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RESEARCH HIGHLIGHTS

+ From Caltech's Resnick Fellows

Towards Ultralight High Efficiency Solar Cells Using 2D Materials & Architectures

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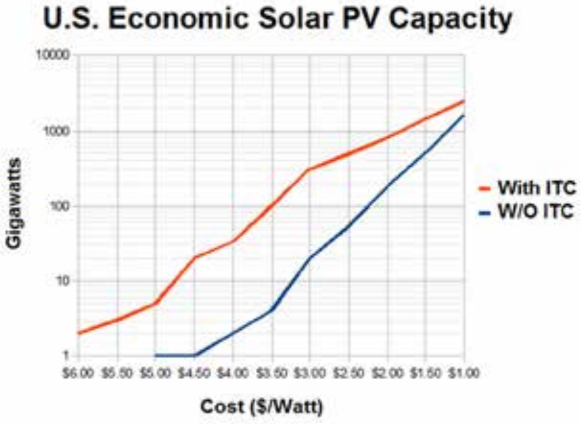
Global Significance

As the world continues to work towards a sustainable future, solar power is proving itself to be an important component of the energy landscape. Experts estimate that solar power could replace fossil fuels to become a primary energy source in some regions of the world, and it has already become highly competitive with traditional energy production in numerous places, including India, Hawaii, Italy, and Spain.

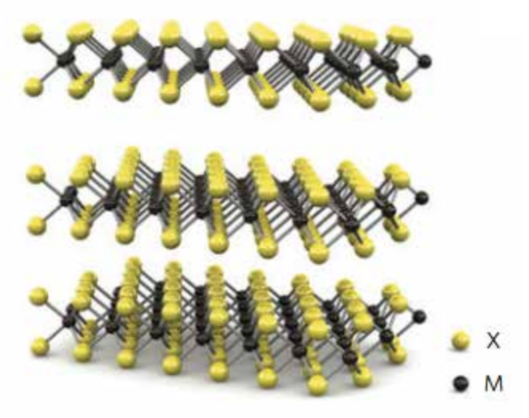
In order to truly challenge traditional methods of power generation, however, the costs associated with photovoltaics must continue to be pushed down in innovative new ways. To do this, there are two major goals: the first to decrease the cost to manufacture a photovoltaic cell, and the second to increase its efficiency (the amount of power that can be extracted from the cell relative to incident power from the sun).

We approach the problem through the exploration of new materials systems. 2-dimensional materials such as MoS_2 and WSe_2 are ideal candidates for cutting costs because they have the potential to make high efficiency solar cells, but with the lowest possible materials cost and weight: a single layer of atoms.

Part of the photovoltaic Senftenberg Solarpark in eastern Germany



Economic photovoltaic capacity vs installation cost in the United States with or without incentives



Typical transition metal dichalcogenide (TMDC) structure: M transition metal, X chalcogenide

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Project Summary

This project focuses on the use of novel 2D materials (MoS_2, WSe_2) for the design of light-weight, high efficiency solar cells. It addresses the challenge of light absorption: a very thin material cannot absorb 100% of light from the sun on its own; we need techniques referred to as 'light trapping' in order to capture every bit of incident energy to make an efficient device. Specifically, we use destructive interference effects to force all light to be absorbed in our solar cell

This project combines three fields:

1. Fundamental materials science to develop high quality samples of MoS_2 and WSe_2
2. Nanophotonics to designed nanoscale structures to improve light absorption
3. Device physics to fabricate and test a complete solar cell

By merging these fields, we investigate the unique physics that can be exploited in a novel, ultrathin materials system. We use tricks that are available to us because our solar cell material is infinitesimally thin, exploring not only a creative approach to enhancing absorption, but additionally characterizing a material that is not well understood within the scientific community.

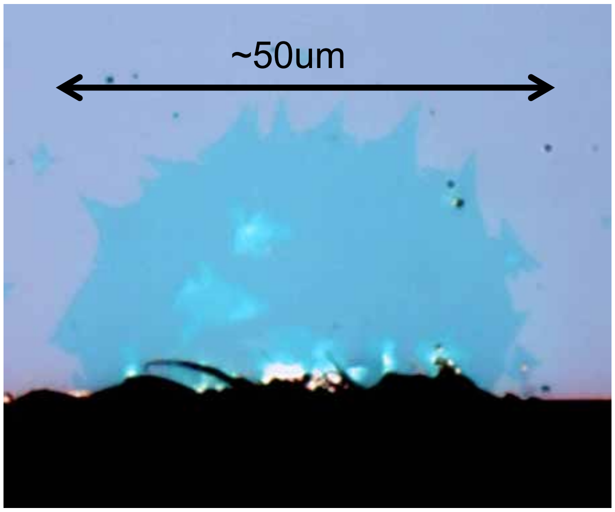
Potential Impact

Raw Materials Costs Savings

- Si: 50¢/gram
- Cost to grow MoS_2: ~40¢/gram
    - MoO_3: 40¢/gram, S: 14¢/gram
    - 70% yield + 10¢ for growth
    - **Active materials costs reduced by ~300x for equivalent power**

Transportation Cost Savings

- Average cost per ton-mile: 0.37¢
- **Reduced by ~100-1000x for 2D solar cells**



Monolayer MoS_2 on SiO_2 on Si

Material	Efficiency	Power Density (kW/kg)
GaAs	~29%	54
Si	20.6%	2.5
graphene/ $MoSe_2$	0.1-1%	250-2500

Comparison of power densities in common solar cell materials with MoS_2 system

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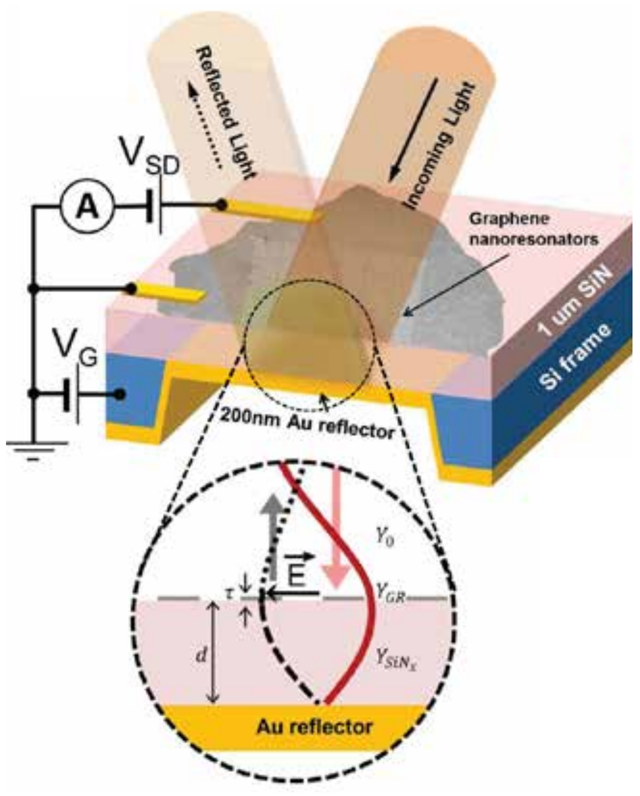
The Science

Materials growth is optimized by a fine tuning of pressure, temperature, and gas flow rates in a process known as Chemical Vapor Deposition for the growth of high quality monolayer MoS_2.

Light Trapping

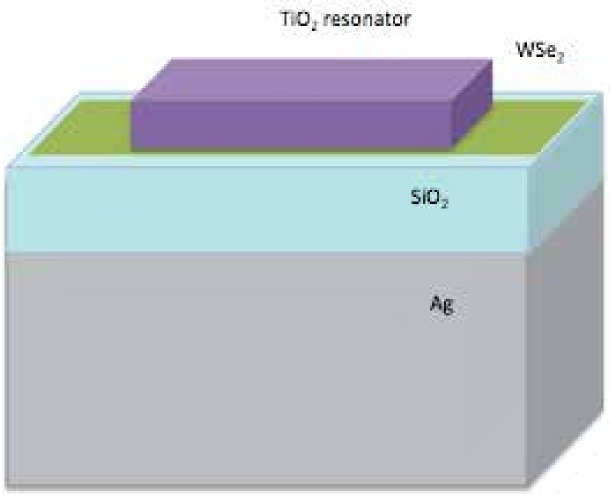
1. Resonators of a high index of refraction material, TiO_2, are fabricated on top of our 2D material (in this case, WSe_2). By patterning a resonator that has a width of ½ the wavelength of light we wish to absorb, we create an interference effect which traps all the light in the WSe_2. This leads to an enhancement of absorption in the photovoltaic material at a wavelength of choice.

2. We place our TiO_2 resonators on a thin layer of SiO_2, terminated with a Ag mirror. The additional confinement of the electric field that results from this second resonance further enhances the absorption in the WSe_2. By carefully tailoring the thickness of the SiO_2 layer, we can minimize the absorption in the Ag and maximize the absorption in our photovoltaic material.



Left: A Salisbury Screen is designed using graphene (another 2D material), and absorption of 24.5% is achieved

Below: A schematic of a resonant geometry for enhancement of absorption into WSe_2



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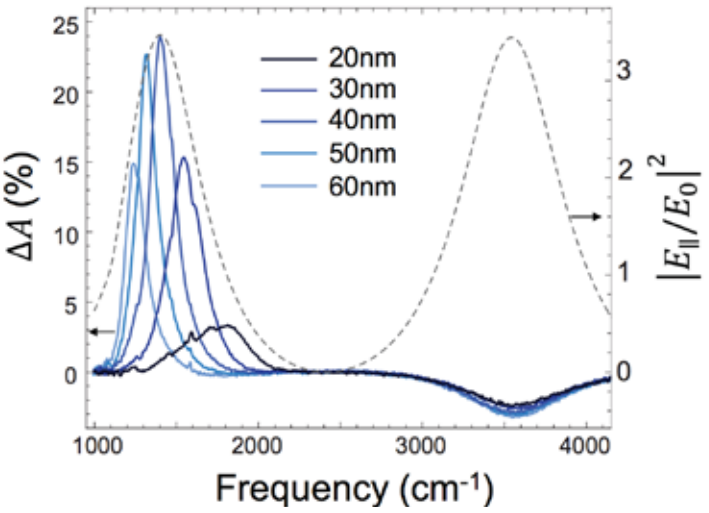
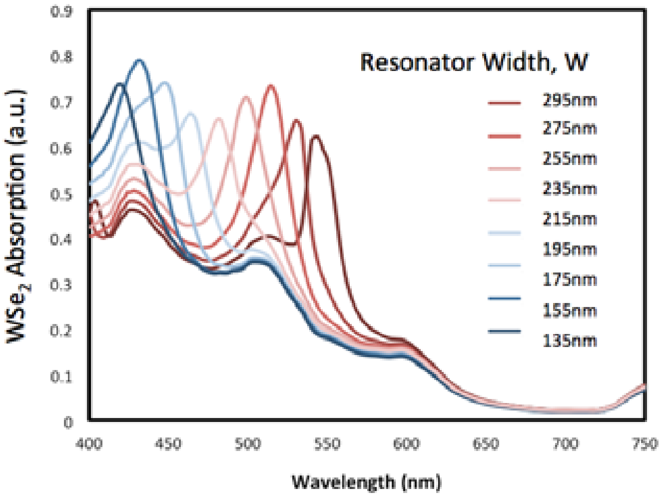
Key Results

Consistent growth of monolayer MoS_2 is demonstrated. Experimental demonstration of Salisbury Screen design is achieved in graphene, 24.5% absorption shown, with a pathway towards 100% outlined. Calculations show 70% absorption into WSe_2 is possible using resonant geometry over a broad range of wavelengths.



Experimental results showing 24.5% light absorption in graphene resonators for different sizes of ribbons. Corresponding maximized electric field shown in grey.



Computational results for varying widths of TiO_2 resonators, showing up to 80% absorption possible in monolayer WSe_2.

Future Steps

- Experimentally demonstrate resonant enhancement of absorption in WSe_2
- Fabricate complete WSe_2/Graphene solar cell

Publications

- Jang, Min Seok and Brar, Victor W. and Sherrott, Michelle C. et al. (2014) Tunable large resonant absorption in a midinfrared graphene Salisbury screen. Physical Review B, 90 (16). Art. No. 165409. ISSN 1098-0121. http://resolver.caltech.edu/CaltechAUTHORS:20141204-101624900
- Brar, Victor W, Jang, Min Seok, Sherrott, Michelle C., Lopez, Josue L, Atwater, Harry A. (2013) Highly Confined Tunable Mid-Infrared Plasmonics in Graphene Nanoresonators. Nano Lett.,13 (6), pp 2541–2547.