CENTER FOR SUSTAINABLE ENERGY AT NOTRE DAME

Photovoltaics, Perovskite and Project Based Learning

Research Experiences for Teachers: Engineering a More Sustainable Energy Future

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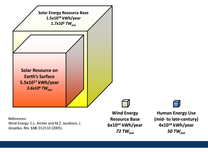
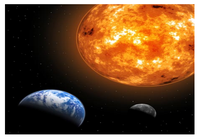
Introduction

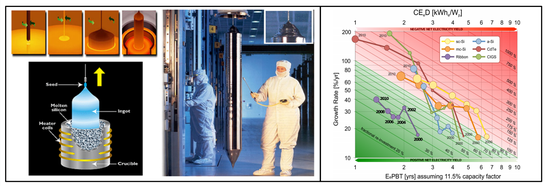
Global energy demands are projected to double in the next 30 years. Scientists are looking into alternative renewable sources of energy. Solar is the most likely candidate among renewable energies because it is the only source that can meet the demands for global energy consumption. While silicon-based photovoltaic [PV] devices have led the way for decades, in most cases, their clean room / high temperature manufacturing processes yield an energy deficiency for at least a decade after installation. Low cost, low temperature, bench top alternatives are needed.





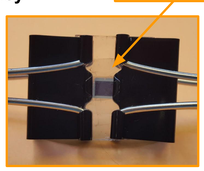
Problem - Choosing Photovoltaic Devices and the Science Behind the Choice

- **Silicon-Based - Too Costly**
  - **High Abundance vs. Purity Issues**
  - **High Fabrication and Energy Costs**

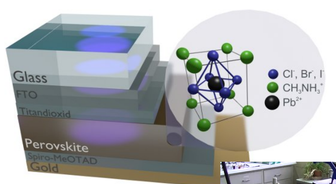


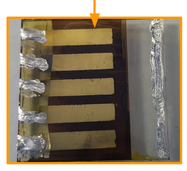
- **Dye-Sensitized Cells**
  - **Easy to Manufacture**
  - **Low Stability and Low Efficiency**

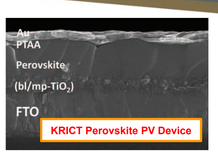
Made in ND Rad Lab



- **Perovskite**
  - **Low Temperature and Low Cost**



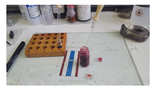




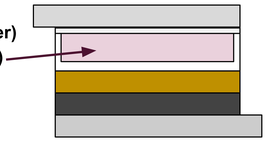
Materials and Methods

- **Manufacture Dye-Sensitized and Perovskite Solar Cells in Low-Temp / BenchTop Environment**
- **Compare Results to Recent Efficiency Trends**

Construct Dye-Sensitized Cell With Blackberry Juice



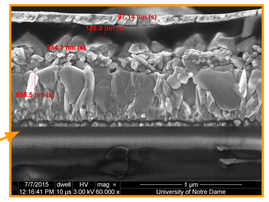
- **FTO**
- **TiO_2 (Blocking/Active/Scatter)**
- **Blackberry Juice (Absorber)**
- **Electrolyte Solution**
- **Graphite**
- **FTO**



Construct Perovskite

- **Au (Counter Electrode)**
- **Spiro-MeOTAD**
- **Perovskite ($CH_3NH_3PbI_3$)**
- **TiO_2 (Blocking/Mesoporous)**
- **FTO / Indium (Electrode)**

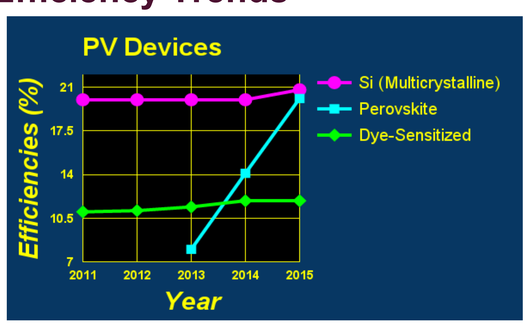
Perovskite Cell Image by ND (400 FESEM) Magellan Electron Microscope



Collect Data and Calculate Fill Factors and Efficiencies

- **JV Curves were measured using a solar simulator at 100mA/cm^2 illumination AM 1.5 G (Cell size ~ 0.12 cm^2)**
- **Fill Factor = (V_{max} * J_{max}) / (V_{oc} * J_{sc})**
- **Efficiency = (V_{oc} * J_{sc} * FF)**

Efficiency Trends



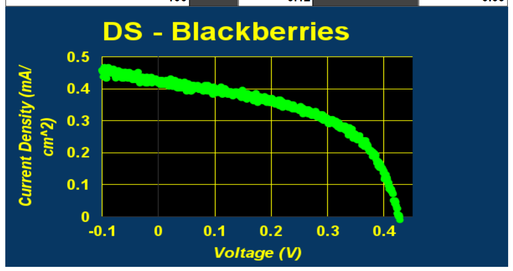
- **Perovskite - KRICT 20.1% - 2015 (Theoretical Limit ~ 31.4%)**
- **Dye-Sensitized devices seemed to have plateaued**
- **Perovskite could catch silicon (Si) efficiencies**

Source: NREL

Results - Dye-Sensitized Cells

- **Blackberry Juice**
- **Ambient Conditions**

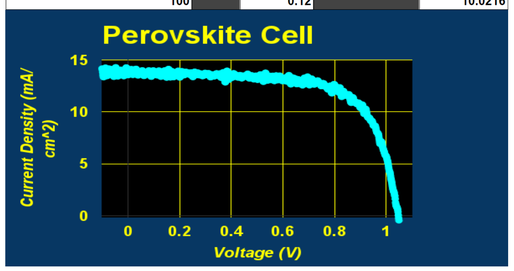
Max Power Density (mW/cm^2)	Voc (V)	Isc (A)	Ideal Power (mW)	Fill Factor (FF)
0.0944	0.4258	5.00488e-005	0.1776	0.5313
Jmp (mA/cm^2)		**Jsc**		
0.2747		0.4171		
Vmp (V)		**Pmax**		**Efficiency**
0.3435		0.0944		0.0009
Pin (mW/cm^2)		**Area (cm^2)**		**Efficiency (%)**
100		0.12		0.09



Results - Perovskite Cells

- **TiO_2/$CH_3NH_3PbI_3$/Spiro-MeOTAD/Au**
- **Mostly Ambient Conditions**

Max Power Density (mW/cm^2)	Voc (V)	Isc (A)	Ideal Power (mW)	Fill Factor (FF)
10.0216	1.0450	0.0017	14.5210	0.6901
Jmp (mA/cm^2)		**Jsc**		
11.7188		13.8957		
Vmp (V)		**Pmax**		**Efficiency**
0.8552		10.0216		0.1002
Pin (mW/cm^2)		**Area (cm^2)**		**Efficiency (%)**
100		0.12		10.0216



Conclusion

Silicon devices have reigned supreme for decades. However, these devices are manufactured in clean rooms at high temperatures for long time periods. A silicon device would need to produce energy for decades to make up for the energy used in its own creation. We have little impact on carbon emissions when we manufacture silicon devices. For this reason, a low temperature, low cost alternative is necessary.

Conclusion

In the lab, I was able to determine that perovskite cells did yield higher efficiencies than dye-sensitized cells. Current research has shown that in 6 short years, perovskite based devices have achieved efficiencies as high as 20.1 % (KRICT, 2015). Perhaps, these new devices will replace or be used in tandem with silicon based photovoltaic devices. However, efficiency is only half of the battle. Long term stability may also be an issue. Perovskite cells tend to degenerate over time.

Curriculum

Day	You will:	Classwork	Homework
1	Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.	Entry Event Select Groups Knows / Need to Knows	Read and Outline Chapter 15 Clipart and Figures
2	Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.	Entry Event - Static Charge Ch 15 p. 556 # 1, 7, 9, 11, 21, 39, and 45	Read and Outline Chapter 16 Clipart and Figures
3	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	Entry Event - Circuits Labs Ch 16 p. 591 # 1, 3, 21, 35	Read and Outline Chapter 17 Clipart and Figures
4	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	Entry Event - Ohm's Law Ch 17 p. 619 # 1, 7, 15. 35.	Read and Outline Chapter 18 Clipart and Figures
5	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	Entry Event - Conductivity Ch 18 p. 653 # 1, 3, 21, 31	Read and Outline Chapter 19 Clipart and Figures
6	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	Entry Event - Magnetism Ch. 19 p. 690 # 1, 5, 13, 19, 31, 49, and 51	Read and Outline Chapter 20 Clipart and Figures
7	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	Entry Event - Electromagnetism Ch. 20 p. 725 # 1, 17, 27	Read and Outline Chapter 21 Clipart and Figures
8	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	Entry Event - AC Circuits Ch 21 p. 748 # 1, 17, 29	Study for Electricity and Magnetism Test
9	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	Series v. Parallel Lab	Write Lab Report
10	Demonstrate mastery of Electricity and Magnetism	Electricity and Magnetism Test	Reflection – Engineering Read and Outline Chapter 22 Read and Outline Chapter 23
11	Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.	Entry Event - Reflection Ch 22 p. 774 # 1, 11, 43 Ch 23 p. 806 # 1, 11, 41	Photovoltaic Processes Read and Outline Chapter 24 Read and Outline Chapter 25
12	Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.*	Entry Event - Refraction Ch 24 p. 840 # 1, 17, 27 Ch 25 p. 871 # 1, 19, 39 Begin Posters	Study for Optics Test
13	Demonstrate mastery of Optics	Optics Test	Continue to work on poster
14 and 15	Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other	Make a Dye Sensitized Solar Cells Collect Data and Calculate Efficiency	Write a Lab Report Add Data to Poster
16	Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.*	Poster Session	

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Acknowledgements

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