

Scientific writing

Dr Roderick MacKenzie

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Lecture aim

- I want to give you a brief tour of **how to write scientific* text** and **how scientific* publishing works**.
- Think of this as a crash course in scientific writing.
- This is derived from my own experiences, so it's useful advice and tips not just some theory.

*For scientific read Engineering, Biological, Medical etc..

Lecture aim

- By the end of the lecture I want you to understand that:

Scientific writing/publishing is **very different to other forms of writing/publishing.** →



Lecture outline

- The process of knowledge dissemination
- What's the point of references
- Clarity of writing
- Figures and graphs
- How to write a scientific paper
- How to write a scientific report
- How to write a thesis
- How do do a literature review

Lecture outline

- **The process of knowledge dissemination**
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- How do do a literature review

How do you get your good idea out to the world?



Idea/New exciting data

- This is the problem we need to solve.

How do you get your good idea out to the world?

- Facebook
- Whasapp
- E-mail
- Youtube
- Periscope
- A random blog

How do you get your good idea out to the world?

- These are pretty good ways to decimate inform about dancing kittens and south Korean pop music.

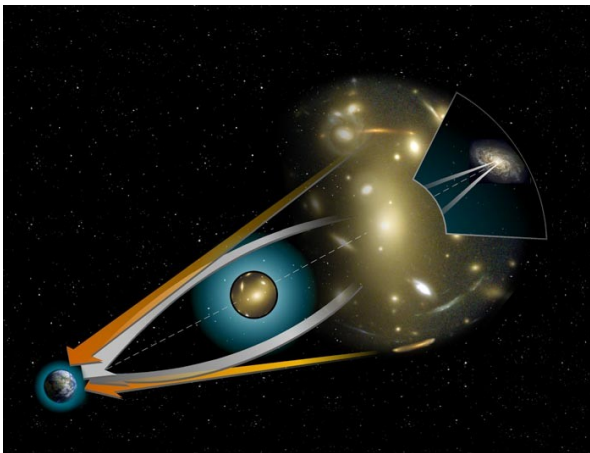
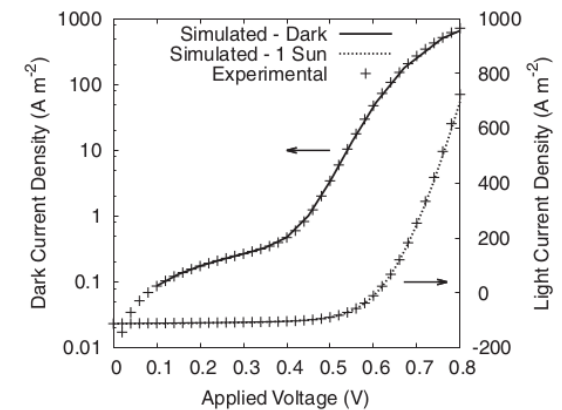
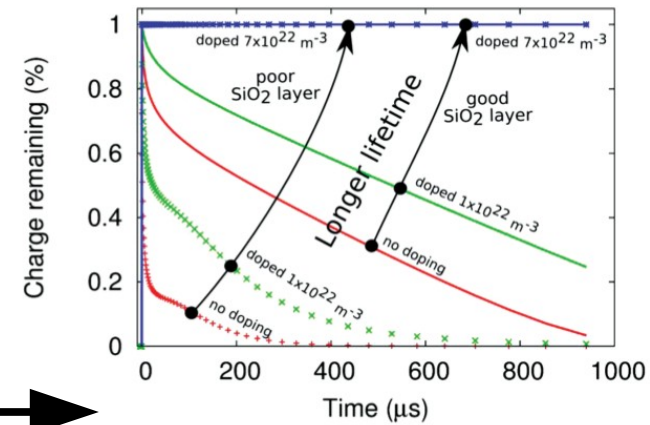
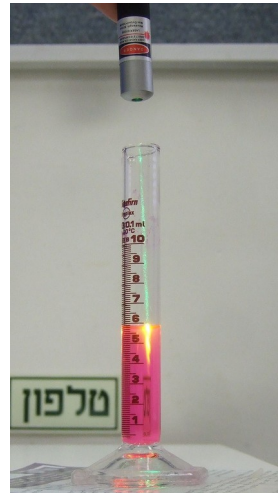


- However, the problem with them is that nobody checks if what you are saying is correct.
- It is therefore not taken seriously.

So how do Scientists and Engineers decimate information?

Step 1: Performing the experiment

- The first step is to gather data and understand the results:



Step 2: Generating a paper...

- Once you have your data or new theory you write it up in draft paper (which we will talk about later).

Combining Plasmonic Trap Filling and Optical Backscattering for Highly Efficiency Third Generation Solar Cells.

Chen [Wang](#)^a, Yijun [Gao](#)^b, Shengpeng [Wan](#)^{a,*}, Pengfei [Ma](#)^a, Roderick C. I. [MacKenzie](#)^{c,*},
Shengping [Fuan](#)^a

a) College of Electronic Science and Engineering, Jilin University Changchun 130012, P. R. China
b) [Universitat zu Köln - II. Physikalisches Institut, Zùlpicher Str. 77, 50937 Köln, Germany](#)
c) Faculty of Engineering, The University of Nottingham, University Park, Nottingham, NG7 2RD, UK
* [e-mail: wan@jlu.edu.cn](mailto:wan@jlu.edu.cn); Roderick.Mackenzie@nottingham.ac.uk

Abstract

Metal oxide contact layers such as [ZnO](#) and [TiO₂](#) are commonly used in third generation solar cells as they can be solution processed and have a relatively high conductivity. It is well known, that by light soaking such devices overall device efficiency can be boosted. This improvement in efficiency is due to high energy UV light exciting hot carriers which then fill trap states in the metal oxide film. Unfortunately, UV causes degradation of the active layer and thus must be filtered out if long lifetimes are to be achieved. In this work, we use [nano-structures](#) embedded in the [ZnO](#) metal oxide layer to generate hot charge carriers from visible light alone, thus removing the need for UV light soaking. Using this approach, we demonstrate that the power conversion efficiency of a [low-bandgap thieno\[3,4-b\]thiophene/benzodithiophene](#) (PTE7) based solar cell can be increased from 7.91% to 9.36%.

Introduction

[Plasmonic nanostructures](#) such as metallic [nanoparticles](#) (MNPs) have recently attracted considerable interest for their ability to support localized surface [plasmon resonances](#) (LSPR).¹⁻³ By exploiting size-function relationships the optical properties of the [nanoparticles](#) can be easily tuned⁴⁻⁶, making them suitable for [optoelectronic](#) applications such as photo-detectors⁷ and solar cells^{8,9}. In particular, the highly confined LSPR modes provide a feasible strategy for bulk [heterojunction](#) (BHJ) organic solar cells (OSCs) to achieve better optical absorption without increasing the thickness of organic layer.¹⁰ It is well known that when integrated into [OSCs](#), these metal [nano-particles](#) can act

- Generally speaking this is a normal MS Word (Libre office) document, which is double spaced so people can write on it.

Author order and what it means..

Chen Wang^a, Yajun Gao^b, Shanpeng Wen^{a,*}, Pengfei Ma^a, Roderick C. I. MacKenzie^{c,*},
Shenqing Ruan^a

- **1st**: The person who did the work*
 - 2nd: The person who helped in the lab.
 - Other people who helped a bit
 - Second last: Co supervisor or someone fairly important but did not get the money for the experiment.
 - **Last**: The person who funded the work*
-
- *These are the most important places to have your name, and you can **upset people a lot** by insisting your name has to be in a set position!

Author order and what it means..

THE AUTHOR LIST: GIVING CREDIT WHERE CREDIT IS DUE

The first author
Senior grad student on the project. Made the figures.

The third author
First year student who actually did the experiments, performed the analysis and wrote the whole paper. Thinks being third author is "fair".

The second-to-last author
Ambitious assistant professor or post-doc who instigated the paper.

Michaels, C., Lee, E. F., Sap, P. S., Nichols, S. T., Oliveira, L., Smith, B. S.

The second author
Grad student in the lab that has nothing to do with this project, but was included because he/she hung around the group meetings (usually for the food).

The middle authors
Author names nobody really reads. Reserved for undergrads and technical staff.

The last author
The head honcho. Hasn't even read the paper but, hey, he/she got the funding, and their famous name will get the paper accepted.

WWW.PHDCOMICS.COM

MARRIAGE vs. The Ph.D.



Marriage



Ph.D.

Typical Length:	7.5 years	7 years
Begins with:	A proposal	A thesis proposal
Culminates in a ceremony where you walk down an aisle dressed in a gown:	✓	✓
Usually entered into by:	Foolish young people in love	Foolish young people without a job
50% end in:	Bitter divorce	Bitter remorse
Involves exchange of:	Vows	Know-how
Until death do you part?	If you're lucky	If you're lazy

Corresponding author

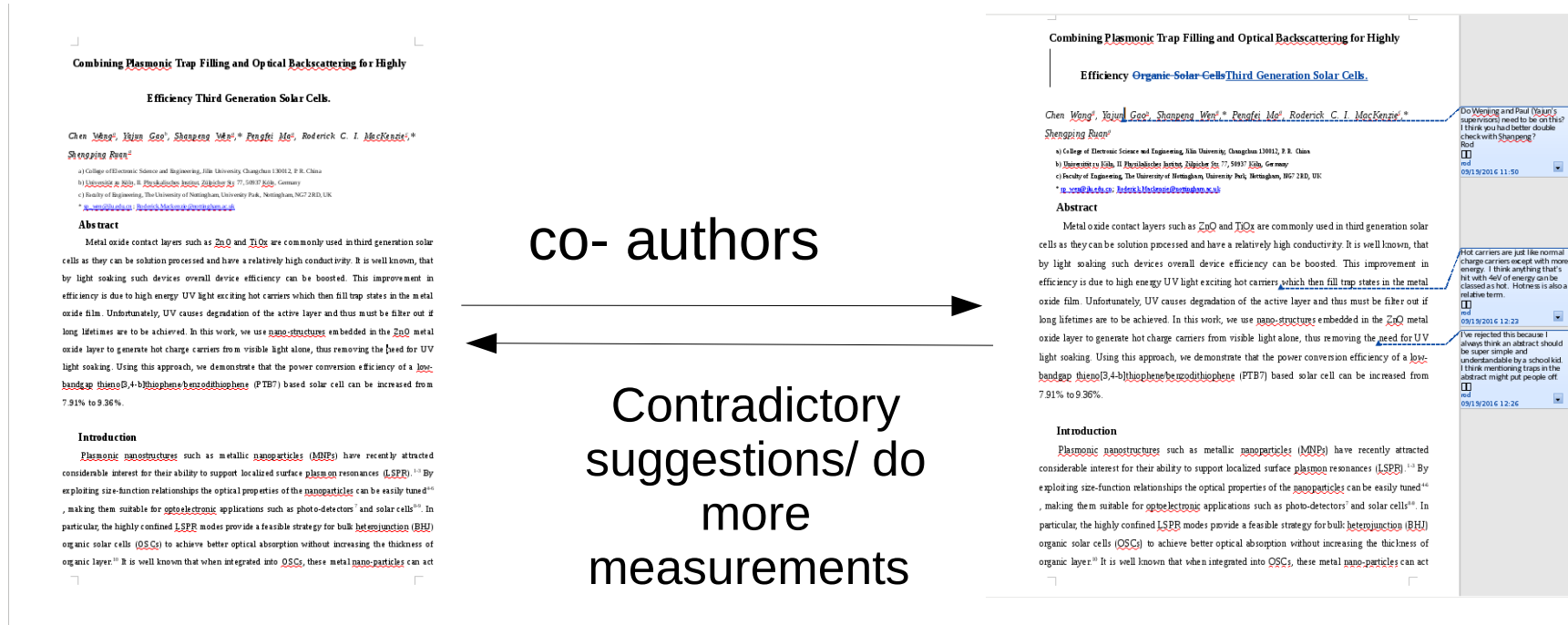
- If you look at this list, you can see a star above some names.

Yajun Gao, Roderick C. I. MacKenzie, Yang Liu, Bin Xu, Paul H. M. van Loosdrecht,* and Wenjing Tian**

- These are the **corresponding authors**
- These are the people **you can e-mail** if you have questions about the paper – they may even respond to e-mails about their work (if the questions are intelligent/polite).
- In UK academic culture people generally, **don't care who is corresponding author**. And it's often the person who just has the job of writing letters to the editor.
- In other academic cultures, corresponding author matters and even the order of the corresponding authors matters (China).

Now send your paper to the co-authors for comment.

- Be patient with them but firm.
- They are very busy people.



Combining Plasmonic Trap Filling and Optical Backscattering for Highly Efficiency Third Generation Solar Cells.

Chen Wang^a, Yajun Gao^b, Shaopeng Wen^{a*}, Pengfei Mo^a, Roderick C. I. MacKenzies^{a*}

Abstract

Metal oxide contact layers such as ZnO and TiO₂ are commonly used in third generation solar cells as they can be solution processed and have a relatively high conductivity. It is well known, that by light soaking such devices overall device efficiency can be boosted. This improvement in efficiency is due to high energy UV light exciting hot carriers which then fill trap states in the metal oxide film. Unfortunately, UV causes degradation of the active layer and thus must be filtered out if long lifetimes are to be achieved. In this work, we use nano-structures embedded in the ZnO metal oxide layer to generate hot charge carriers from visible light alone, thus removing the need for UV light soaking. Using this approach, we demonstrate that the power conversion efficiency of a ZnO-bandgap thin TiO₂/4-biophenylene-biindole (PTB7) based solar cell can be increased from 7.91% to 9.36%.

Introduction

Plasmonic nanostructures such as metallic nanoparticles (MNPs) have recently attracted considerable interest for their ability to support localized surface plasmon resonances (LSPR).¹⁻³ By exploiting size-function relationships the optical properties of the nanoparticles can be easily tuned⁴, making them suitable for optoelectronic applications such as photo-detectors⁵ and solar cells⁶. In particular, the highly confined LSPR modes provide a feasible strategy for bulk heterojunction (BHJ) organic solar cells (OSCs) to achieve better optical absorption without increasing the thickness of organic layer.⁷ It is well known that when integrated into OSCs, these metal nanoparticles can act

Combining Plasmonic Trap Filling and Optical Backscattering for Highly Efficiency Organic Solar Cells/Third Generation Solar Cells.

Chen Wang^a, Yajun Gao^b, Shaopeng Wen^{a*}, Pengfei Mo^a, Roderick C. I. MacKenzies^{a*}

Abstract

Metal oxide contact layers such as ZnO and TiO₂ are commonly used in third generation solar cells as they can be solution processed and have a relatively high conductivity. It is well known, that by light soaking such devices overall device efficiency can be boosted. This improvement in efficiency is due to high energy UV light exciting hot carriers which then fill trap states in the metal oxide film. Unfortunately, UV causes degradation of the active layer and thus must be filtered out if long lifetimes are to be achieved. In this work, we use nano-structures embedded in the ZnO metal oxide layer to generate hot charge carriers from visible light alone, thus removing the need for UV light soaking. Using this approach, we demonstrate that the power conversion efficiency of a ZnO-bandgap thin TiO₂/4-biophenylene-biindole (PTB7) based solar cell can be increased from 7.91% to 9.36%.

Introduction

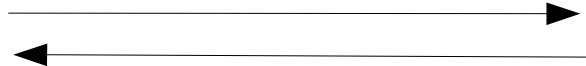
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Do Wenjing and Paul Yajun's supervisors need to be on this? I think you had better double check with Shaopeng?
Red
09/12/2016 11:50

Hot carriers are just like normal charge carriers except with more energy. I think anything that's hit with less of energy can be classed as hot. Hotness is also a relative term.
Red
09/12/2016 12:22

You rejected this because I always think an abstract should be super simple and understandable by a schoolkid. I think mentioning traps in the abstract might put people off
Red
09/12/2016 12:26

co- authors

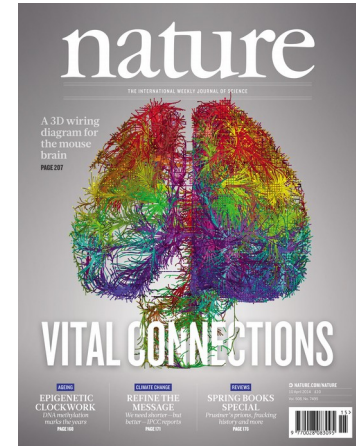


Contradictory suggestions/ do more measurements

- They will then send you back changes and suggestions to the paper using track changes.
- Your paper can go back and forth quite a few times.

Once you are happy with your paper you select a journal to send it to.

- Journals are judged to some extent by their impact factor:
 - Nature 38.138 (Science journal)
 - Cell 28.710 (Science journal)
 - Journal of Physical Chemistry A 2.8 (Engineering)
 - Physical Review B 3.7 (Engineering)
 - IEEE Journal of Quantum Electronics 1.8 (Engineering)



- Ideally you want to put your paper **somewhere where** it will be **read by people** in your field.

The cover letter

- With the paper you usually need to write a cover letter



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12th September 2016

Dear Editors,

We would very grateful if you could consider the attached manuscript "*Combining Plasmonic Trap Filling and Optical Backscattering for High Efficiency Third Generation Solar Cells*", for publication in Energy and Environmental Science.

High efficiency third generation solar cell, often use transparent metal oxide contacts such as those made from TiO_2 . It is common to light soak these layers using high energy (UV) light, this significantly increases device efficiency by generating hot charge carriers, which fill trap states in the oxide layer. However, UV is well known to degrade both organic and inorganic materials, and thus this process is not compatible with the search for longer device lifetimes.

In this manuscript, we demonstrate the general result, that by tuning the shortest side of metal nano-particles to generate hot charge carriers from visible light, then by embedding these nano-particles in the metal oxide contact layer of a solar cell; the benefits of UV light soaking can be gained from visible light alone. We then tune the longest dimension of the metal nano-particles to promote light trapping in the device. Using this general strategy, we demonstrate that a state-of-the-art low-bandgap thieno[3,4-b]thiophene/ benzodithiophene/ Phenyl-C70-butyric acid methyl ester (PTB7:PCBM) cell, can have its efficiency boosted from 7.91% to 9.36%.

- The cover letter should tell the editor why he should publish your paper.
- Why his readers will be interested in it.
- And why your paper will get cited and thus increase his journals impact factor.

Send the paper/letter to the journal



College of Electronic Science and Engineering

Combining Plasmonic Trap Filling and Optical Backscattering for Highly Efficient Third Generation Solar Cells

Chen Xiao*, Zhou Guo*, Shengnan Ma*, Xiaoli Ma*, Andrew C. J. McKenna*, Giovanni Dotoli*

1College of Electronic Science and Engineering, 230 Nanhu Road, 311126 Hangzhou, P. R. China
2School of Electronic and Electrical Engineering, 401004 Chongqing, China
3The University of Nottingham, Nottingham University Park, Nottingham, NG7 2RD, UK
*Corresponding Author: xiaochen@cease.zhu.edu.cn

Abstract
Metal oxide contact layers such as ZnO and TiO₂ are commonly used in third generation solar cells as they can enhance passivation and have a relatively high conductivity. It is well known that by light trapping such devices would drive efficiency can be boosted. This improvement is also achieved by high energy UV light trapping but carries which then fill trap states in the metal oxide film. Unfortunately, UV causes degradation of the active layer and thus must be filtered out. Long lifetimes are to be achieved. In this work, we use plasmonic structures embedded in the ZnO metal oxide layer to generate hot charge carriers from a visible light source, thus reversing the band for UV light trapping. Using this approach, we demonstrate that the power conversion efficiency of a ZnO backscattering (BS) device is 18.5% (AM1.5G) based solar cell can be increased to 21.9% to 23.2%.

Introduction
Plasmonic nanostructures such as metallic nanoparticles (NPs) have recently attracted considerable interest for their ability to support localized surface plasmon resonances (LSPRs). By exploiting size-tunable relationships the optical properties of the nanostructure can be easily tuned, making them suitable for optoelectronic applications such as photo-detection, and solar cells¹⁻³. In particular, the highly confined LSPR modes provide a visible strategy for light trapping in third generation solar cells (3GSCs) to achieve better optical absorption without increasing the thickness of organic layer⁴. It is well known that when integrated into 3GSCs, these metal nanoparticles act

Dear Editors,
We would like to submit our paper "Combining Plasmonic Trap Filling and Optical Backscattering for Highly Efficient Third Generation Solar Cells", to your journal. We believe this work is of high quality and will be of interest to your readers. We have enclosed the manuscript and cover letter for your consideration. We would be pleased to receive your comments and suggestions. Thank you very much for your time and consideration. Sincerely,
Chen Xiao

1 month

Wait for the editor to read the paper

1 month

Editor sends the paper to the reviewers

1 month

3 reviewers make recommendations

Reject?

Reject (Some journals reject 70% of papers at this stage)

1 month

6 month

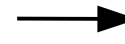
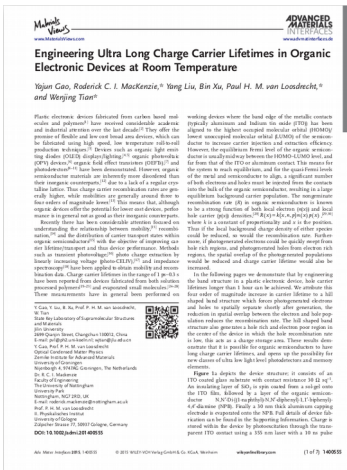
You change the paper according to the reviewers recommendations.

Accept?

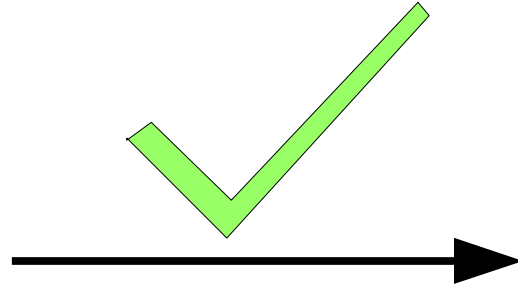
Type setting and final paper published on line.

Overall acceptance rate for Nature: 7%

Typical is about 50%



The process of knowledge dissemination



Idea/New exciting data

- But papers are a very raw form of knowledge, how is this distilled and refined.....

Refining knowledge..

- After 10 years or so when lots of papers have been published in a given field and there has been a body of knowledge been generated.
- Somebody will write a book on the topic.

Book



- These first books are generally hard to understand and complex.

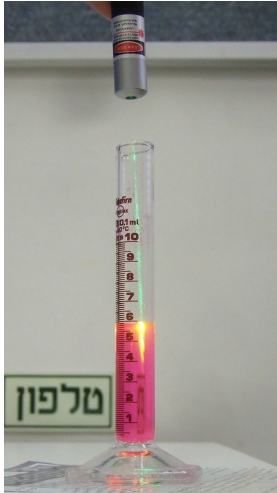
Academic books

- Often the contents of these early academic books, is mainly correct but there can be errors and mistakes in the filed.
- They should also be treated with caution.



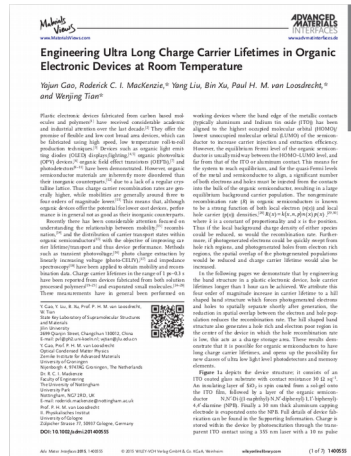
- In general after about 10-15 years there will have been enough books written on a topic and enough papers published that we have a good idea of what is correct/not correct in a field.

Overview of the process, from paper to lecture.



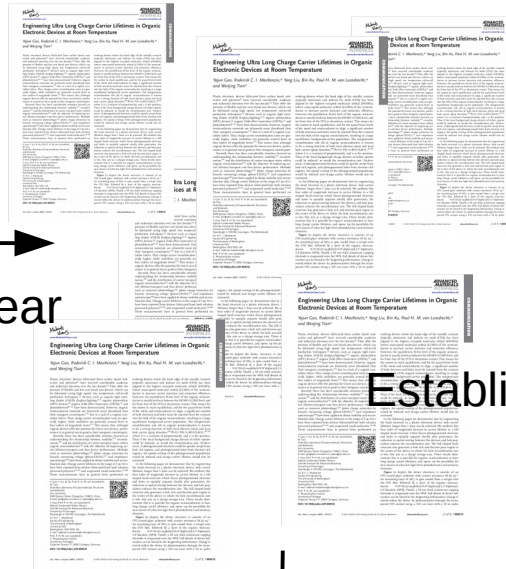
Experiment

→
1 year



Paper

→
10 year



Established field

↓
5-10 years



Lectures

←
5 years



Book

- Time scales can vary, these are just to give you an idea.

Lecture outline

- The process of knowledge dissemination
- **What's the point of references?**
- Clarity of writing
- Good figures and graphs.
- How to write a scientific report
 - Abstract/Method/Discussion/Conclusion
- How to write a scientific paper.
 - Abstract/Introduction/Results/Discussion/Conclusion
- What editors look for in a paper.
- How to write a thesis

References, an example.

1 Introduction

Organic solar cells have recently shown great promises as a low cost source of low carbon electricity, their efficiencies have rapidly improved from 3% in 2007¹ to over 10% today.² There has been much work done on optimizing all aspects of organic photovoltaic devices (OPVs) including; development of narrow bandgap polymers to improve light absorption;³ developing better contacts^{4,5} to replace expensive Indium Tin Oxide;^{6,7} and development of faster production technologies to reduce the fabrication cost.⁸⁻¹⁰ However the cost per Watt of energy produced with an organic solar cell is still not competitive to silicon^{2,11} and for OPV devices to become commercially viable, improvements still need to be made in both efficiency and cost.

In the following pages we demonstrate how a significant

Grounding everything you say to the literature.

1 Introduction

Organic solar cells have recently shown great promises as a low cost source of low carbon electricity, their efficiencies have rapidly improved from 3% in 2007¹ to over 10% today.² There has been much work done on optimizing all aspects of organic photovoltaic devices (OPVs) including; development of narrow bandgap polymers to improve light absorption;³ developing better contacts^{4,5} to replace expensive Indium Tin Oxide;^{6,7} and development of faster production technologies to reduce the fabrication cost.⁸⁻¹⁰ However the cost per Watt of energy produced with an organic solar cell is still not competitive to silicon^{2,11} and for OPV devices to become commercially viable, improvements still need to be made in both efficiency and cost.

In the following pages we demonstrate how a significant

- Can you see that every time I say something is true, I put a reference to back it up.
- If people don't believe what I am saying, then they can go and find the references to convince them selves.
- If they disagree with me, they not only have to disagree with me but also the author of the other paper.
- They also provide a jumping in point for people who are new to the subject.

References

- Generally in science/engineering you are not allowed to make statements without a reference backing them up.
- For example you can not write,
 - **“I think solar energy is the fastest growing form of energy”**
- because that is what they do in the sun ->
- You must back it up with a reference.
Solar energy is the fastest growing form of energy^[1]



Web references?

- **Web references are bad**, this is because your written work will be read by other long after you are dead.
- This means that in **200 years**, someone needs to be able to find the reference you are citing.

ON THE MOVEMENT OF SMALL PARTICLES SUSPENDED IN STATIONARY LIQUIDS REQUIRED BY THE MOLECULAR-KINETIC THEORY OF HEAT

by A. Einstein

[*Annalen der Physik* 17 (1905): 549-560]

$$F = -\frac{R}{N} T \lg \int e^{-\frac{EN}{RT}} dp_1 \dots dp_\ell = -\frac{RT}{N} \lg B.$$

Let us now imagine a liquid enclosed in the volume V ; let the partial volume V^* of V contain n dissociated molecules or suspended bodies, which are retained in the volume V^* by a semipermeable wall; this will affect the integration limits of the integral B entering the expressions for S and F . Let the total volume of the dissolved molecules or suspended bodies

¹In this section it is assumed that the reader is familiar with the author's papers on the foundations of thermodynamics (cf. *Ann. d. Phys.* 9 (1902): 417 and 11 (1903): 120). Knowledge of the papers cited and of this section of the present paper is not essential for the understanding of the present paper's results.

How should I set out my references?

- There are lots of different forms of referencing, which should I use?:

(1) Emmott, C. J.; Urbina, A.; Nelson, J. Effects of Annealing and Degradation on Regioregular Polythiophene-Based Bulk Heterojunction Organic Photovoltaic Devices. *Sol. Energy Mater. Sol. Cells* **2012**, *97*, 14–21.

[1] M. A. Green, K. Emery, Y. Hishikawa, W. Warta, and E. D. Dunlop, *Prog. Photovolt: Res. Appl.* **20**, 12 (2012).

14. Cabanillas-Gonzalez, J., Grancini, G. & Lanzani, G. Pump-probe spectroscopy in organic semiconductors: monitoring fundamental processes of relevance in optoelectronics. *Adv. Mater.* **23**, 5468–5485 (2011).

- It does not matter at all, but do stick to one style!
- I suggest you use a reference manager, to do the hard work for you (See H14ERP).

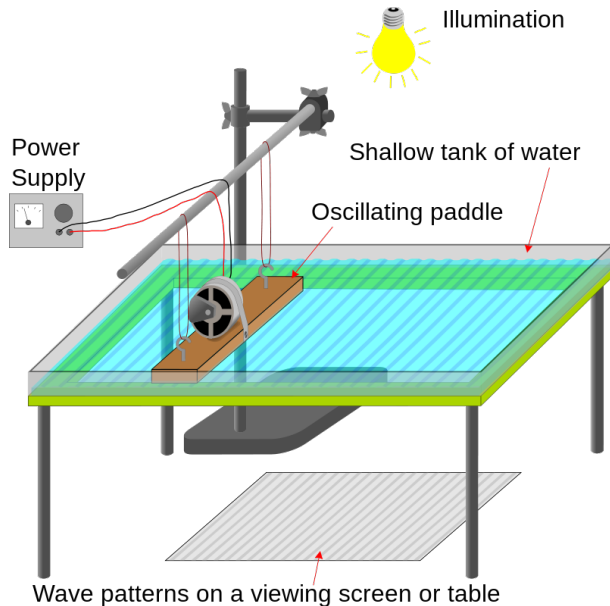
Lecture outline

- The process of knowledge dissemination
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- How to write a thesis

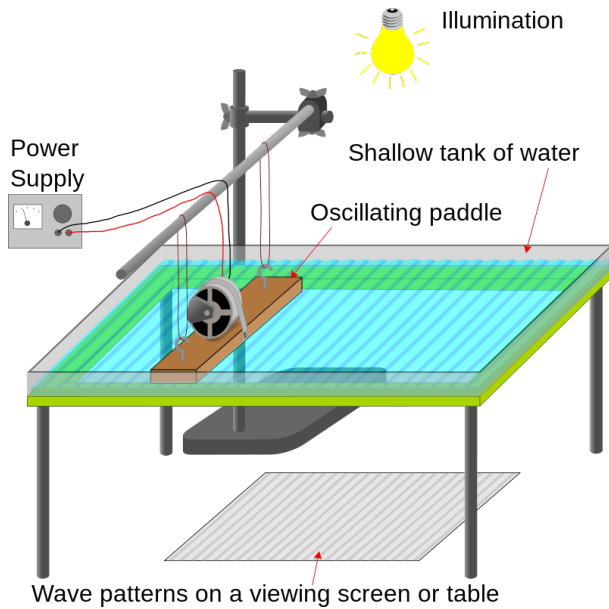
How to write scientific English

- Scientific English should use **short sharp** sentences which say **exactly** what you want to with the very **minimum of words**.
- An example of a bad sentence would be:

“To do the experiment we all got together in the lab on Tuesday and measured the waves in the wave tank many times.”



A better example would be



Using a ripple tank (with an oscillator running at 10 Hz), the interference pattern was projected onto the desk (see diagram). We then used a ruler to measure the peak-to-peak distance which was found to be 1.5 cm.

- Notice every part of this sentence tells me new information, it is sharp, short and accurate.

Deadwood phrases

a majority of -- most

a sufficient amount of -- enough

according to our data -- we find

accordingly -- therefore, so

after the conclusion of -- after

along the lines of -- like

as is the case -- as is true

ascertain the location of -- find

at such time as -- when

at the present time -- now

at this point in time -- now

give consideration to -- consider,
examine

give indication of -- show, indicate,
suggest

happen(s) to be -- am/is/are

has been proved to be -- is

if conditions are such that -- if

in a number of -- several, many

in all cases -- always

in case -- if

in close proximity to -- near

in excess of -- more than

in the vicinity of -- near

in this case -- here

in view of the fact that -- because,
since

is capable of -- can

is found to be -- is

is in a position to -- can

it has been found that -- (nothing)

it has long been known that --
(nothing)

it is a fact that -- (nothing)

it is evident that -- (nothing)

Deadwood phrases

prior to -- before

provided that -- if

put an end to -- end

reach a conclusion -- conclude

serves the function of being -- is

subsequent to -- after

the question as to -- whether

there can be little doubt that --
probably

utilize or utilization -- use

with reference to -- about

with the exception that -- except
that

future predictions -- predictions

general rule -- rule

green colored -- green

increase in increments -- increase

initial prototype (model) --
prototype

joint cooperation -- cooperation

major breakthrough --
breakthrough

modern science of today -- modern
science

most optimum -- optimum

necessary requirement --
requirement

Your go!



- Describe this experiment in as few words as possible.
- Then discuss this with your partner.
- We will read these out a bit later.

<https://www.youtube.com/watch?v=p4Mq1B1-XOw>

- Finally, in English, when you write Science and Engineering documents.
- Don't try to show the reader how clever you are by using long words, or fancy language, just keep every sentence to the very minimum.
- Try to **avoid acronyms** (TLAs!) they just make stuff much harder to understand.
- Always, try to write as if you are trying to explain what you are doing to a **clever child**.

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Good figures and graphs

- What's this about?

Tom (named "Jasper" in his debut appearance) is a grey and white [domestic shorthair cat](#). ("Tom" is a generic name for a male cat.) He is usually but not always, portrayed as living a comfortable, or even pampered life, while [Jerry](#) (named "Jinx" in his debut appearance) is a small, brown, [house mouse](#) who always lives in close proximity to Tom. Despite being very energetic, determined and much larger, Tom is no match for Jerry's wits. Jerry also possesses surprising strength for his size, approximately the equivalent of Tom's, lifting items such as anvils with relative ease and withstanding considerable impacts. Although cats typically chase mice to consume them, it is quite rare for Tom to actually try to consume Jerry. Most of his attempts are just to torment or humiliate Jerry, sometimes in revenge, and sometimes to obtain a reward from a human for catching Jerry. By the final "fade-out" of each cartoon, Jerry usually emerges triumphant, while Tom is shown as the loser.

However, other results may be reached. On rare occasions, Tom triumphs, usually when Jerry becomes the aggressor or when he pushes Tom a little too far. In [The Million Dollar Cat](#) Jerry learns that Tom will lose his newly acquired wealth if he harms any animal, "including a mouse;" he then torments Tom a little too much until he retaliates. In [Timid Tabby](#) Tom's look-alike cousin pushes Jerry over the edge. Occasionally and usually ironically, they both lose, usually when Jerry's final trap or attack on Tom backfires or Jerry overlooks something. In Chuck Jones' [Filet Meow](#), Jerry orders a shark from the pet store to scare Tom away from eating a goldfish, but finds himself entirely intimidated as well. Finally, they occasionally end up being friends, although within this set of stories, there is often a last minute event that ruins the truce. One story that has friendly ending is [Snowbody Loves Me](#).

Good figures and graphs

- Don't know and it' looks quite boring...

Good figures and graphs

- What's this about?
- What's happening?



Good figures and graphs

- What's this about?
- What's happening?
- All we need to understand what is going on is good pictures/figures and a little bit of text or figure captions.



Think of a paper or a report as a cartoon.

Can you understand it by looking at the figures alone.

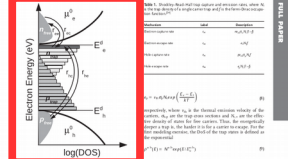
Extracting Microscopic Device Parameters from Transient Photocurrent Measurements of PHT/PCBM Solar Cells

Roshanik C. C. Mestranca* · Christopher G. Shuttle, Michael L. Chalmers, and Jeremy Nelson

By installing top-layer conductors in a transient differential mode, a PHT/PCBM solar cell experimental transient photocurrent (TPC) measurement across the current-voltage (I - V) curve to both the light and the dark can be implemented. Using the set of model parameters, the experimental TPCs are simulated and the parameters are then varied to reproduce the measured TPCs. The model is validated by comparing the simulated I - V curve at short-circuit and open-circuit conditions with the experimentally measured I - V curve. The model is then used to extract the microscopic parameters of the device and the effect of the top-layer conductors on the device performance. The model is used to extract the microscopic parameters of the device and the effect of the top-layer conductors on the device performance. The model is used to extract the microscopic parameters of the device and the effect of the top-layer conductors on the device performance.

1. Introduction
Photocurrent (PC) has been used as a diagnostic tool for solar cells and photodiodes for many years. It is a non-destructive technique that can be used to measure the performance of a device under various conditions. The PC is a function of the device parameters and the incident light intensity. The PC is a function of the device parameters and the incident light intensity. The PC is a function of the device parameters and the incident light intensity.

Figure 1. Schematic diagram of the experimental setup for the TPC measurement.

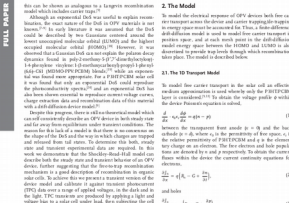


2. Model
The device is modeled as a two-terminal device with a top-layer conductor (TC) and a bottom-layer conductor (BC). The TC is connected to a voltage source (V) and the BC is connected to ground. The incident light (I) is shown entering the cell. The photocurrent (PC) is shown flowing from the TC to the BC. The diagram is labeled with various parameters such as V , I , PC , and $\log(DOS)$.

3. Results and Discussion
The experimental TPCs are compared with the simulated TPCs. The model is used to extract the microscopic parameters of the device and the effect of the top-layer conductors on the device performance. The model is used to extract the microscopic parameters of the device and the effect of the top-layer conductors on the device performance.

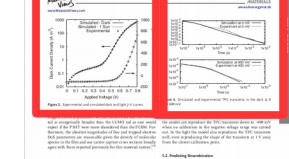
4. Conclusion
The model is used to extract the microscopic parameters of the device and the effect of the top-layer conductors on the device performance. The model is used to extract the microscopic parameters of the device and the effect of the top-layer conductors on the device performance.

Figure 2. Comparison of the experimental TPCs with the simulated TPCs.



5. Model
The model is used to extract the microscopic parameters of the device and the effect of the top-layer conductors on the device performance. The model is used to extract the microscopic parameters of the device and the effect of the top-layer conductors on the device performance.

Figure 3. Comparison of the experimental TPCs with the simulated TPCs.



6. Model
The model is used to extract the microscopic parameters of the device and the effect of the top-layer conductors on the device performance. The model is used to extract the microscopic parameters of the device and the effect of the top-layer conductors on the device performance.

7. Conclusion
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8. Conclusion
The model is used to extract the microscopic parameters of the device and the effect of the top-layer conductors on the device performance. The model is used to extract the microscopic parameters of the device and the effect of the top-layer conductors on the device performance.



Good figures and graphs

- And let's face it what you write will be pretty dull so people are not going to read the text anyway :)
- Communicate through pictures
- Examples of good and bad graphs/figures...



Always
assume this!

Examples of wonderful figures.

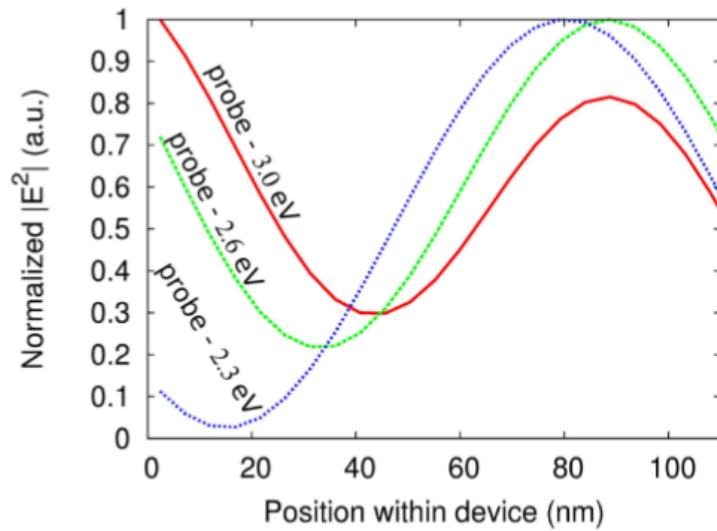


FIG. 8. (Color online) Normalized modal profiles of the probe light for photon energies of 2.3 (blue), 2.6 (green), and 3.0 eV (red). It can be seen that as photon energy is increased the photon density on the left-hand side of the device increases. Thus at low photon energies the EA measurement will only be sensitive to band bending on the right-hand side of the device, while at higher photon energies, the EA measurement will be able to measure average band bending over the whole device.

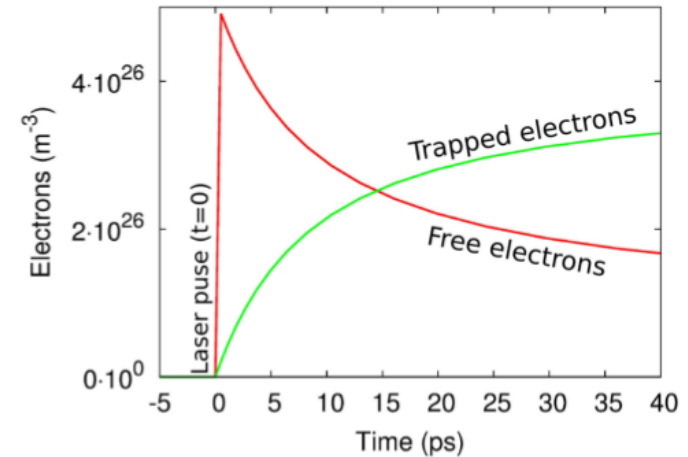
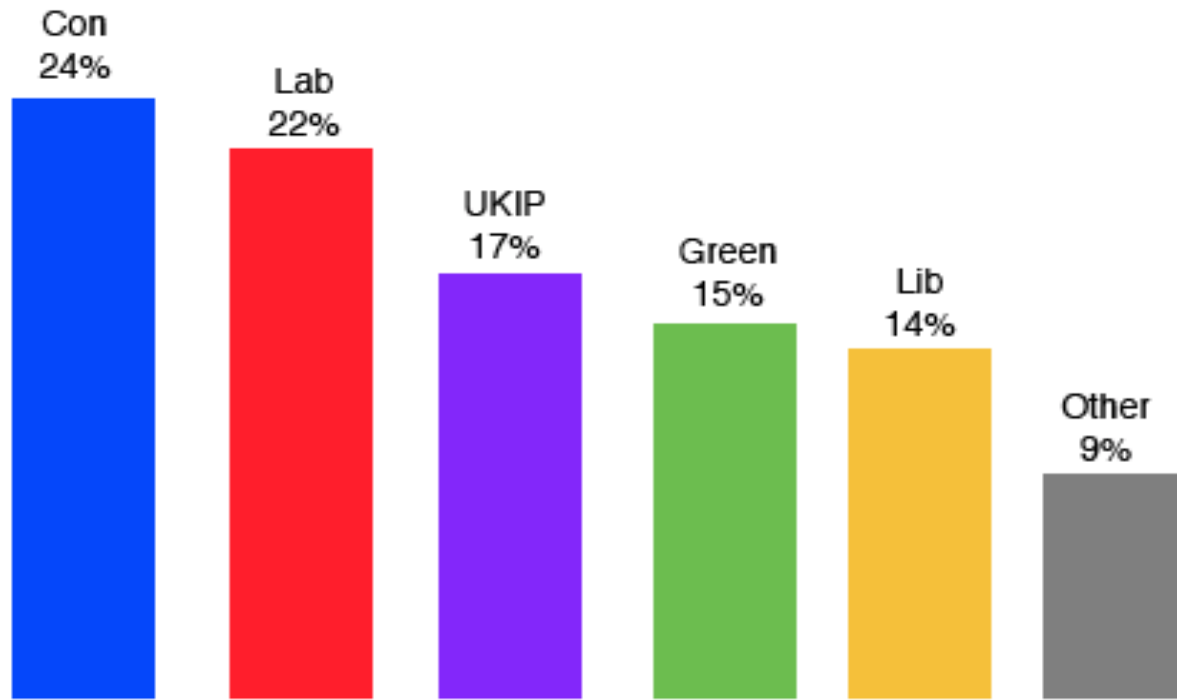


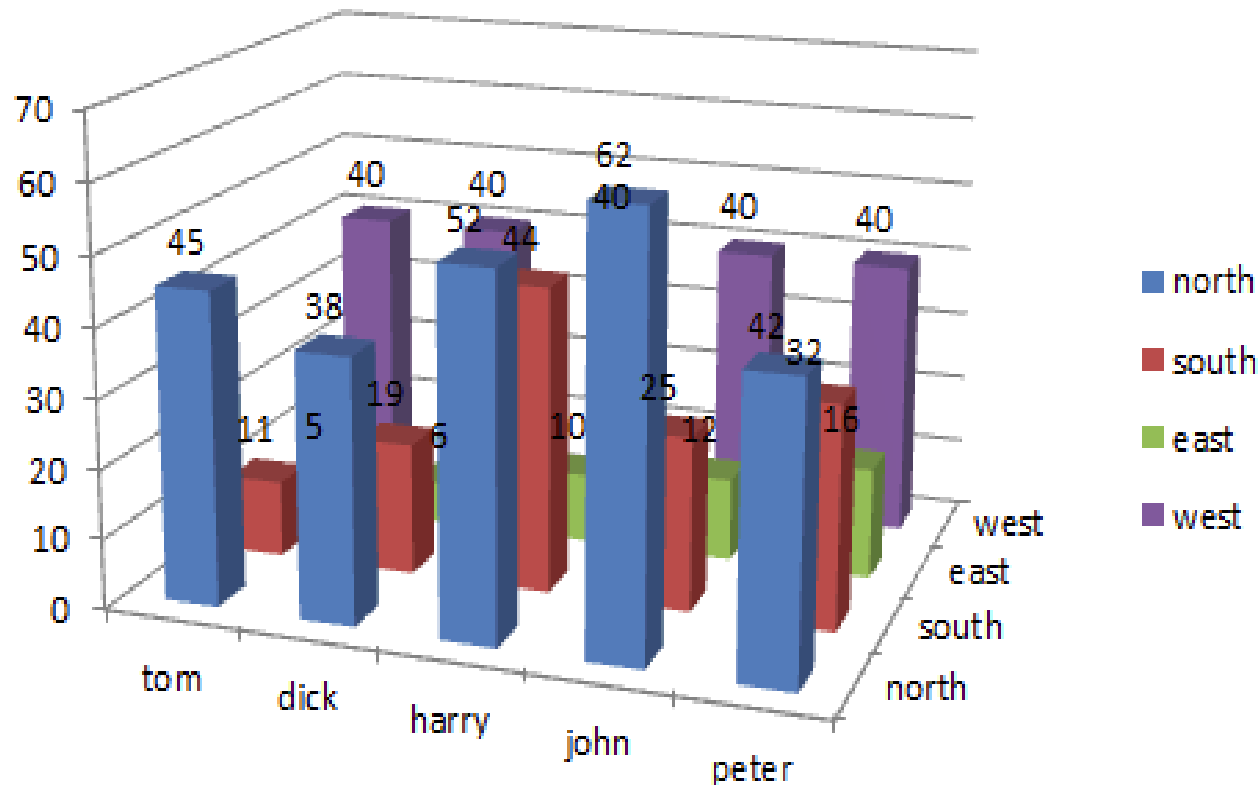
FIG. 9. (Color online) The average carrier density corresponding to free (hot) and trapped (cool) electrons during the measurement. Initially all photogenerated carriers are free but as they cool they become trapped. It can be seen that during the first 10 ps there are more free carriers than trapped carriers; this is the reason for the initial fast separation of the charge packets. It can be seen that past 10 ps most carriers are trapped and thus do not move; this is the reason for the second slow phase to the charge separation transient. At long times the number of trapped carriers decreases; this is due to recombination.

Is this a good or a bad figure?



ComRes UK poll, fieldwork 29-31 May 2009

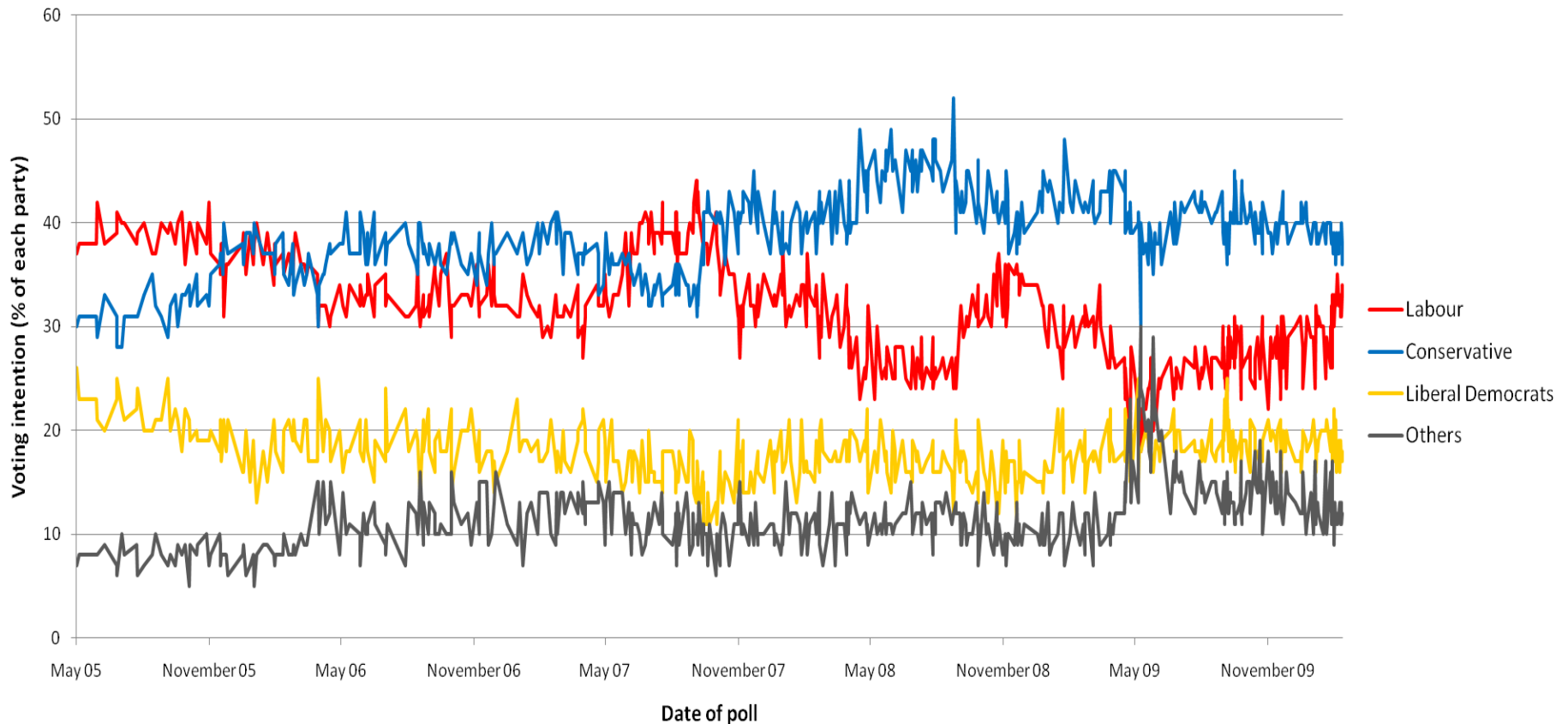
Good or a bad?



- Remember you are trying to communicate a message to the reader

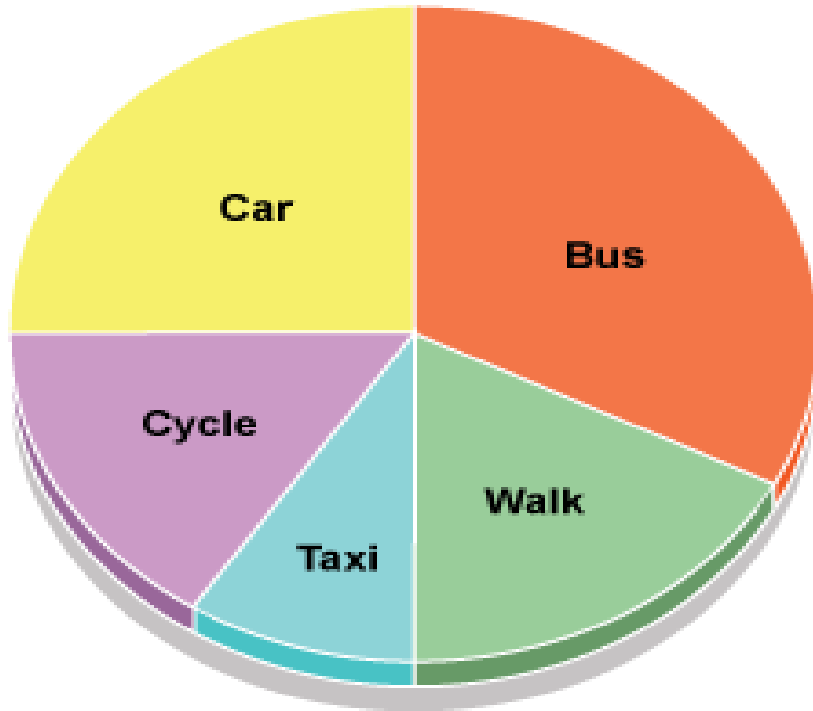
Good or a bad?

Voting intentions of major UK political parties: May 2005 - March 2010



- What has the author done to make the figure more clear?

Good or a bad?



What is missing on this graph?

Good or a bad?

The Oil Age World Oil Production 1859 - 2050

Oil was created from the remains of plants and animals distilled over millions of years. The source of most oil found today can be traced to two brief periods of global warming some 90 and 150 million years ago, and to the shallow seas teeming with algae that covered much of the earth at the time. As generations of sea life settled to the bottom, a unique carbon-rich sedimentary rock was formed. Over time, some of the rock sank deep beneath the surface, where the earth's natural heat gently cooked the rock's organic fraction, transforming it into a dark liquid: Petroleum—literally "rock oil"—was born.

Oil can migrate great distances from its subterranean birthplace, and much of it eventually escapes to the surface. Prehistoric people gathered thick crude from pools and smeared it on boats and dwellings to repel water. Slugs of burning crude entered ancient man, inspiring at least one religion.¹ The Chinese and Indians crafted medicines from petroleum, while classical Greek fire² wreathed havoc on Medieval battleships.

The Oil Age began in earnest in 1859, when Edwin Drake drilled one of the world's first commercial oil wells in Titusville, Pennsylvania. Marked had discovered how to tap the immense stores of petroleum were refined barrels—first by kerosene before the early 1900s. In the early decades of the oil age, most petroleum was refined into kerosene for illuminating the homes and businesses of a rapidly industrializing world.

Oil proved more effective than coal in running the world's navies, trains and shipping networks. The rise of the automobile propelled demand for a new type of refined gasoline—that surprised everyone in total production of refined oil revolutionized

ized war, fueling a new generation of motorized tanks, airplanes and submarines. Oil powered the rapid suburbanization of America in the 1950s and 1960s, as millions took to the road and air travel took off.

Unreasonable everyday products—from pharmaceuticals to clothing to computers—depend on oil and its refinement into complex chemicals and plastics. Modern industrial farming, which feeds much of the world, would grind to a halt if deprived of diesel-powered tractors, oil and gas-based fertilizers to grow and harvest crops, and the fuel tanks to process, package and ship food to supermarkets worldwide. Stocked with cheap calories, the world's population has skyrocketed—from 1.5 billion at the start of the Oil Age to more than 6.8 billion in 2010.

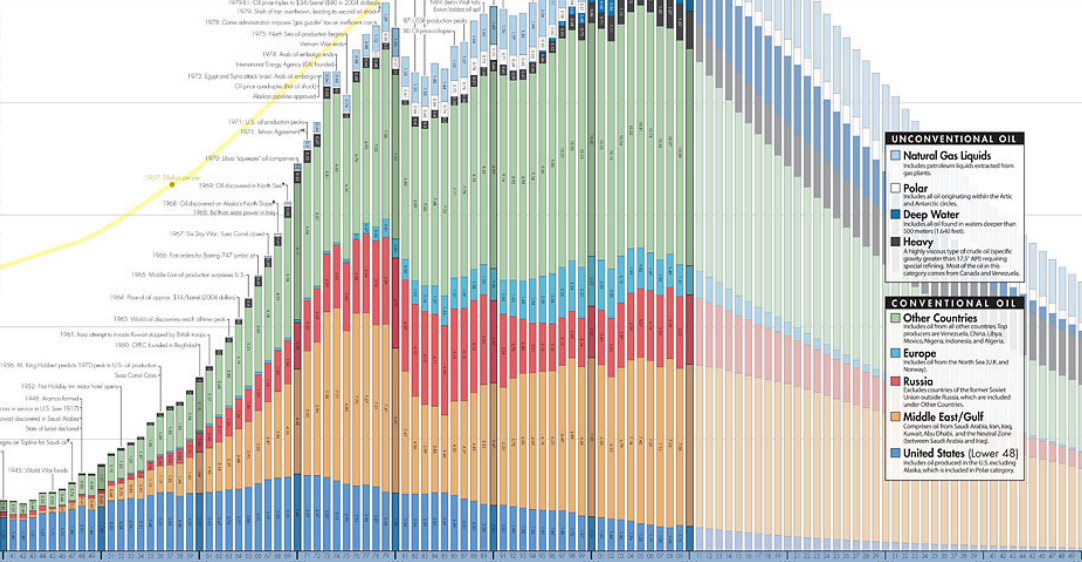
Oil is an incredibly dense energy source. A gallon of crude containing 3.2 kilos generates as much energy as five kilos of coal, 10 kilos of wood, or the work of 50 people toiling all day. Oil supplies about 35% of the industrial world's total energy needs and 95% of the fuel used to transport people and goods. Unusually portable, oil can be shipped anywhere in the world in tankers, trucks and trains. Interventions in the flow of oil have caused severe disruptions in industrial societies, as witnessed during the 1973 and 1979 oil shocks.

Oil is finite and non-renewable. Oil's earth's total endowment of conventional crude, we're consumed about half so far. New discoveries of oil peaked in the mid-1960s and by the early 1980s we began consuming more oil than we found. Today experts say we know about four to six barrels of oil for each one discovered. Meanwhile flows from three-quarters of the world's largest oil-producing countries have already topped out and are shrinking year by year.³ These trends point to a crossroads that draws closer every day: the peak and decline of global oil production.

American geophysicist Marion King Hubbert was the first to analyze the phenomenon of "peak oil." Decades ago he observed how oil production—whether in a field or region—tended to follow a bell curve, rising steadily in the early years, then slowing as the most productive wells played out and new drilling failed to catch up. The peak, he found, occurred near the midpoint, when about half of the deposits had been extracted.⁴ In 1956, Hubbert drew on these observations to correctly predict the 1970 peak in U.S. petroleum production.

When will the world's oil flows crest? Estimates vary, but a growing number of experts believe the peak is at hand. One prominent geologist, Colin Campbell, whose projections are displayed on this poster, says global oil production likely peaked in 2008. Other forecasts place the peak somewhere between 2005 and 2020. If either of these measures, we are within a few years of entering the second half of the Oil Age—an era marked by ever-dwindling supplies of man's most precious commodity.

Is the world ready for peak oil? One influential report suggests that industrial societies should take action decades in advance of the peak to avoid major disruptions.⁵ For industrial societies that depend on oil for everything from transportation and heating to manufacturing and food production, time is running out. Whether we can develop substitutes soon enough to sustain our way of life is a question that looms larger every day.



Peak Oil
2008: Most forecasts for global oil production peak in 2008. Other forecasts peak in 2006 or 2005. The BP forecast peaks in 2006. The EIA forecast peaks in 2005. The Campbell forecast peaks in 2008. The Campbell forecast is based on the Hubbert model, which assumes that oil production in a region follows a bell curve. The Campbell forecast is based on the Hubbert model, which assumes that oil production in a region follows a bell curve.

- UNCONVENTIONAL OIL**
 - Natural Gas Liquids**: Includes production from shale, tar sands, etc.
 - Polar**: Includes oil and gas reserves in the Arctic.
 - Deep Water**: Includes oil and gas reserves in deep water.
 - Heavy**: Includes oil reserves with a specific gravity greater than 1.07, requiring special refining. Most of the world's heavy oil reserves are in Canada and Venezuela.
- CONVENTIONAL OIL**
 - Other Countries**: Includes production from Mexico, Nigeria, Indonesia, and others.
 - Europe**: Includes production from the North Sea, U.K., and Norway.
 - Russia**: Includes production from the former Soviet Union, which includes reserves in the Arctic.
 - Middle East/Gulf**: Includes production from Saudi Arabia, Kuwait, Abu Dhabi, and the Persian Gulf region.
 - United States (Lower 48)**: Includes production from the lower 48 states, which includes reserves in the Arctic.

The Power of Oil

Transportation
About 55% of oil goes to power the world's trucks, airplanes, trains, and ships, together consuming some 600 million gallons. For many types of transportation—including cars, trucks and airplanes—there are few alternatives to oil. Today the world depends on oil in the form of gasoline, diesel and kerosene for more than 95% of its transportation energy needs.

Electricity and Heat
Enough 70% of electrical power in the U.S. comes from fossil fuels—including oil. Nuclear energy (20%) and other renewables (1%) make up the rest. Oil is used for electricity generation in many other countries. In the U.S., about 40% of homes are heated by oil.

Chemicals and Plastics
Modern life wouldn't be the same without the plastics, drugs, detergents, synthetic rubber, and fibers that we take for granted. Oil is the source of most of these products. It is also the source of many of the fertilizers and pesticides used in agriculture. Without these products, our food supply would be severely threatened.

Energy Sources
Roughly 34% of the world's energy comes from oil, and more than 80% comes from fossil fuels (oil, gas and coal).

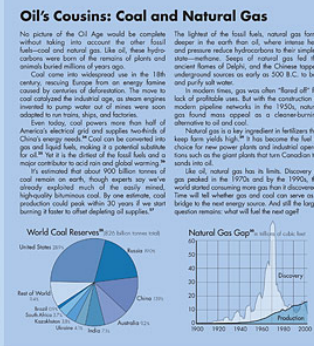
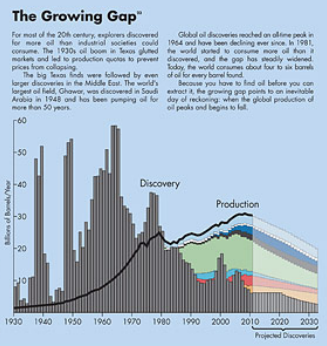
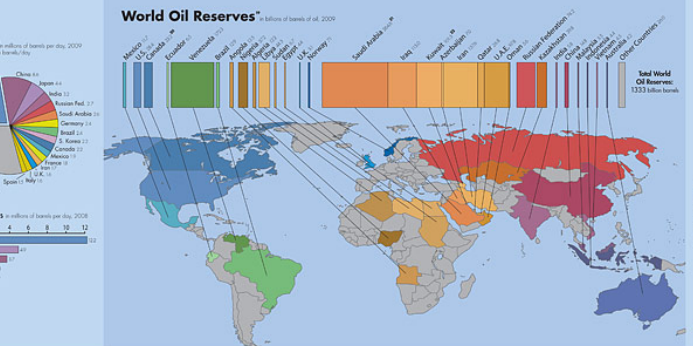
Production and Consumption

Oil Producers (million barrels per day, 2009)
Saudi Arabia, United States, Russia, Canada, Brazil, Mexico, Venezuela, Nigeria, Algeria, Angola, Iraq, Kuwait, Oman, Qatar, Bahrain, United Arab Emirates, Libya, Egypt, Sudan, Chad, Congo, Gabon, Equatorial Guinea, Congo, DRC, Republic of Congo, Angola, Nigeria, Algeria, Libya, Sudan, Chad, Congo, Gabon, Equatorial Guinea, Congo, DRC, Republic of Congo.

Oil Consumers (million barrels per day, 2009)
China, India, U.S., Japan, South Korea, Germany, France, Italy, Spain, U.K., Canada, Mexico, Brazil, Russia, Saudi Arabia, Kuwait, Oman, Qatar, Bahrain, United Arab Emirates, Libya, Egypt, Sudan, Chad, Congo, Gabon, Equatorial Guinea, Congo, DRC, Republic of Congo.

Top Oil Exporters (million barrels per day, 2008)
Saudi Arabia, Russia, United States, Canada, Mexico, Venezuela, Nigeria, Algeria, Angola, Iraq, Kuwait, Oman, Qatar, Bahrain, United Arab Emirates, Libya, Egypt, Sudan, Chad, Congo, Gabon, Equatorial Guinea, Congo, DRC, Republic of Congo.

Top Oil Importers (million barrels per day, 2008)
United States, China, India, Japan, South Korea, Germany, France, Italy, Spain, U.K., Canada, Mexico, Brazil, Russia, Saudi Arabia, Kuwait, Oman, Qatar, Bahrain, United Arab Emirates, Libya, Egypt, Sudan, Chad, Congo, Gabon, Equatorial Guinea, Congo, DRC, Republic of Congo.



Notes
1. The ancient Egyptians used asphaltum (a form of petroleum) to waterproof their boats. The ancient Greeks used asphaltum to waterproof their ships. The ancient Romans used asphaltum to waterproof their buildings. The ancient Chinese used asphaltum to waterproof their boats. The ancient Indians used asphaltum to waterproof their boats. The ancient Persians used asphaltum to waterproof their boats. The ancient Egyptians used asphaltum to waterproof their boats. The ancient Greeks used asphaltum to waterproof their ships. The ancient Romans used asphaltum to waterproof their buildings. The ancient Chinese used asphaltum to waterproof their boats. The ancient Indians used asphaltum to waterproof their boats. The ancient Persians used asphaltum to waterproof their boats.

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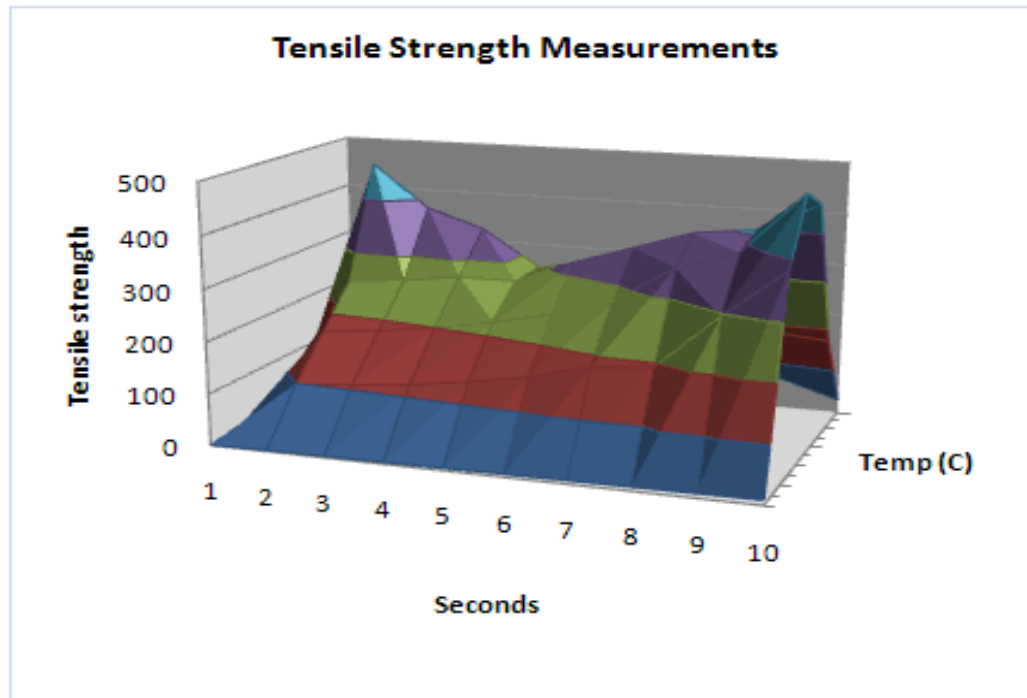
3. The world's largest oil-producing countries are Saudi Arabia, Russia, and the United States. Saudi Arabia's production has been declining since 2002. Russia's production has been declining since 2008. The United States' production has been declining since 2008.

4. Hubbert's model is based on the Hubbert model, which assumes that oil production in a region follows a bell curve. The Hubbert model is based on the Hubbert model, which assumes that oil production in a region follows a bell curve.

5. The report is based on the Hubbert model, which assumes that oil production in a region follows a bell curve. The report is based on the Hubbert model, which assumes that oil production in a region follows a bell curve.

Good or a bad?

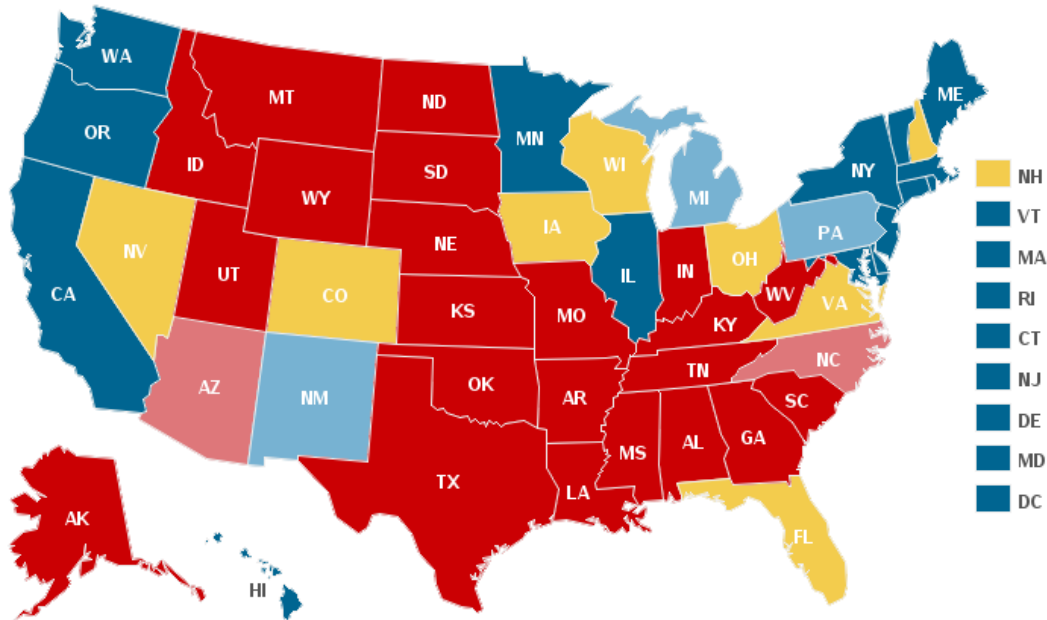
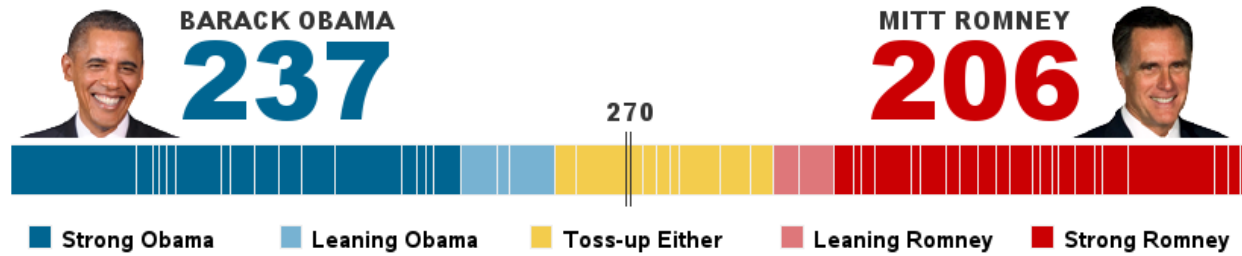
Surface Charts: come in handy if you are to determine the optimum combination between two sets of data.



Electoral Prediction Map

Which candidate will win each state and reach 270 electoral votes first?
Hover your mouse over the states to see the number of electoral votes.

Total number of Electoral College votes: **538**
Total needed to win: **270**



Based on data from CNN.com the morning of November 5, 2012, using SAS/GRAPH software

You should think of every figure as a work of art.

Lecture outline

- The process of knowledge dissemination
- What's the point of references
- Clarity of writing
- Good figures and graphs.
- **How to write a scientific paper.**
- How to write a scientific report
- How to write a thesis.
- How to write a literature review.

Rule 1: Short is good

The physical meaning of charge extraction by linearly increasing voltage transients from organic solar cells

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Carrier mobility in organic solar cells is almost exclusively determined by the Charge Extraction by Linearly Increasing Voltage (CELIV) technique: indeed much of our understanding of the recombination and charge transport mechanisms in organic solar cells is based on CELIV measurements. However, since the conception of the CELIV method, our understanding of organic semiconductors has significantly advanced. In this work, we critically examine the CELIV methods ability to provide accurate material data in the light of recent advances in our understanding of trap states and their influence on mobility in organic semiconductors. We then apply this knowledge to understand the mechanisms responsible for degradation in organic solar cells. © 2013 AIP Publishing LLC. [http://dx.doi.org/10.1063/1.4818267]

Organic solar cells offer the potential of a low-cost, low-carbon source of electricity. Within the last few years, power conversion efficiencies have increased from 3% to over 10%. However, to further increase energy conversion efficiencies, a larger proportion of the photogenerated charge carriers need to reach the contacts of the cell.¹ To achieve this, the lifetime (τ) and the mobility (μ) of the materials charge carriers must be maximised.² Researchers often use the Charge Extraction by Linearly Increasing Voltage (CELIV)³ method to measure mobility⁴ within research devices to guide both device and material development. However, since Jaska^{5,6} first proposed the CELIV method, our understanding of organic semiconductors has considerably improved.^{7–11} In particular, our understanding of charge transport in these material systems has considerably developed.¹² In this letter, we examine the underlying theoretical assumption made by Jaska⁵ in the derivation of the CELIV measurement technique and hold them up to scrutiny against today's knowledge of organic semiconductor materials.¹³ The ability to accurately measure mobility in organic solar cells is to continue to be developed.

In Jaska's⁵ original paper, he derived the now well known equation to extract mobility from CELIV transients,
$$\mu = \frac{2}{A_{\text{cell}}} \frac{d}{(1 + 0.36 \frac{d}{l})} \quad (1)$$

where A describes the ramp rate (V/s) of a negative triangular voltage function applied to the cell; this voltage ramp usually starts at around 0 V and decreases to typically -1 V to -5 V applied bias within 10–30 μ s; l is the thickness of the device; A_{cell} is the ratio of the current due to charge

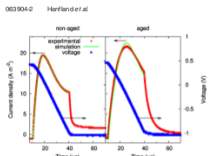


FIG. 1. Experimental CELIV measurement (at a ramp speed of 0.4 V ns⁻¹) at a cell area of 176 cm² for 176 s using a 4 V source capacitor. The inset shows the CELIV transient at 45°C with a constant voltage offset.

area. Thus, we must ask if the mobility of the material in the device is changing during the measurement, how does this affect our value of mobility as measured by the CELIV method?

Finally, the CELIV method was derived for a material system where one material had a very low mobility and the other carrier species had a high mobility. However, due to improved polymers,¹⁴ today's high efficiency devices have more balanced mobilities and it is thus not clear that our carrier remains immobile and thus CELIV theory holds. In the following pages, we address these questions using a combination of experimentation and theory: the result is a better understanding of how CELIV transients can be interpreted.

Inferred bulk recombination densities were fabricated and a C60/OPV/PT/PCBM/PEOP/PPSS/Ag/glass structure¹⁵ (Poly(9,9-dioctylfluorene-2,9-diyl) (PPH) and phenyl-C61-butyric acid methyl ester (PCBM) were mixed in a weight ratio of 1:0.67. The active and poly(9,9-dioctylfluorene-2,9-diyl) poly(styrene-alt-maleic) (PEOP/PPSS) (90nm) layer were deposited by spin coating. The metal grid was thermally evaporated. Devices were annealed at 130°C for 19min. Cell aging was performed using a UV source equivalent to exposure under AM1.5G irradiation at 45°C with a relative humidity of 6% for 176 h. The resulting CELIV transients before and after aging are plotted in Figure 1. By applying Eq. (1) to the experimental data, a mobility of $5.5 \times 10^{-4} \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ before the cell is aged is obtained, and a decreased mobility of $2.3 \times 10^{-4} \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ after aging is obtained.

Before attempting to understand the change in measured mobility upon degradation, we first use our device model¹⁶ to better understand the physical mechanisms which can alter CELIV transients. To model CELIV transients from an organic solar cell, we use an effective medium approximation where the LUMO level of the fullerene is taken as the electron transport edge and the HOMO level of the polymer is taken as the hole mobility edge. To calculate the electric field profile within the device, Poisson's equation is solved in one dimension,

where ϵ_0 is the permittivity of free space, ϵ_r is the relative permittivity of the medium, $n_{\text{net}}(x, y, z)$ is the sum of the free and trapped electron (hole) population. To simulate the movement of free carriers, the bipolar drift-diffusion equations are solved,

$$J_e = q n \mu_n \frac{dE}{dx} - D_n \frac{dn}{dx} \quad (2)$$
$$J_h = -q p \mu_p \frac{dE}{dx} - D_p \frac{dp}{dx} \quad (3)$$

where μ_n (μ_p) is the free electron (hole) mobility, E_{LUMO} (E_{HOMO}) is the spatially dependent potential of the LUMO (HOMO), D_n (D_p) are the electron (hole) diffusion coefficients. Conservation of particles is forced using the carrier conservation equation and its discrete carrier trapping and recombination we use the Shockley-Read-Hall model.¹⁷ The carrier traps are defined as an exponential distribution of states,

$$D(E) = N^0 \exp(-E/E_0^2) \quad (4)$$

where N^0 are the electronic trap densities at the LUMO and HOMO edge.^{18,19} We use the characteristic electronic tail slope energies and E_0 is the distance from the LUMO/HOMO edge. A full list of device parameters are given in the supplementary information.²⁰ Parameters were chosen to be symmetric and to be close to those already reported in literature.²¹

If Eq. (4) is a measure of free carrier mobility as described by Jaska in his derivation, then the density of carrier traps should not affect the shape of the CELIV transient. To test Jaska's approximation, Figure 2 shows five simulated CELIV transients with all device parameters held constant except the carrier trap densities. It can be seen that an increase in the density of carrier traps does not only increase the magnitude of the CELIV peak, but also shifts the CELIV peak to the right. If we use Eq. (1) to extract the mobilities, we obtain values of 1.1×10^{-3} to $3.0 \times 10^{-3} \text{ m}^2 \text{ V}^{-1} \text{ s}^{-1}$, thus we can determine from this

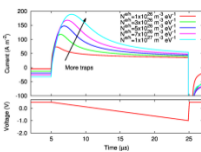


FIG. 2. The influence of carrier trap states on the CELIV transient. It can be seen that the density of trap states can both the position and magnitude of the transient. The CELIV method gives the mobility values with a trap density of $1 \times 10^{19} \text{ cm}^{-3}$ as $1.1 \times 10^{-3} \text{ m}^2 \text{ V}^{-1} \text{ s}^{-1}$ and the mobility of carrier with a trap density of $1 \times 10^{23} \text{ cm}^{-3}$ as $3.0 \times 10^{-3} \text{ m}^2 \text{ V}^{-1} \text{ s}^{-1}$.

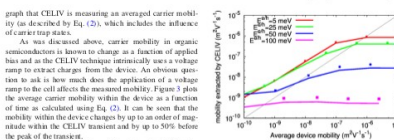


FIG. 3. The influence of the voltage ramp rate on the average mobility within the device as simulated in Fig. 2. The black line shows the peak of the CELIV transient curve. It can be verified the measurement process provides us can change the mobility by up to 50% before the CELIV peak (see right hand side of Figure 5): this is because during the application of the CELIV voltage ramp the quasi Fermi levels of the free carriers will progressively move to lower energies forcing ever more deeply trapped states to release the carriers in order to move towards equilibrium, furthermore shallowly trapped carriers take less time to thermalize and become mobile than carriers in deeper traps. Thus, after just a single uniform charge sheet being removed from the device, charge is removed progressively from deeper and deeper traps across the entire device. This means that the charge sheet (and region (c)) in the CELIV derivation

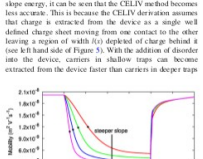


FIG. 4. Substrate diagram comparing the idealized removal of carriers from a device with traps as described in the derivation of the CELIV method (where carriers are considered to be immobile) as presented in the device with traps across the entire device. Thus, the distance (d) of the free carriers, charge carriers are released progressively from deeper and deeper traps across the entire device. Thus, the distance (d) of the free carriers, charge carriers are released progressively from deeper and deeper traps across the entire device. Thus, the distance (d) of the free carriers, charge carriers are released progressively from deeper and deeper traps across the entire device. Thus, the distance (d) of the free carriers, charge carriers are released progressively from deeper and deeper traps across the entire device.

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- People are not that interested in what you have to say, so don't waste their time by writing too much.
- Always assume they have better things to do than to read your work.
- Keep it short and to the point.

The abstract

The physical meaning of charge extraction by linearly increasing voltage transients from organic solar cells

Robert Hanfland,^{1,2,3} Martin A. Fischer,¹ Wolfgang Brütting,² Uli Würfel,^{1,4} and Roderick C. I. MacKenzie^{3,5(a)}

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Carrier mobility in organic solar cells is almost exclusively determined with the Charge Extraction by Linearly Increasing Voltage (CELIV) technique; indeed much of our understanding of the recombination and charge transport mechanisms in organic solar cells is based on CELIV measurements. However, since the conception of the CELIV method, our understanding of organic semiconductors has significantly advanced. In this work, we critically examine the CELIV methods ability to provide accurate material data in the light of recent advances in our understanding of trap states and their influence on mobility in organic semiconductors. We then apply this knowledge to understand the mechanisms responsible for degradation in organic solar cells. © 2013 AIP Publishing LLC. [<http://dx.doi.org/10.1063/1.4818267>]

- Keep the abstract short.
- 200-300 words.
- It should be about the level of a first year undergraduate course so almost anyone can understand what is in the paper.
- It should outline the key findings.
- Not too technical.



<https://www.youtube.com/watch?v=ys8wHUPd6Vo&t=905>

The introduction: Paragraph 1

Organic solar cells offer the potential of a low-cost,¹ low-carbon source of electricity. Within the last five years, power conversion efficiencies have increased from 3%² to over 10%³ today. However, to further increase energy conversion efficiencies, a larger proportion of the photogenerated charge carriers need to reach the contacts of the cell.⁴ To achieve this, the lifetime (τ) and the mobility (μ) of the materials charge carriers must be maximized.⁴ Researchers often use the Charge Extraction by Linearly Increasing Voltage (CELIV)^{5,6} method to measure mobility^{7,8} within research devices to guide both device and material development. However, since Juska^{5,6} first pioneered the CELIV method, our understanding of organic semiconductors has considerably improved.^{9,10} In particular, our understanding of charge transport in these material systems has considerably developed.¹¹ In this letter, we examine the underlying theoretical assumptions made by Juska⁶ in the derivation of the CELIV measurement technique and hold them up to scrutiny against today's knowledge of organic semiconductor materials.⁹ The ability to accurately measure mobility in organic semiconductors is essential if the material systems used in organic solar cells are to continue to be developed.

In Juska's⁵ original paper, he derived the now well known equation to extract mobility from CELIV transients,

$$\mu = \frac{2}{3} \frac{d^2}{A t_{\max}^2 \left(1 + 0.36 \frac{\Delta j}{j(0)}\right)}, \quad (1)$$

where, A describes the ramp rate (V/s) of a negative triangular voltage function applied to the cell; this voltage ramp usually starts at around 0 V and decreases to typically -1 V to -5 V of applied bias within 10–20 μ s; d is the thickness of the device; $\Delta j/j(0)$ is the ratio of the current due to charge

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- Accessible to everyone, and should outline the problem in very general terms.
- Why care about solar cells?
- Why should I care about what you are writing about?

The introduction: Paragraph 2

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- Introduce the general problem/area that you are going to solve.

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- Explain to an expert in the field why this is important.
- But still keep the language simple and to the point.
- Cite retentive literature.

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- This section of the paper should be littered with references to show that you have read other peoples work and understand what you are talking about.

Experimental method (Or methods section)

- Describe what you did in the experimental method.
- You must include enough detail so someone can repeat your experiment
- Here's the catch.... People don't like reading experiential sections they are boring!
- So describe what you did in really brief terms. Maybe a paragraph or two.
- Then put the rest of the text in the supplementary information (SI).

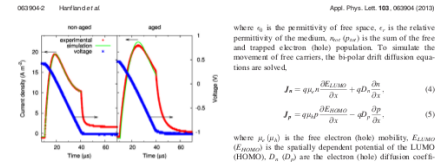


FIG. 1. Experimental CELV measurements (a) a non-appl cell and (b) a cell appl for 1776 h using a UV source equivalent to a square at 1 Sun at 45 °C with a relative humidity of 6%.

zero. Thus, we must ask if the mobility of the material in the device is changing during the measurement, how does this effect our value of mobility as measured by the CELV method?

Finally, the CELV method was derived for a material system where one material had a very low mobility and the other carrier species had a high mobility. However, due to improved polymers,¹⁰ today's high efficiency devices have more balanced mobilities and it is not clear that one carrier remains immobile and that CELV theory holds. In the following pages, we address these questions using a combination of experimentation and theory; the result is a better understanding of how CELV transients can be interpreted.

Inverted hole-transporting devices were fabricated with a C60/PCPDTBT/PCBM/PEOP/PS/Ag and structure.¹⁰ Poly(3-hexylthiophene-2,5-diyl) (P3HT) and poly(9,9'-dioctylfluorene-co-benzofuran) (PFB) were used in a weight ratio of 1:0.67. The active and poly(3,4-ethylenedioxythiophene) poly(phenylenevinylene) (PEDOT/PSS) (90nm) layer were deposited by spin coating. The metal grid was thermally evaporated. Devices were annealed at 130 °C for 10 min. Cell aging was performed using a UV source equivalent to 1 sun under AM 1.5G radiation at 45 °C with a relative humidity of 6% for 1776 h. The resulting CELV transients before and after aging are plotted in Figure 1. By applying Eq. (1) to the experimental data, a mobility of $9.5 \times 10^{-6} \text{ m}^2 \text{ V}^{-1} \text{ s}^{-1}$ before the cell is aged is obtained, and a decreased mobility of $2.5 \times 10^{-6} \text{ m}^2 \text{ V}^{-1} \text{ s}^{-1}$ after aging is obtained.

Before attempting to understand the change in measured mobility upon degradation, we first use our device model to better understand the physical mechanisms which can alter CELV transients. To model CELV transients from an organic solar cell, we use an effective medium approximation where the LUMO level of the fullerene is taken as the electron mobility edge and the HOMO level of the polymer is taken as the hole mobility edge. To calculate the electric field profile within the device, Poisson's equation is solved in one dimension,

$$\frac{d}{dx} \left(\epsilon_0 \epsilon_r \frac{d\phi}{dx} \right) = q(n_{\text{free}} - p_{\text{free}}), \quad (3)$$

where ϵ_0 is the permittivity of free space, ϵ_r is the relative permittivity of the medium, n_{free} (p_{free}) is the sum of the free and trapped electron (hole) population. To simulate the movement of free carrier, the bipolar drift-diffusion equations are solved,

$$J_n = q\mu_n n \frac{d\phi}{dx} + qD_n \frac{dn}{dx}, \quad (4)$$

$$J_p = -q\mu_p p \frac{d\phi}{dx} - qD_p \frac{dp}{dx}, \quad (5)$$

where μ_n (μ_p) is the free electron (hole) mobility, D_{LUMO} (D_{HOMO}) is the spatially dependent potential of the LUMO (HOMO), D_n (D_p) are the electron (hole) diffusion coefficients. Conservation of particles is forced using the carrier conservation equations and to describe carrier trapping and recombination we use the Shockley-Read-Hall model.¹¹ The carrier traps are defined as an exponential distribution of states,

$$g^{\pm}(E) = N^{\pm} \exp(-E/E_{\text{tr}}^{\pm}), \quad (6)$$

where N^{\pm} are the electronic trap densities at the LUMO and HOMO edge, E_{tr}^{\pm} are the characteristic electrostatic tail slope energies and E is the distance from the LUMO/HOMO edge. A full list of device parameters are given in the supplementary information,¹² parameters were chosen to be symmetric and to be close to those already reported in the literature.¹⁰

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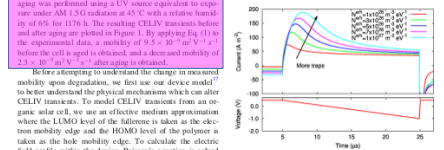


FIG. 2. The influence of carrier trap states on the CELV transient. It can be seen that the density of trap states can shift the position and magnitude of the transient. The CELV method gives the mobility of the carrier with a trap density of $1 \times 10^{16} \text{ m}^{-3}$ as $1.1 \times 10^{-6} \text{ m}^2 \text{ V}^{-1} \text{ s}^{-1}$, and the mobility of a carrier with trap density of $1 \times 10^{17} \text{ m}^{-3}$ as $3.0 \times 10^{-6} \text{ m}^2 \text{ V}^{-1} \text{ s}^{-1}$.

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DOI: <http://dx.doi.org/10.1063/1.4818267>

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• Some people/journals like to separate out the results section and the discussion of the results section.

• I don't.

The physical meaning of charge extraction by linearly increasing voltage transients from organic solar cells

Robert Hartsell,^{1,2} Martin A. Fischer,¹ Wolfgang Brütting,¹ Uli Würfel,^{1,4} Franko Büchel,¹ and Jürgen Salbeck,¹ ¹ Fraunhofer Institute for Solar Energy Systems, Heilbronner Str. 7, 91054 Erlangen, Germany ²Department of Physics, University of Warwick, Coventry, CV4 7AL, UK ³University of Applied Sciences, 39 78084 Freiburg, Germany ⁴Maxwell Research Centre University of Freiburg, Stefan-Meier-Str. 21, 78084 Freiburg, Germany ⁵Faculty of Engineering, University of Nottingham, Nottingham NG7 2RD, United Kingdom (Received 3 May 2013; accepted 24 July 2013; published online 9 August 2013)

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where d describes the ramp rate (V/s) of a negative triangular voltage function applied to the cell; this voltage ramp usually starts at around 0V and decays to typically $-1V$ to $-5V$ of applied bias within 10 – $20 \mu s$ at the timescale of the device; A_{eff} is the ratio of the current due to charge

¹United Kingdom; ²China; ³Malaysia

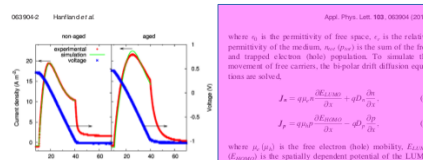


FIG. 1. Experimental CELIV transient (at a non-aged cell and at a cell aged for 175h) using a 1V source equivalent to equation (1) at a 43 °C with a relative humidity of 65%.

where μ_e (μ_h) is the free electron (hole) mobility, E_{LUMO} (E_{HOMO}) is the spatially dependent potential of the LUMO (HOMO), D_e (D_h) are the electron (hole) diffusion coefficients. Conservation of particles is enforced using the carrier conservation equations, and to describe carrier trapping and recombination we use the Shockley Read Hall model.¹⁴ The carrier traps are defined as an exponential distribution of sites,

$$N_t(D) = N_t^0 \exp(-E/E_t^0) \quad (6)$$

where N_t^0 is the electronic trap density at the LUMO and HOMO edge, E_t^0 is the characteristic electronic trap charge energy and E is the distance from the LUMO/HOMO edge. A full list of device parameters are given in the supplementary information,¹⁵ parameters were chosen to be symmetric and to be close to those already reported in the literature.¹⁶ If Eq. (1) is a measure of free carrier mobility as described by Jaska in his derivation, then the density of carrier traps should not affect the shape of the CELIV transient. To test Jaska's approximation, Figure 2 plots free simulated CELIV transients with all device parameters held constant except for the carrier trap densities. It can be seen that an increase in the density of carrier traps not only increases the magnitude of the CELIV peak, but also shifts the CELIV peak to the right. If one uses Eq. (1) to extract the mobility, we obtain values of 1.1×10^{-4} to $3.6 \times 10^{-4} m^2 V^{-1} s^{-1}$. Thus, we can determine from this

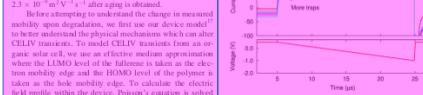


FIG. 2. Influence of carrier trap states on the CELIV transient. It can be seen that the density of trap states can shift the position and magnitude of the transient. The CELIV method gives the mobility of the carriers with a ramp density of $1 \times 10^6 V s^{-1}$ at $1 \times 10^{-4} m^2 V^{-1} s^{-1}$ using the mobility of carrier with a trap density of 1×10^{15} to $1 \times 10^{17} cm^{-3}$.

$$\frac{d}{dt} \left(\frac{d}{dt} n + \frac{d}{dt} p - j_0 \right) = 0 \quad (7)$$

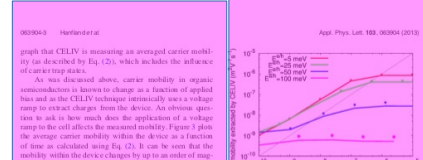


FIG. 3. Influence of the voltage ramp rate on the average mobility. The mobility is calculated with Eq. (2). The black dots show the CELIV method, the red circles show the mobility of the carriers with a ramp density of $1 \times 10^6 V s^{-1}$ at $1 \times 10^{-4} m^2 V^{-1} s^{-1}$ using the mobility of carrier with a trap density of 1×10^{15} to $1 \times 10^{17} cm^{-3}$.

where μ_e (μ_h) is the free electron (hole) mobility, E_{LUMO} (E_{HOMO}) is the spatially dependent potential of the LUMO (HOMO), D_e (D_h) are the electron (hole) diffusion coefficients. Conservation of particles is enforced using the carrier conservation equations, and to describe carrier trapping and recombination we use the Shockley Read Hall model.¹⁴ The carrier traps are defined as an exponential distribution of sites,

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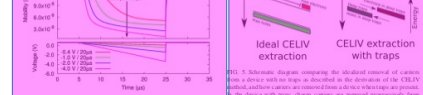


FIG. 4. Influence of the voltage ramp rate on the average mobility. The mobility is calculated with Eq. (2). The black dots show the CELIV method, the red circles show the mobility of the carriers with a ramp density of $1 \times 10^6 V s^{-1}$ at $1 \times 10^{-4} m^2 V^{-1} s^{-1}$ using the mobility of carrier with a trap density of 1×10^{15} to $1 \times 10^{17} cm^{-3}$.

where μ_e (μ_h) is the free electron (hole) mobility, E_{LUMO} (E_{HOMO}) is the spatially dependent potential of the LUMO (HOMO), D_e (D_h) are the electron (hole) diffusion coefficients. Conservation of particles is enforced using the carrier conservation equations, and to describe carrier trapping and recombination we use the Shockley Read Hall model.¹⁴ The carrier traps are defined as an exponential distribution of sites,

$$N_t(D) = N_t^0 \exp(-E/E_t^0) \quad (6)$$

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FIG. 5. Schematic diagram comparing the idealised removal of carriers from a device with traps as described in the derivation of the CELIV method, with an applied voltage as compared to a device with traps as present. In the device with traps, charge carriers are removed progressively from deeper and deeper traps across the device. Thus the transient (red) peak is CELIV theory becomes poorly defined. Also, CELIV assumes that only mobile charge carriers (free charge) contribute to the current, but free holes (black) also contribute to the current.

• I tend to merge the results/discussion into an interesting story.

Conclusions

- 1 Paragraph max
- Summarize the key results

In conclusion, we have applied a modern model and understanding of organic semiconductors in combination with experiments to evaluate a method of experimentally measuring mobility originally proposed by Juska. We concluded that; (a) carrier trap states change the shape of the CELIV transient significantly; (b) the CELIV measurement itself changes the average carrier mobility by up to 50%; (c) the mobility as measured by CELIV can provide a good estimate to the mobility of the most mobile charge carrier for ordered materials, however, for materials with a high density of trap states, the estimate may be less reliable. For typical organic solar cells the accuracy of CELIV is within one or

- Keep it short, punchy, and tell the reader what you found out. Don't tell the reader again what you did.

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becomes ill defined and CELIV becomes less accurate. Organic solar cells often have mobilities ranging from 1×10^{-6} to $1 \times 10^{-8} \text{ m}^2 \text{ V}^{-1} \text{ s}^{-1}$ and tail slopes from 30 mV to 70 mV, thus we would expect CELIV to be accurate to within two orders of magnitude. See the supplementary information for a more detailed analysis of this process. * Also included in the supplementary information are investigations into how asymmetric mobilities affect CELIV transients. We find that CELIV tends to measure the mobility of the most mobile charge carrier and asymmetric mobilities do not cause a double peak in the measured current.

From the above discussion, it is clear that both free carrier mobility and the density/distribution of trap states are key parameters in defining the shape of CELIV transients. This brings us back to the question of how to understand the degradation data in Figures 1(a) and 1(b). To understand what the aging process is physically doing to our cell, the numerical model was fit simultaneously to the CELIV transient from the non-degraded cell in Figure 1(a) and the light and dark IV curves. To perform the fit, mobility, trap densities, tail slope energies were allowed. After the model was calculated, we were able to fit the aged experimental data by only further adjusting the carrier trap densities, we can therefore say during the aging process additional trap states are generated within the material (possibly due to the introduction of water and oxygen) and although CELIV measurements could be interpreted to suggest the free carrier mobility, as being a part of this is not necessarily the case.

In conclusion, we have applied a modern model and understanding of organic semiconductors in combination with experiments to evaluate a method of experimentally measuring mobility originally proposed by Juska. We concluded that: (a) carrier trap states change the shape of the CELIV transient significantly; (b) the CELIV measurement itself changes the average carrier mobility by up to 50%; (c) the mobility as measured by CELIV can provide a good estimate to the mobility of the most mobile charge carrier for ordered materials, however, for materials with a high density of trap states, the estimate may be less reliable. For typical organic solar cells the accuracy of CELIV is within one or

two orders of magnitude. We demonstrate that the change to the CELIV transient upon aging can be explained by the formation of trap states.

We are grateful for access to the University of Nottingham High Performance Computing Facility.

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These are not conclusions

- “All objectives were achieved” - the reader does not care.
- “The work was a success” - leave that up to the reader to decide.
- “We performed measurements on 100 solar cells” - no one cares.
- “We had highly efficient devices” - let the reader decide.

Lecture outline

- The process of knowledge dissemination
- What's the point of references
- Clarity of writing
- Good figures and graphs.
- How to write a scientific paper
- **How to write a scientific report**
- How to write a thesis.
- How to do a literature review.
- Abstract/Method/Discussion/Conclusion
 - Abstract/Introduction/Results/Discussion/Conclusios

Lab reports

Generally lab reports take the same form as a paper:

- **Title**
 - Obvious ✓
 - **Abstract**
 - We have discussed this ✓
 - **Introduction**
 - We have discussed this ✓
 - **Methods**
 - This is what you did. i.e. your method used for doing the experiment
 - **Results** ✓
 - We have discussed this
 - **Discussion** ✓
 - We have discussed this
 - **Literature cited** ✓
 - We have discussed this
-
- You do generally however have more space in a lab report and they are in general more relaxed. You don't necessarily have to use so many references
 - They are generally under 10 pages long and in size 12 text with diagrams/pictures/equations.

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- How to write a scientific report
- **How to write a thesis**
- How to do a literature review.

How to write a thesis

You guessed it the structure is pretty much the same:

+ indicates that the chapter can span multiple chapters.

- 1 page: **Title**
 - 1 page: **Abstract**
 - Chapter 1: **Introduction**
 - Chapter 2+: **Methods**
 - Chapter 3+: **Results**
 - Chapter 4: **Discussion**
 - Chapter 5: **Conclusion**
-
- So now you really know how to write any type of scientific document!

Your go

- Write a mini paper with a few sentences in each section.
- With one figure.
- I will come around and give you feedback.
- This should only take 5 min.



<https://www.youtube.com/watch?v=UtHMeJUKdo>

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Literature review

- *What is a literature review?*
 - It is a **summary** of all the **key literature** published **in a field**.
 - *Why write a literature review?*
 - To show your reader (your supervisor) that you have read, and understand the main published works in your field.
 - They are also very useful to read if you are just getting into a field (They are sometimes called **review articles**).
- Coursework 1: will be to write a 3000 word (minimum) literature review on the topic of your MSc project.
 - Due date on the last day of this term (Friday 7th April).

Literature review

- **What a literature review should not be:**
 - A description of what others have published in the form of a set of summaries
- **What should a literature review be:**
 - It should be a critical discussion, showing insight and an awareness of differing arguments, theories and approaches.
 - It should analyze of the relevant published work, linked at all times to your own purpose and rationale.

According to Caulley (1992) of La Trobe University:

- Compare and contrast different authors' views on an issue
- Group authors who draw similar conclusions
- Criticise aspects of methodology
- Note areas in which authors are in disagreement
- Highlight exemplary studies
- Highlight gaps in research
- Show how your study relates to previous studies
- Show how your study relates to the literature in general
- Conclude by summarising what the literature says

The purposes of the review are:

- To define and limit the problem you are working on
- To place your study in an historical perspective
- To avoid unnecessary duplication
- To evaluate promising research methods
- To relate your findings to previous knowledge and suggest further research

In summary: A good literature review, therefore, is critical of what has been written, identifies areas of controversy, raises questions and identifies areas which need further research.

How to write a literature review:

- You will need to group together, compare and contrast the varying opinions of different writers on certain topics.
- What you must not do is just describe what one writer says, then describe what the next writer says and so on ...
- Your structure should be dictated instead by topic areas, controversial issues or by questions to which there are varying approaches and theories. Within each of these sections, you would then discuss what the different literature argues, remembering to link this to your own purpose.
- If there is disagreement in the field, you need to indicate clearly that you are aware of this.
- At the end of the review you should include a summary of what the literature implies.

- Decide what you need to read, your supervisor may suggest one or two good papers to start with.
- Before you start reading it may be useful to compile a list of the main areas and questions involved, this list may change as you read.

Make sure that:

- You include a clear, short introduction which gives an outline of the review, including the main topics covered and the order of the arguments, with a brief rationale for this.
- Split your review up into relevant subsections based around topics in your field.
- Include a short summary at the end of each section.
- You always acknowledge opinions which do not agree with.
- If you ignore opposing viewpoints, your argument will in fact be weaker.

How to get started!

- When I'm learning about a new topic I try to find **easy to understand** things first.
- I always **start** with Wikipedia and general articles on the web (for an hour or so)
- I then use scholar.google.com to search for key words and try to identify key papers which look interesting.
- Then, try also to identify key people or groups working on a topic and find what they are doing.
- Figure out who you respect in a field and who you don't respect.
- Follow references at the bottom of papers.

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