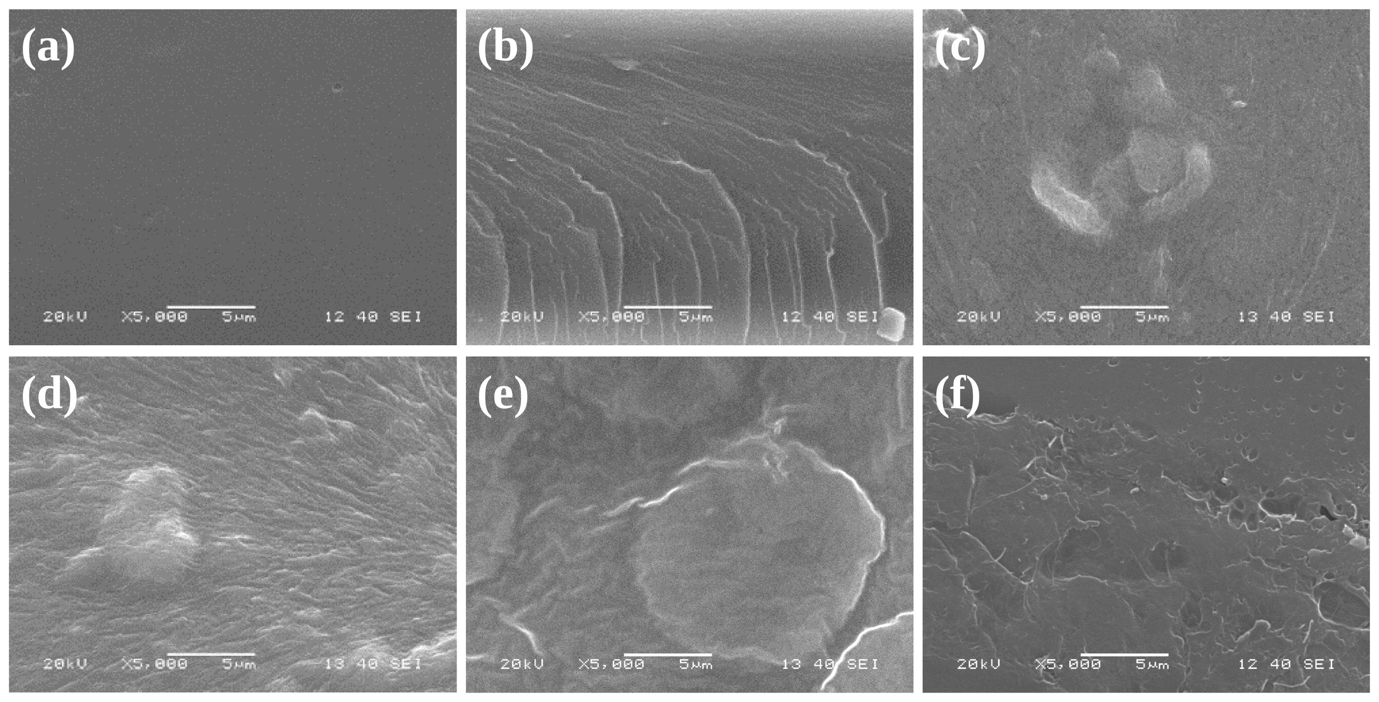
Results & Discussion



(a) XRD patterns of graphite, GO, and RGO, and SEM images of (b) graphite, (c) GO, and (d) RGO

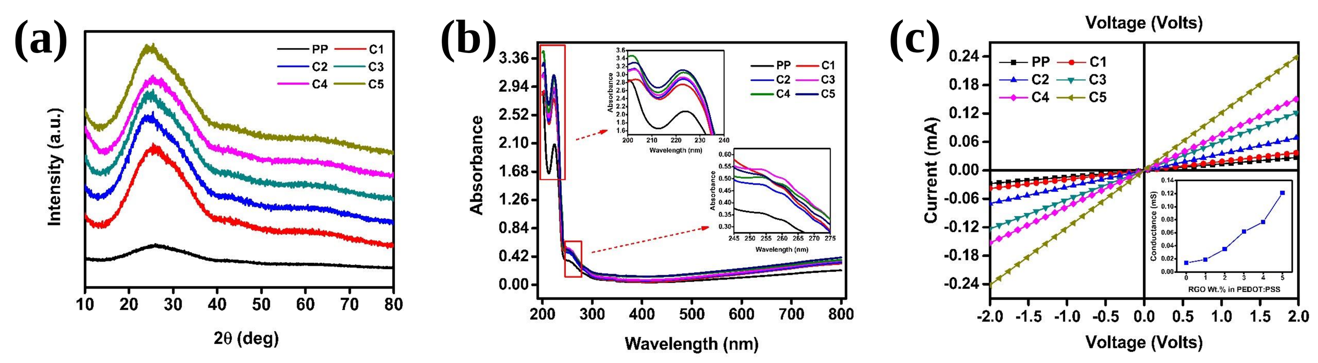
- The shift of graphitic peak in XRD patterns suggests the expansion of graphitic layers in GO due to oxidation resulting in incorporation of functional groups among the graphene sheets, and then successful reduction causing removal of functional groups from the graphene sheets of RGO.
- The SEM images confirm the expansion of graphitic layers in GO, and their exfoliation in RGO.

Results & Discussion



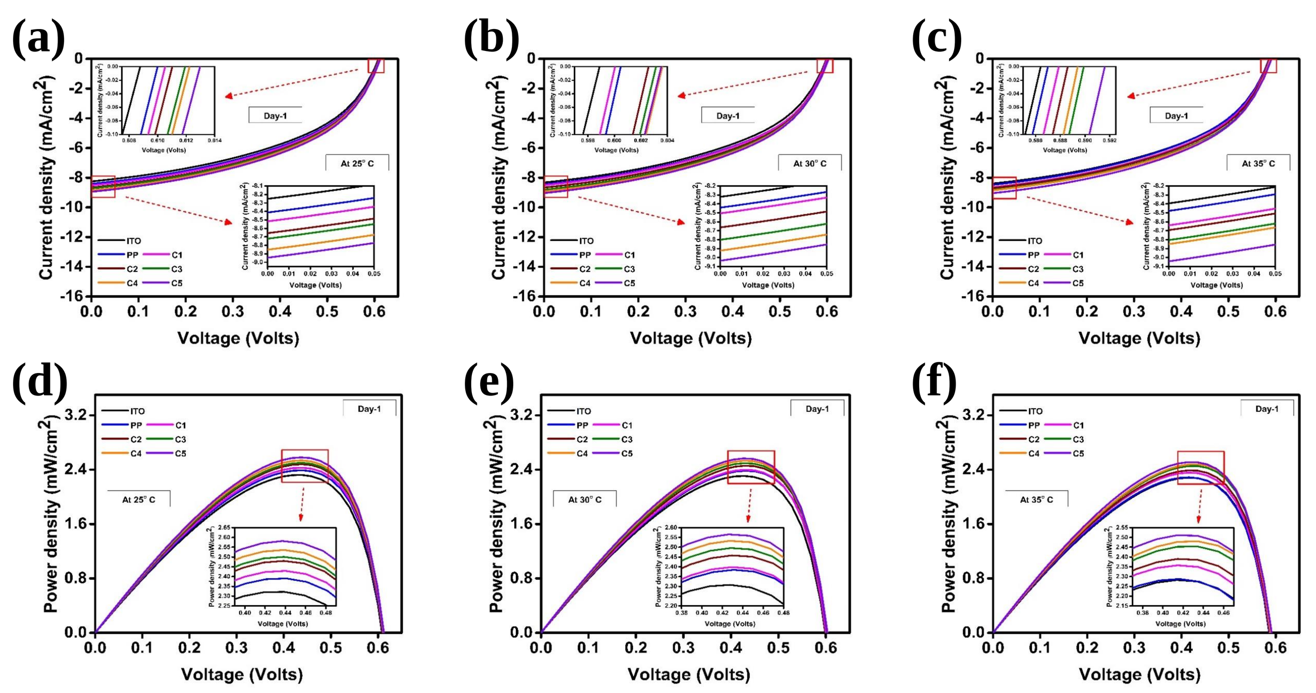
SEM images of (a) PP, (b) C1, (c) C2, (d) C3, (e) C4, and (f) C5

The morphology of pristine PEDOT:PSS film is smooth and homogeneous, but for the composites, as the wt.% of RGO in PEDOT:PSS increases, the morphology becomes more and more irregular and layered due to the wrapping of PEDOT:PSS around the agglomerates of RGO flakes.



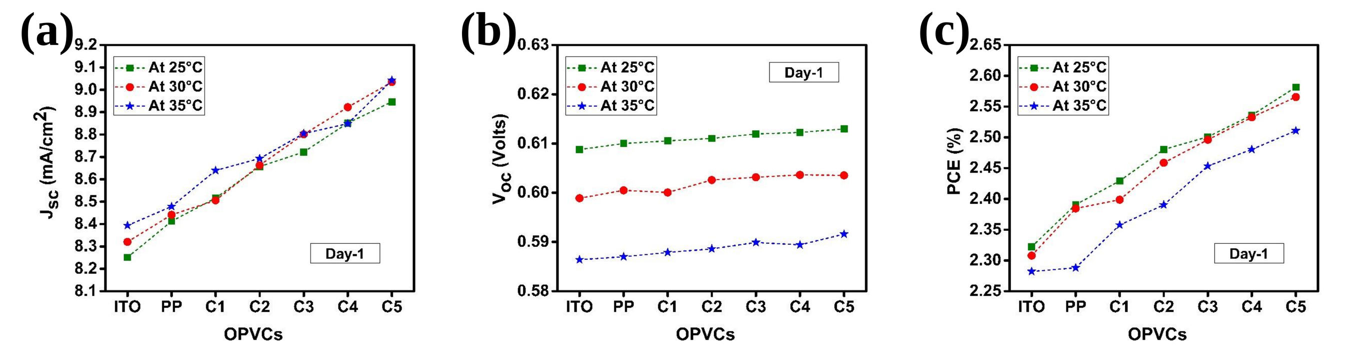
(a) XRD patterns, (b) UV-Vis spectra, and (c) I-V characteristics of the composites

- The broad XRD peak of PEDOT:PSS corresponds to the stacking of planar inter-chained rings in the polymer and the absence of characteristic diffraction peaks for RGO in composites is due to the wrapping of RGO flakes by PEDOT:PSS.
- The absorbance peak at 225 nm, and the broader shoulder from 245 nm to 275 nm for all materials correspond to the phenyl parts in PSS, and transitions of the benzene rings of PSS respectively. Trivial absorbance in visible region shows transparent nature of materials.
- Enhancement of electrical current, and hence conductance with increase in wt.% of RGO in PEDOT:PSS is due to the establishment of a conducting network in the composite by filler and host which also confirms the fine dispersion of RGO in the polymer matrix.



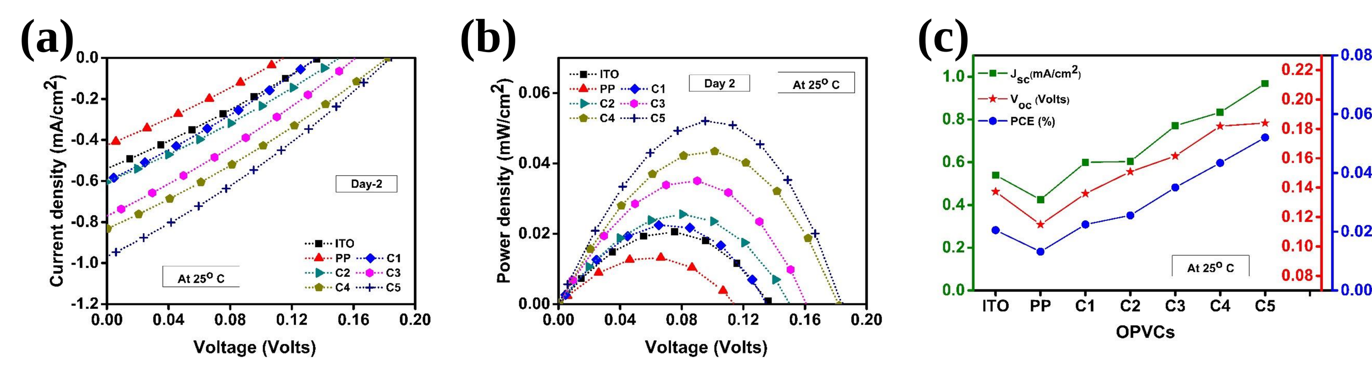
J-V characteristics of all OPVCs on the first day of fabrication at (a) 25°C, (b) 30°C, and (c) 35°C, and the variation of power density with voltage of all OPVCs at (d) 25°C, (e) 30°C, and (f) 35°C

Results & Discussion



Variation of (a) J_{sc}, (b) V_{oc}, and PCE of all OPVCs at 25°C, 30°C, and 35°C

- The significant enhancements in J_{sc}, V_{oc} and PCE with addition of the transparent electrode and with the wt.% of RGO in PEDOT:PSS can be explained due to the improved transport of charge carriers through the conducting PEDOT:PSS matrix supported by even better conducting network offered by the incorporation highly conductive RGO in it.
- J_{sc} is slightly increasing whereas V_{oc}, and PCE are considerably declining with increase in temperature which can be due to chemical degradation of the materials used in OPVCs.



(a) J-V characteristics of devices, (b) variation of power density with voltage, and (c) variation of Jsc, Voc, and PCE of the devices on the second day at 25°C

- Greater Jsc, Voc, and PCE of the "ITO" OPVC compared to "PP" OPVC.
- Enhancing Jsc, Voc, and PCE with increase in RGO wt.% in PEDOT:PSS.

Name of the OPVC	PCE (%) on day-1 at 25°C	PCE (%) on day-1 at 30°C	PCE (%) on day-1 at 35°C	PCE (%) on day-2 at 25°C
ITO	2.322	2.308	2.282	0.021
PP	2.391	2.384	2.288	0.013
C1	2.429	2.399	2.358	0.022
C2	2.48	2.459	2.39	0.026
C3	2.501	2.496	2.453	0.035
C4	2.236	2.533	2.48	0.043
C5	2.581	2.566	2.511	0.052

Conclusions

- Composites prepared by solution processing using different wt.% of RGO in PEDOT:PSS showed improvement in the conductivity along with a trivial change in their absorbance in visible region favoring their applications as transparent electrodes in fabrication of OPVCs.
- The OPVCs fabricated by spin-coating technique found to have enhanced Jsc, Voc, and PCE with increase in wt.% of RGO in PEDOT:PSS.
- The performance of the OPVCs declined with increase in temperature and with time.
- Maximum PCE of 2.581% with corresponding J_{sc} of 8.946 mA/cm^2 along with V_{oc} of 0.6129 V has been obtained at 25°C for the "C5" OPVC on the first day of fabrication.
- This research encourages the preparation of composites of different conducting polymers with other conducting materials for various applications in different optoelectronic devices.

Acknowledgement

This work has been financially supported by SERB-DST, INDIA (Grant no. SB/S2/CMP-109/2013)

References

- Khodakarimi, S., Hekhmatshoar, M. H., Nasiri, M., Moghaddam, M. K., & Abbasi, F., Journal of Materials Science: Materials in Electronics 27(2), 1278-1285 (2016).
- Araźna, A., Janeczek, K., Futera, K., & Koziol, A., IOP Conference Series: Materials Science and Engineering 104, 1, 012027 (2016).
- Jørgensen, M., Norrman, K., & Krebs, F. C., Solar energy materials and solar cells, 92(7), 686-714 (2008).
- Yoo, D., Kim, J., & Kim, J. H., Nano Research 7(5), 717-730 (2014).
- Mahakul, P.C., Sa, K., Das, B., Subramaniam, B.V.R.S., Saha, S., Moharana, B., Raiguru, J., Dash, S., Mukherjee, J. and Mahanandia, P., Journal of Materials Science 52(10), 5696-5707 (2017).

Corresponding email: pmahanandia@gmail.com