USE OF GRAPHENE AS AN ALTERNATIVE ELECTRON COLLECTION LAYER IN SOLAR CELLS

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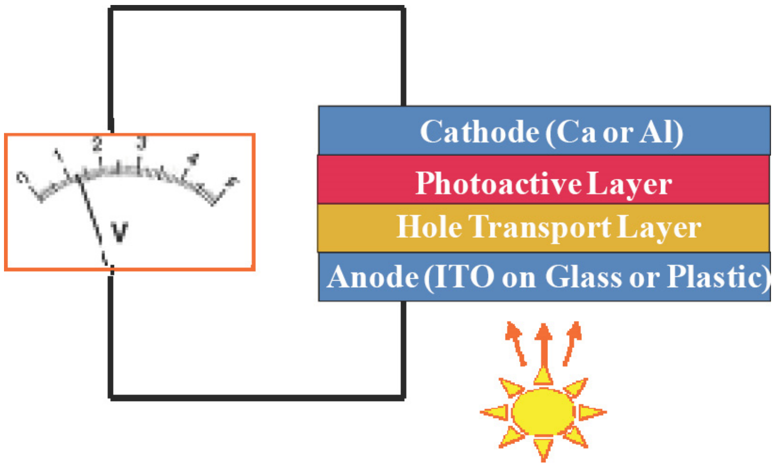
Introduction

- Solar cell technology issues:
  - Cost of production
  - Cost of materials
  - Efficiency
- How to overcome these issues?

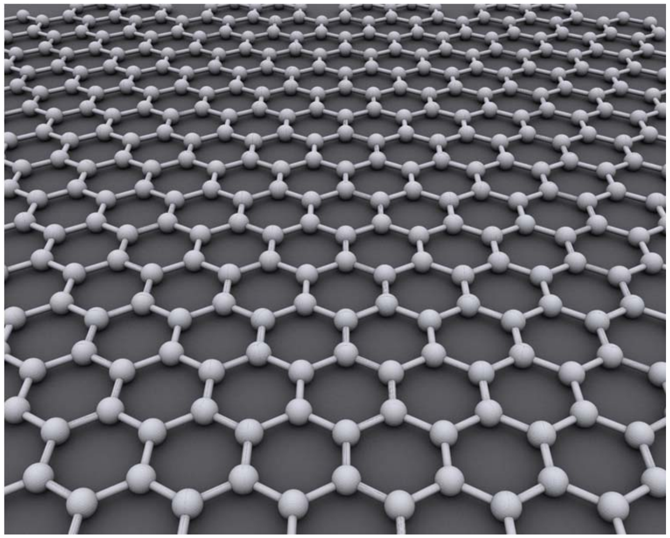
Popular Technology

- Indium Tin Oxide (ITO) is widely used
  - Pros:
    - Transparent at small thicknesses
    - High electrical conductivity
  - Cons:
    - Expensive (Indium and deposition processes)
    - Fragility



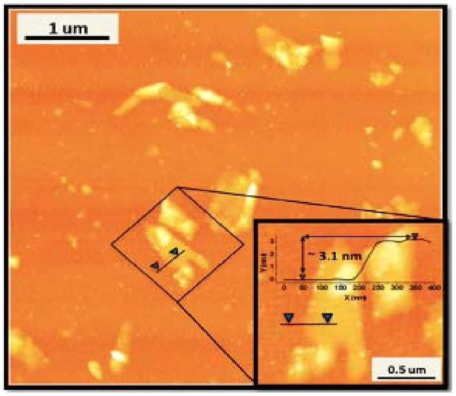
Proposed Alternative

- Graphene
  - Pros:
    - Inexpensive
    - Lightweight
    - Flexible
    - High electrical conductivity
    - Transparent
  - Cons:
    - Technology is still in its infancy
      - First produced in the lab in 2003



Graphene-TiO_2 Nanocomposite Study

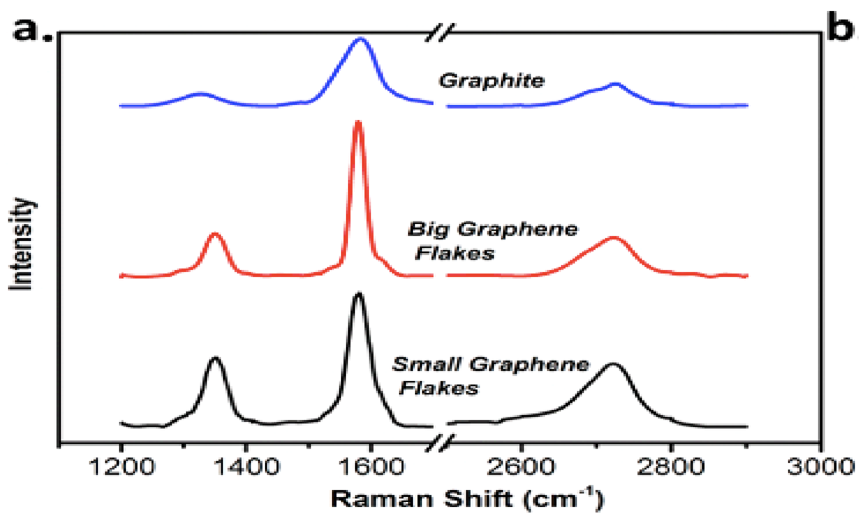
- Graphene in conjunction with TiO_2:
  - Overcome unfavorable characteristics of TiO_2
    - Poor adhesion to substrates
    - Crack formations under high temperature production
    - Non-ideal crystallinity
  - Still takes advantage of the photocatalytic properties of TiO_2
- Low temperature liquid-phase exfoliation of graphite powders to create graphene nanocomposites
  - Sub-150° C
  - Conventional methods require over 400° C
    - Significant production cost reduction



Research at Universitat Jaume 1 and Oxford University

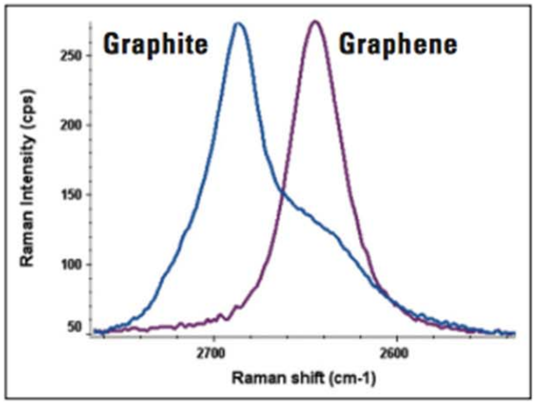
Raman Spectra

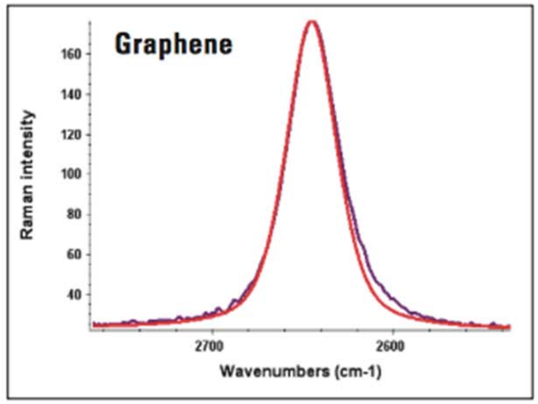
- G’ or 2D band (around 2700 cm^{-1})
  - Indicates how effective the production method was at producing pristine graphene nanocomposites
    - Tighter peak at lower wavelength suggests less interaction between stacked graphene layers
      - In other words, a more 2-Dimensional surface

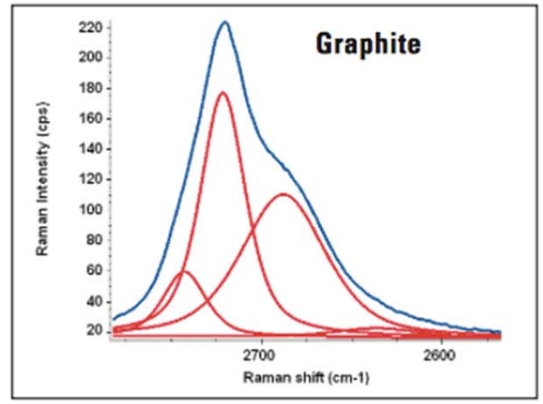


Raman Spectra of Graphene

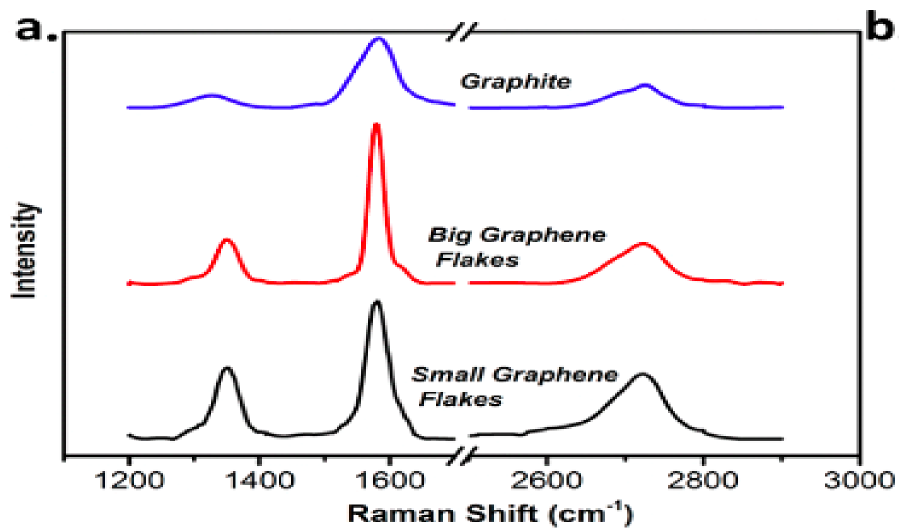
Ideal:



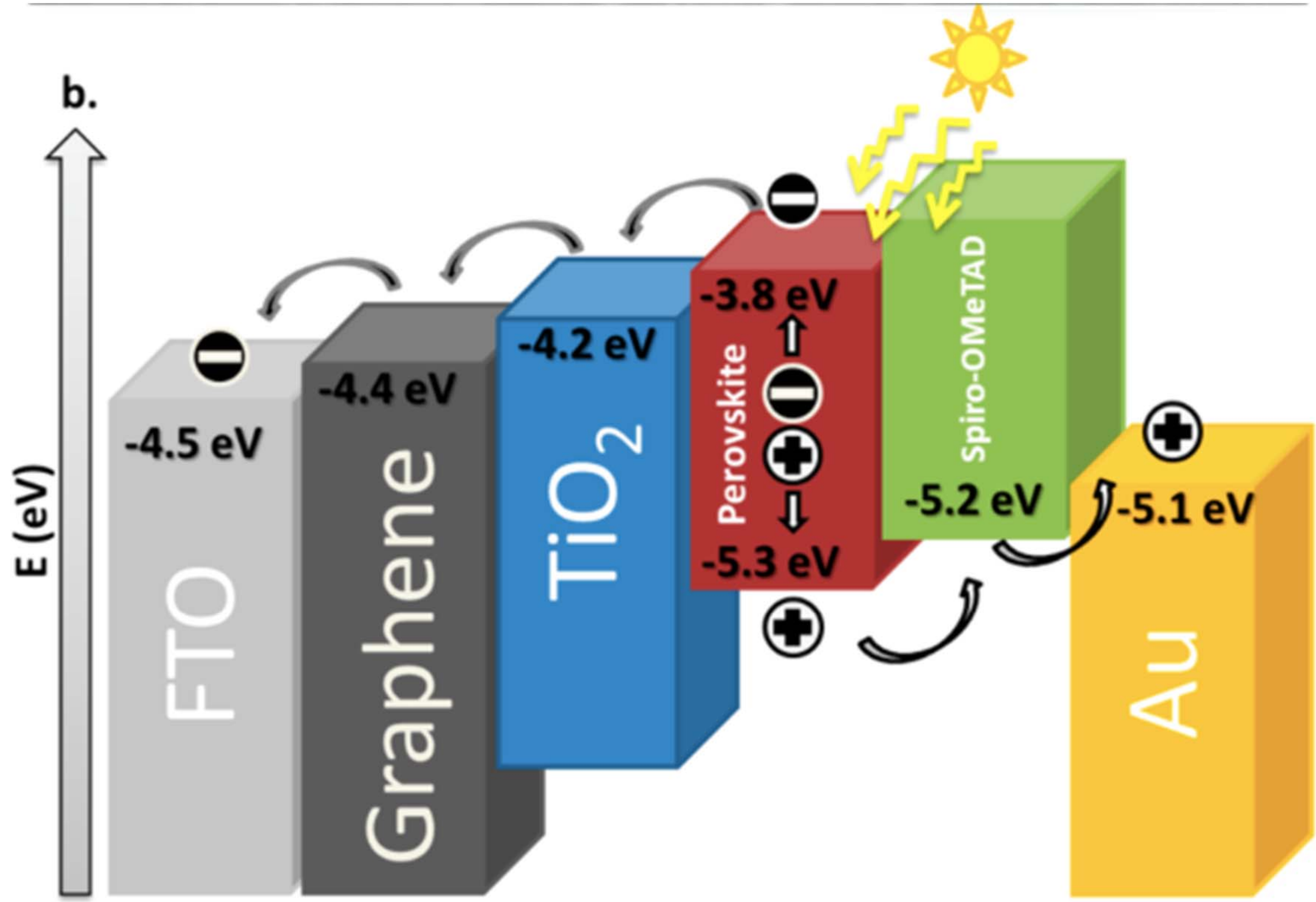




Growth:

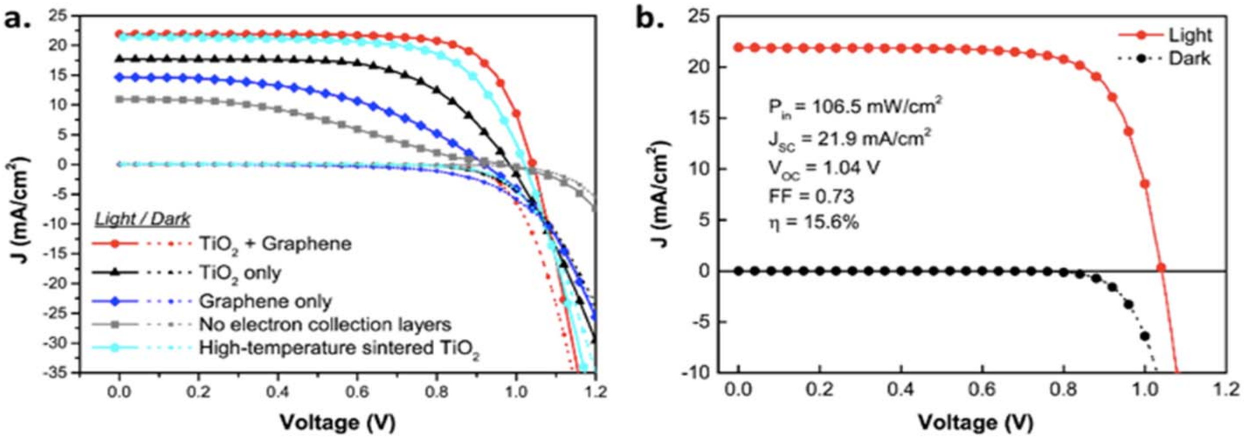


Flat Band Energy Diagram



J-V Characteristics

- Nanocomposites fabricated and tested as an n-type electron collection layer on Fluorine doped Tin Oxide (FTO)
- Clearly the fill factor for the TiO_2+Graphene is greater than the alternatives tested in this study
- Results show an impressive power conversion efficiency of 15.6%



AM1.5G illumination at 100 mW/cm2

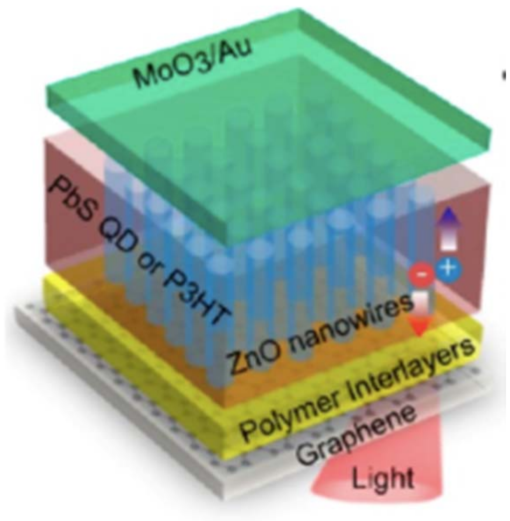
Comparison

- Illustrates the advantage of the graphene-TiO_2 nanocomposites compared to some alternatives
  - TiO_2+Graphene resulted in the largest FF and PCE, as well as the lowest series resistance

sample	J_{sc} (mA/cm^2)	V_{oc} (V)	FF	PCE (%)	R_s ($Ohm{\cdot}cm^2$)
TiO_2 + graphene	21.9	1.04	0.73	15.6	4.3
TiO_2 only	17.7	1.00	0.61	10.0	10.1
graphene only	14.6	0.90	0.48	5.9	20.3
no electron collection layer	10.8	0.95	0.37	3.7	79.1
high-temperature sintered TiO_2	21.4	1.00	0.70	14.1	5.9

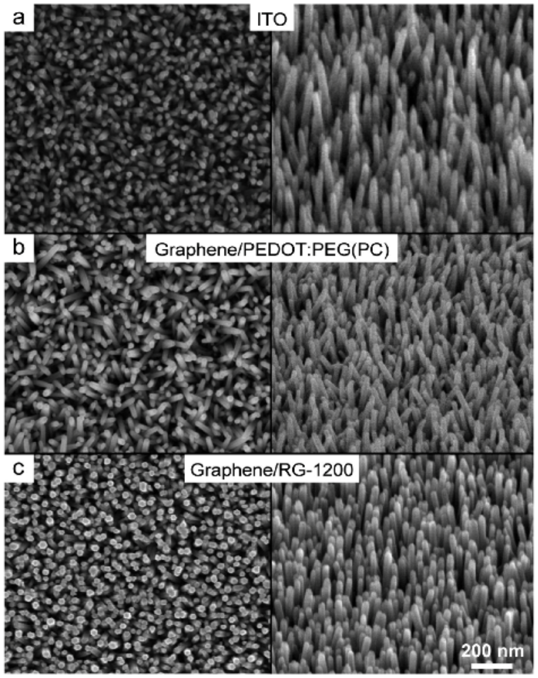
Graphene Cathode-Based ZnO Nanowire Study

- Nano-wire based solar cell structures are of interest because of
  - Efficient charge extraction
  - Large interfacial area
  - Flexibility
- ZnO used because of its
  - Low temperature processability
  - Favorable lattice matching with graphene



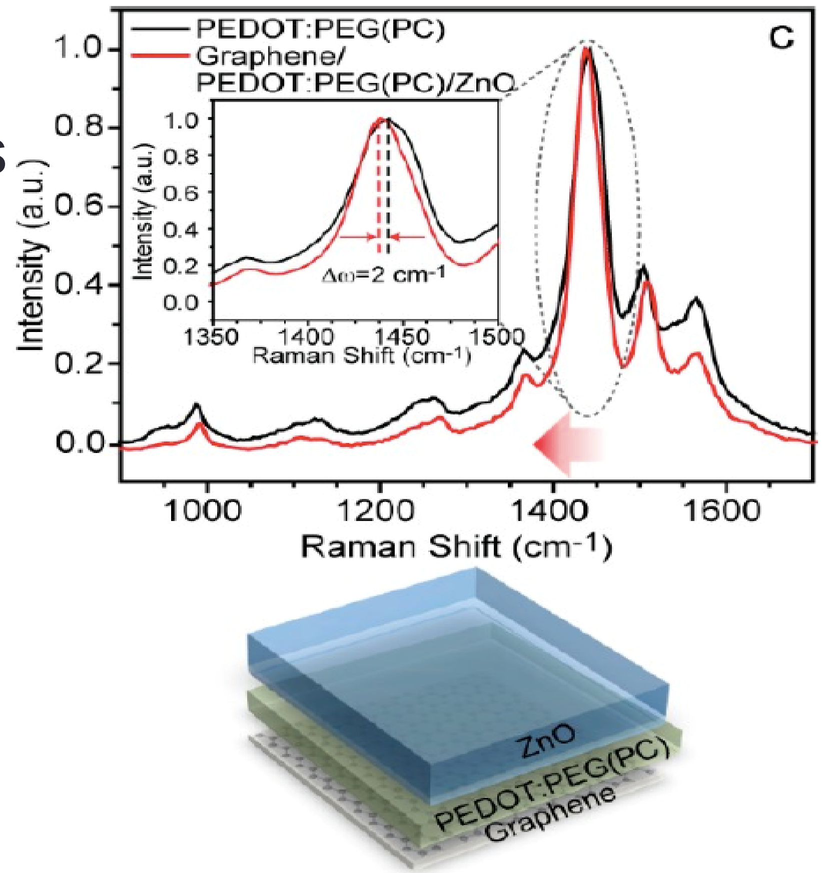
Interlayers

- Growing ZnO directly on graphene results in non-uniform deposition of ZnO seed layer
  - Graphene surface must be modified with a conducting polymer layer prior to seed layer deposition
- Conducting polymers used in this study
  - PEDOT:PEG(PC)
  - RG-1200

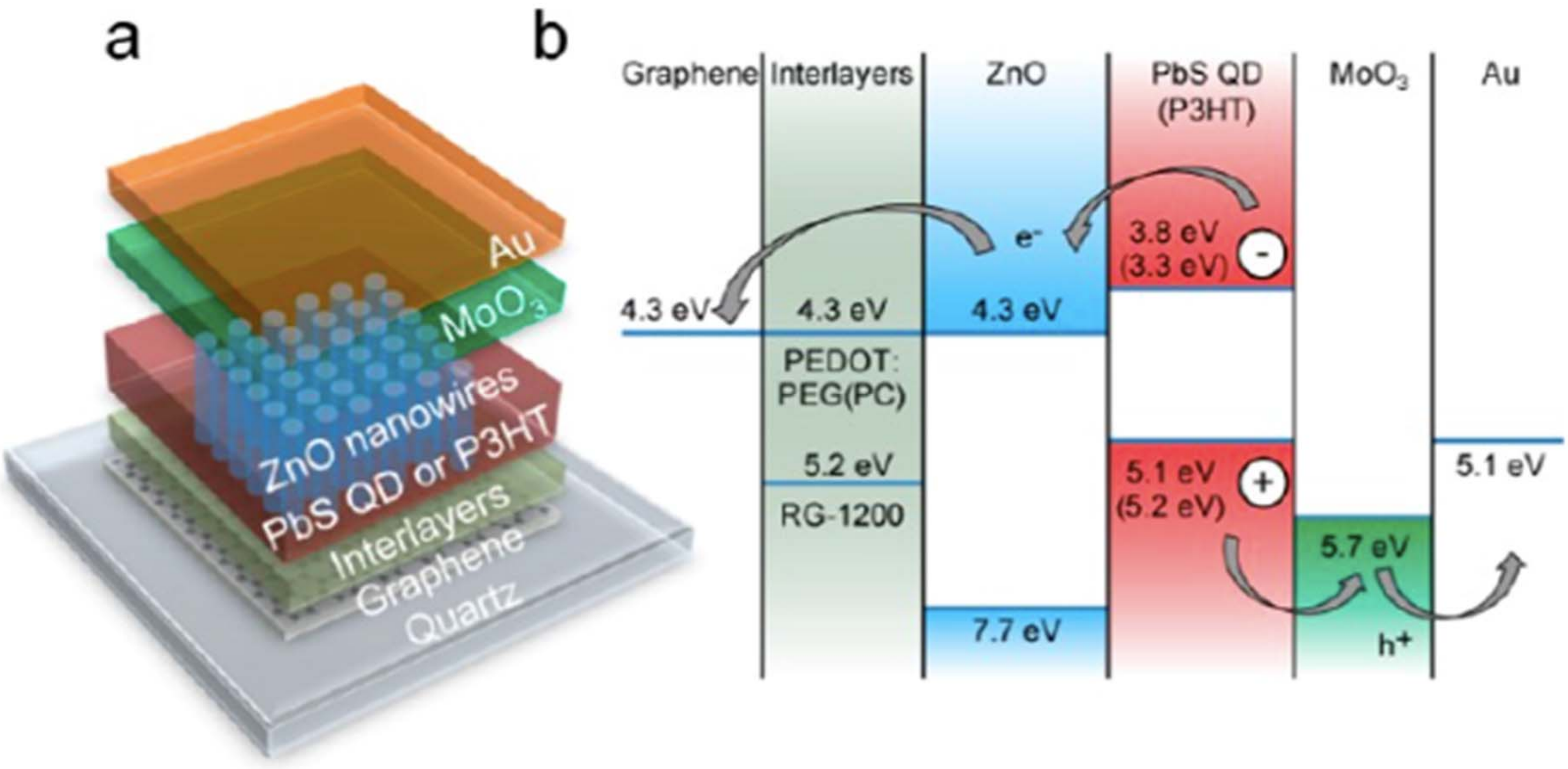


Raman Spectra

- Used here to observe possible interactions such as charge transfer doping between layers
  - Due to misaligned Fermi levels
- Results:
  - Red shift by $2cm^{-1}$
  - Linewidth narrows by $4cm^{-1}$
  - Indicates a reduction in doping in polymer
    - Electrons will move from ZnO to polymer to graphene

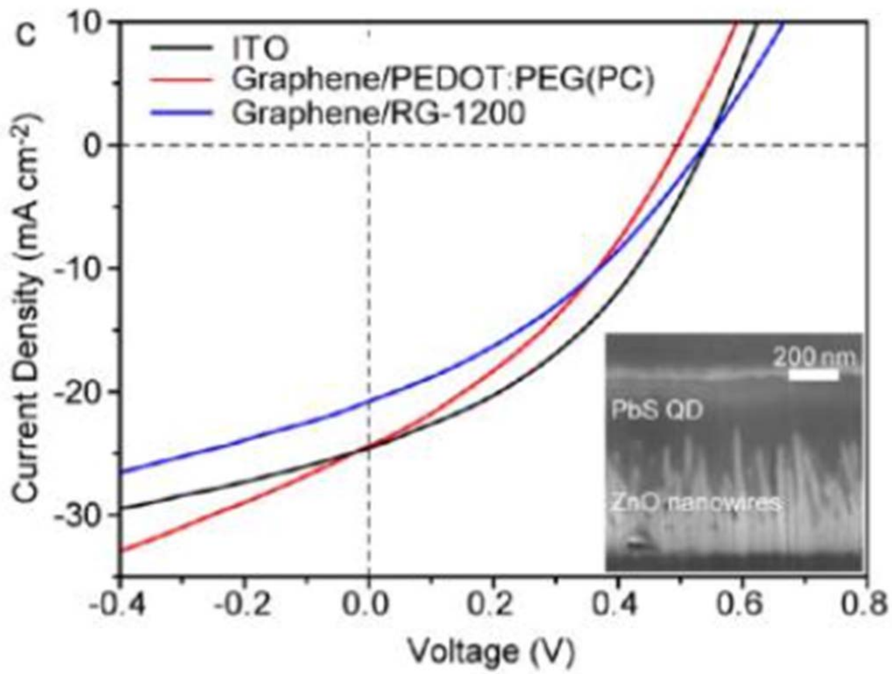


Flat Band Energy Diagram



J-V Characteristics

- Graphene/ZnO nanowire cathode-based hybrid solar cells fabricated using
  - PbS QDs as p-type hole transporting material
  - ZnO nanowires as electron-transporting channels to the cathode (graphene)



AM1.5G illumination at 100 mW/cm^2

Comparison with ITO

- Power conversion efficiency approaches that of ITO
- Advantages of this study
  - Cheaper production and cost of materials
  - More flexible material

cathode	interface layer	hole transport layer	J_{SC} (mA/cm^2)	V_{OC} (V)	FF (%)	PCE (%)
ITO		PbS QD	24.6 (24.3 ± 0.3)	0.54 (0.49 ± 0.04)	38.6 (36.3 ± 1.6)	5.1 (4.4 ± 0.6)
graphene	PEDOT:PEG(PC)	PbS QD	24.4 (22.5 ± 1.3)	0.50 (0.49 ± 0.01)	34.6 (34.4 ± 0.3)	4.2 (3.8 ± 0.3)
graphene	RG-1200	PbS QD	20.8 (18.5 ± 1.9)	0.54 (0.54 ± 0.01)	34.9 (33.3 ± 3.2)	3.9 (3.3 ± 0.6)

Conclusion

- Graphene-TiO_2 Nanocomposite study:
  - Reduced cost of production/materials
  - Increased PCE
- Graphene/ZnO Nanowire study:
  - Reduced cost of production/materials
  - Explicit comparison to ITO
    - Shows that Graphene technology can be a viable alternative

References

- T. Casey, “Graphene Heats Up Race For Cheap Organic Solar Cells”, CleanTechnica, 2014, web http://cleantechnica.com/2014/01/01/graphene-for-low-cost-organic-solar-cells/

- J. Wang, J. Ball, E. Barea, A. Abate, J. Alexander-Webber, J. Huang, M. Saliba, I. Mora-Sero, J. Bisquert, H. Snaith, R. Nicholas, “Low-Temperature Processed Electron Collection Layers of Graphene/ TiO2 Nanocomposites in Thin Film Perovskite Solar Cells”, *Nano Letters*, 2013, web http://pubs.acs.org/doi/pdf/10.1021/nl403997a

- H. Park, S. Chang, J. Jean, J. Cheng, P. Araujo, M. Wang, M. Bawendi, M. Dresselhaus, V. Bulovic, J. Kong, S. Gradecak, “Graphene Cathode-Based ZnO Nanowire Hybrid Solar Cells”, Nano Letters, 2012, web http://pubs.acs.org/doi/pdf/10.1021/nl303920b

- http://www.thermoscientific.com/content/dam/tfs/ATG/CAD/CAD%20Documents/Application%20&%20Technical%20Notes/Molecular%20Spectroscopy/Raman/Raman%20Instruments/D19504~.pdf