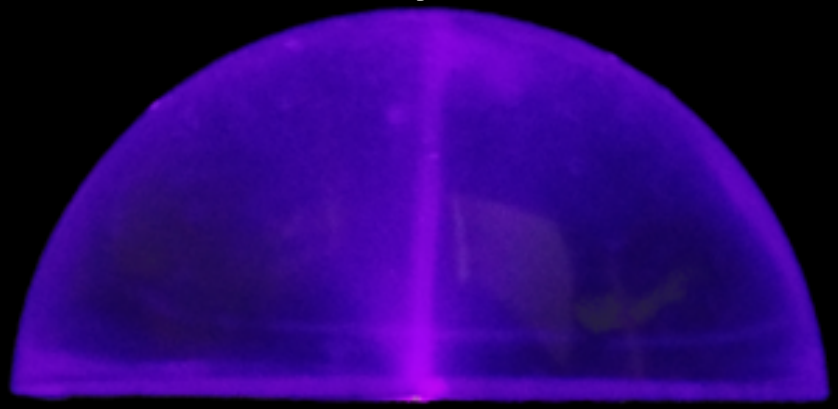
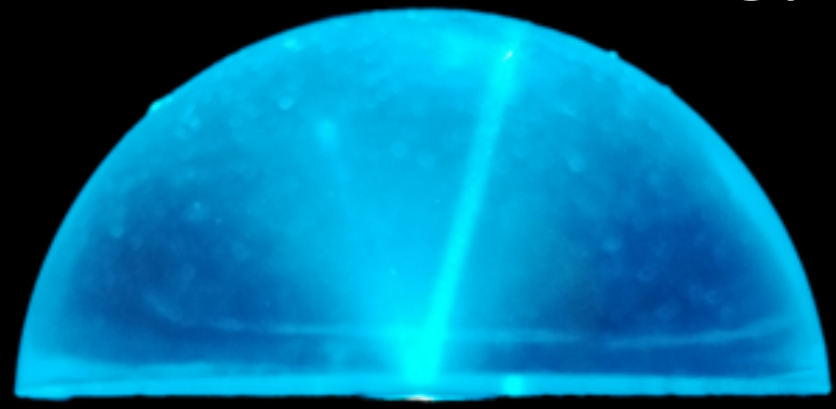
Laboratory of Solar and Quantum Technology

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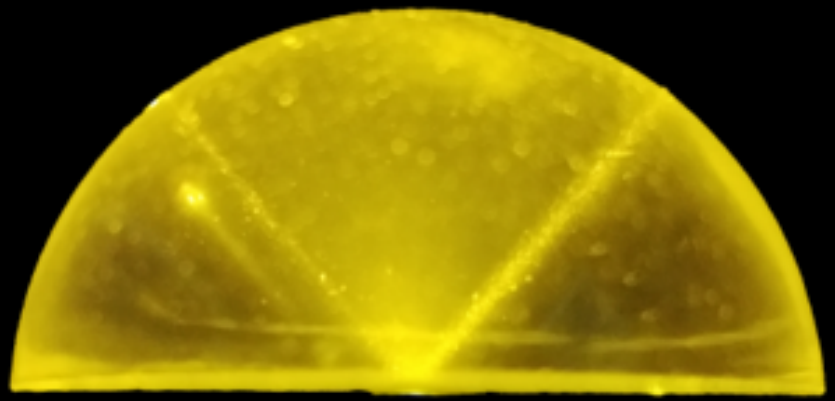
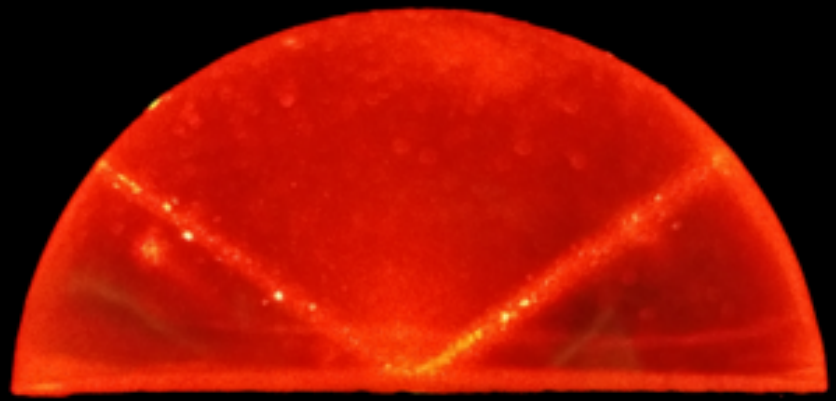
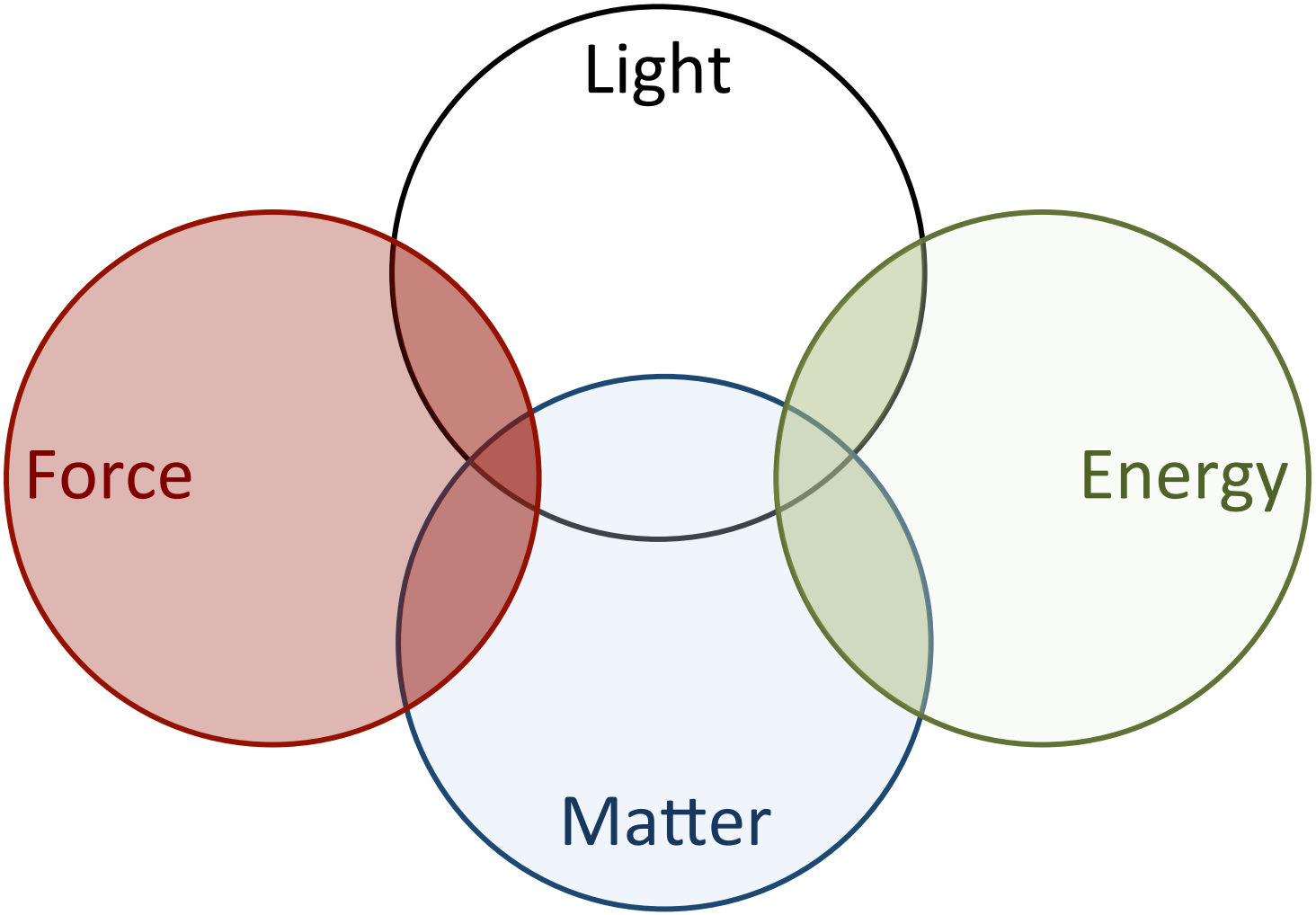
December 9, 2016

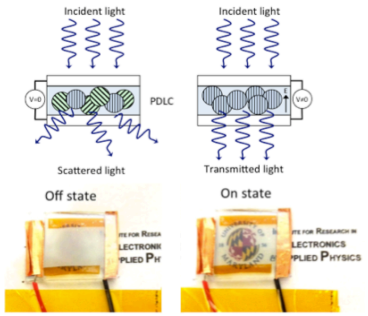



Laboratory of Solar and Quantum Technology

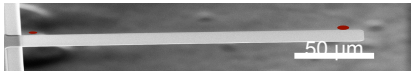


Laboratory of Solar and Quantum Technology

Space travel using radiation pressure



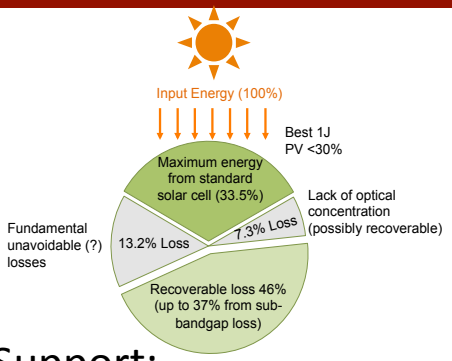
Can switchable optical materials propel and steer a space craft?



Support:

NASA NNX15AW53A

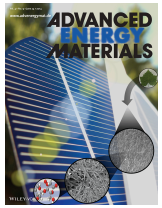
Solar energy

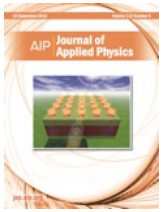


Can we use photonics to beat tradition efficiency limits of solar cells?

-bandgap shifting

-radiative emission modification and cooling



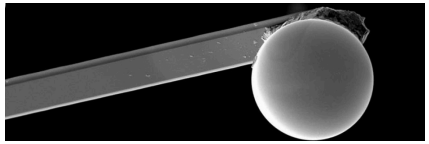


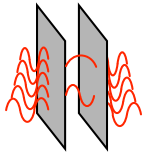
Support:

NSF CBET-1335857

Quantum fluctuations – forces and torques from *nothing*

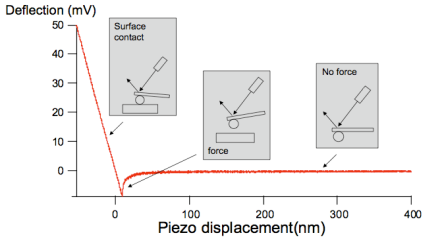
Can we manipulate the quantum fluctuations of vacuum to drive nanomachines?





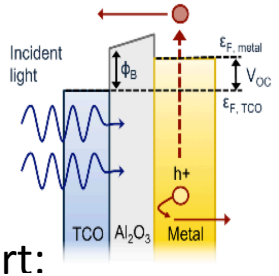
Support:

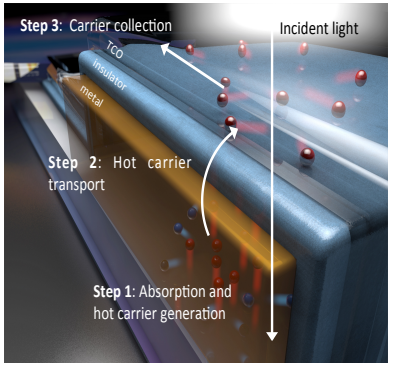
NSF AMO-1506047



Hot electron plasmonics

Can hot electrons be used to make novel devices?





Support:

NSF ECCS-1554503

ONR N00014-16-1-2540

Outline

- Active control of light trapping for a smart solar window

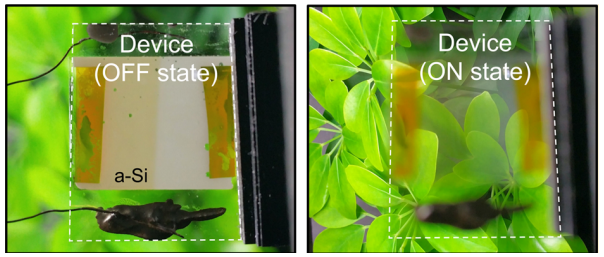
  Murray, Ma, and Munday *ACS Photonics* (in press 2017)
  DOI: 10.1021/acsphotonics.6b00518

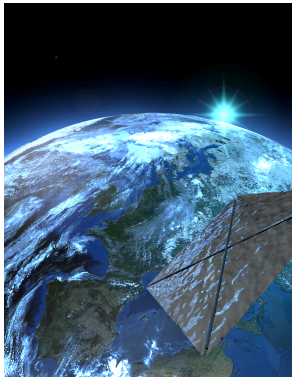
- Tunable radiation pressure for space propulsion

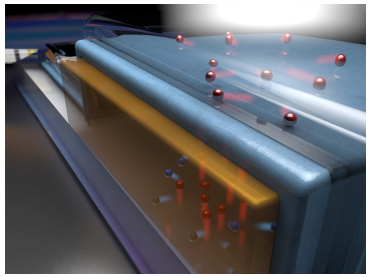
  Ma, Murray, and Munday *Advanced Optical Materials* (accepted 2017)

- Hot carrier detectors and energy converters

  Gong and Munday, *Nano Lett.* 15, 147–152 (2015)







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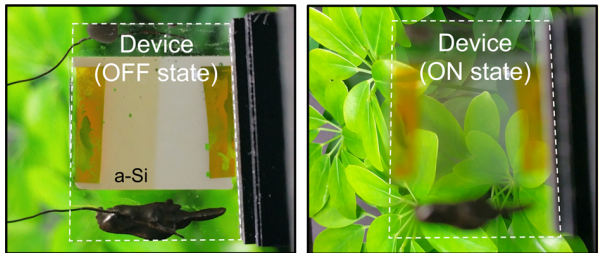
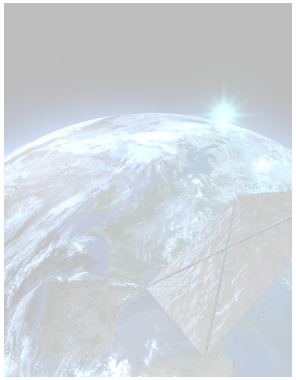
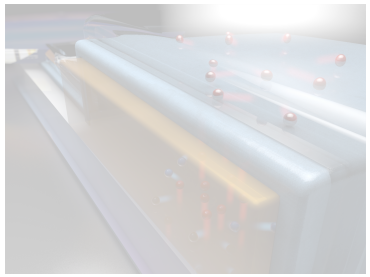
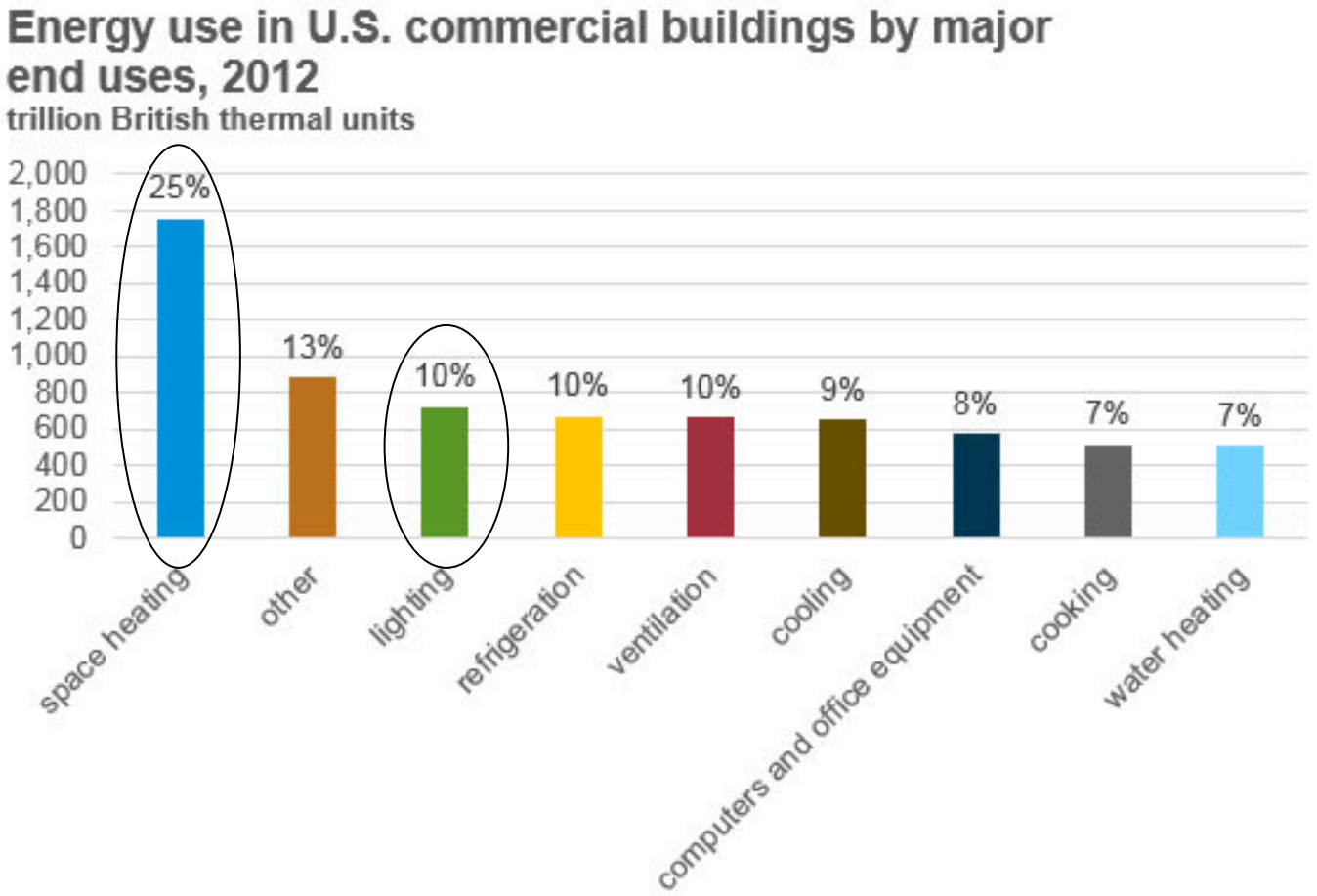






About 40% of total U.S. energy consumption is in residential and commercial buildings



Source: U.S. Energy Information Administration, *2012 Commercial Buildings Energy Consumption Survey: Energy Usage Summary*, Table 5 (March 2016)

Switchable solar windows

Electrochromic windows

Pros:

- Control external lighting
- Some control of heating

Cons:

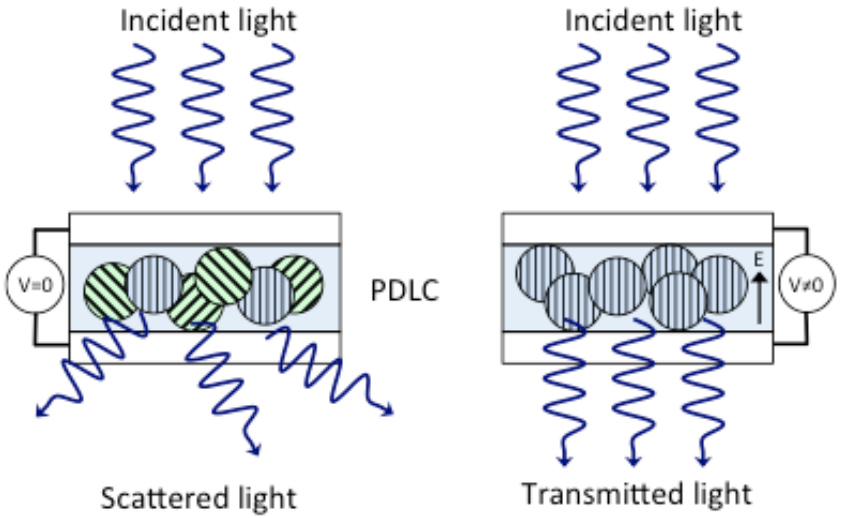
- Power consumption
- Absorptive: wastes energy
- No glare control

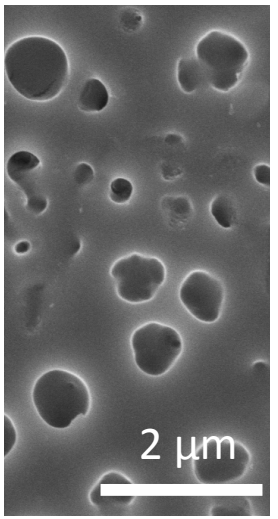
Polarized liquid crystal windows

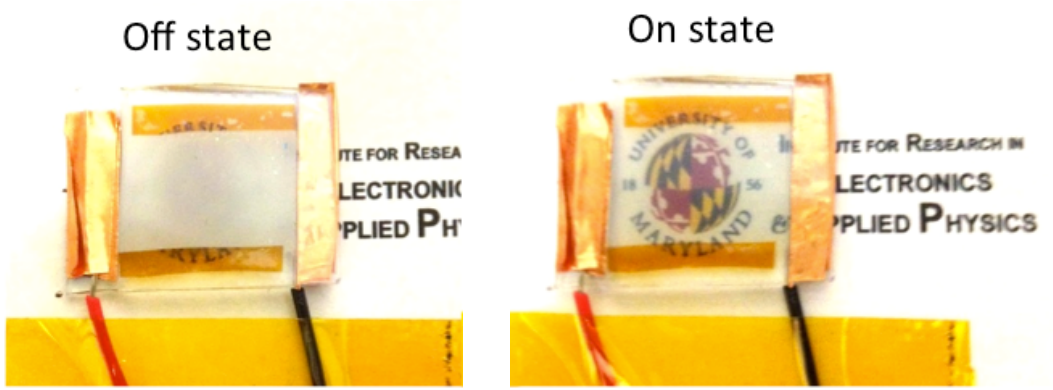
Semi-transparent solar cells

Polymer dispersed liquid crystals

- Mix of birefringent liquid crystals and polymer
- With no bias: randomly oriented by local fields and thermal energy
  - Scatter
- With bias: ordinary axes align to electric field
  - No scattering

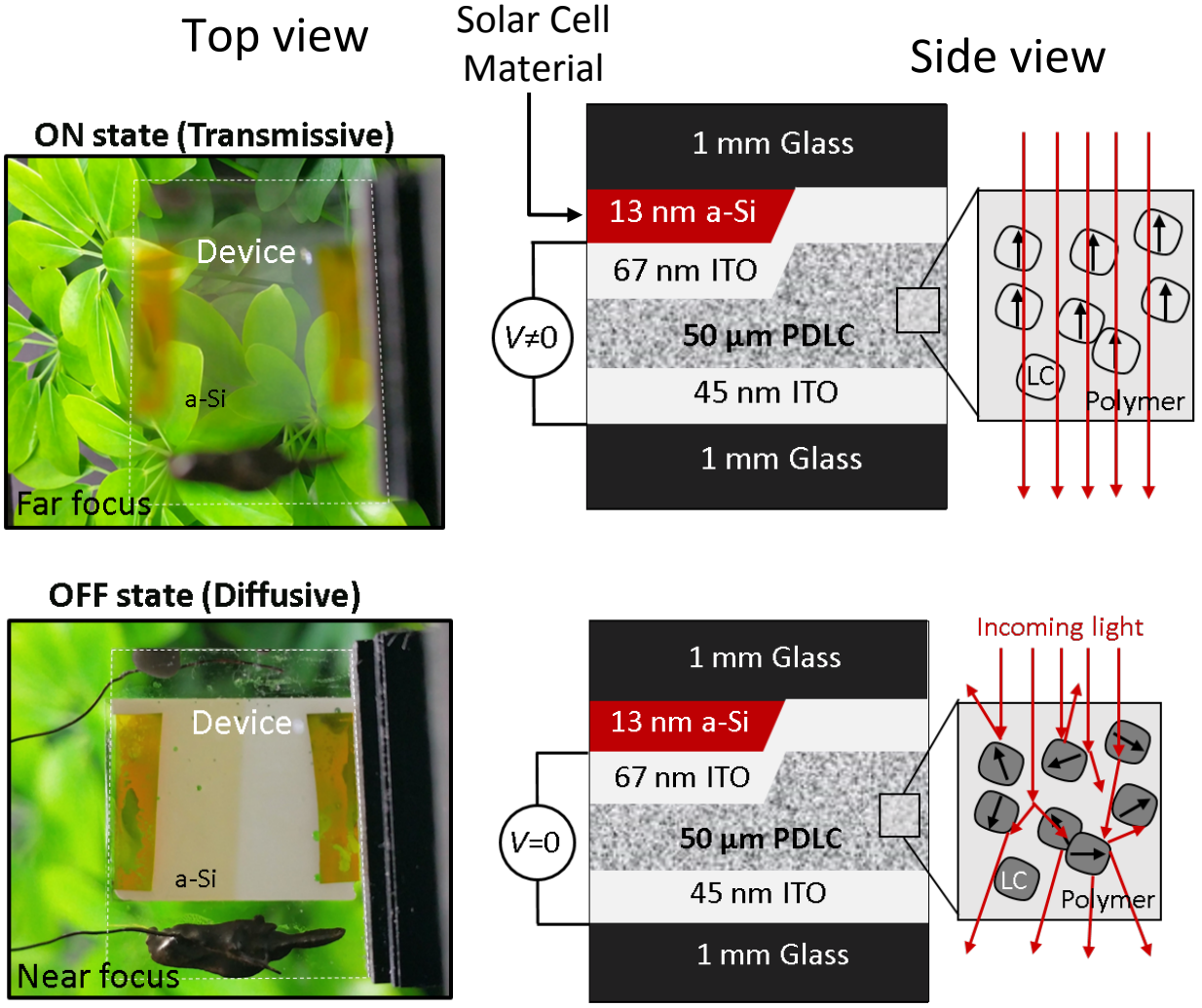






By incorporating an absorber, we can electrically modulate the light trapping.

Switchable light trapping for solar smart windows



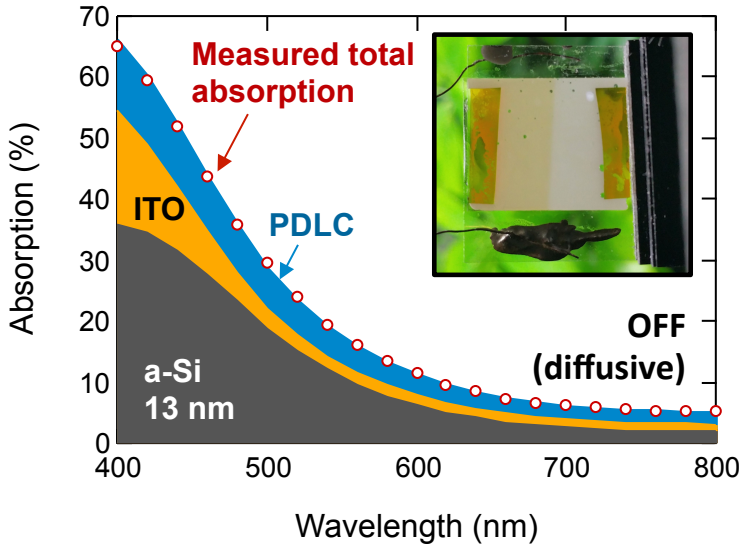
- "On state"
  - Clarity
- "Off state"
  - Efficient power generation
  - privacy, reduces radiative heating

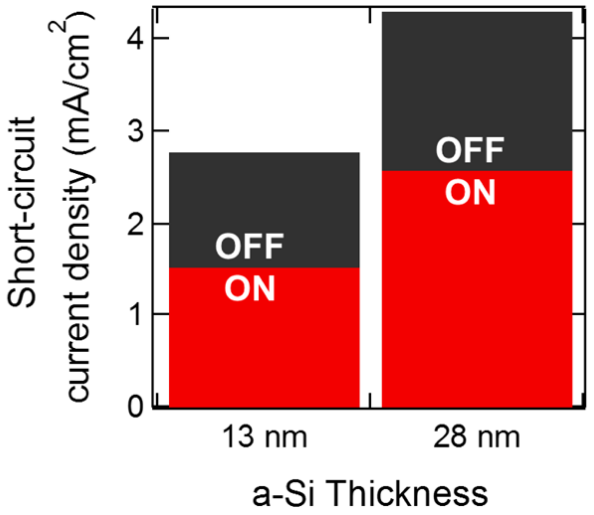
Murray, Ma, and Munday *ACS Photonics* (in press) DOI: 10.1021/acsphotonics.6b00518

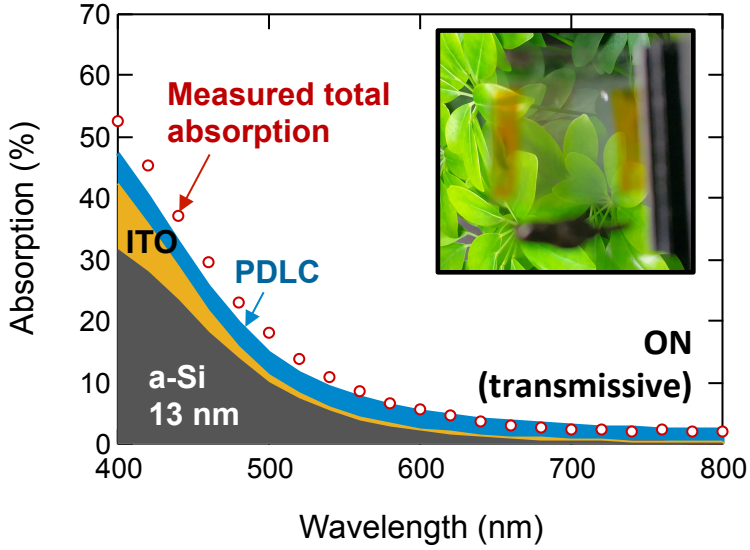
Video of switching

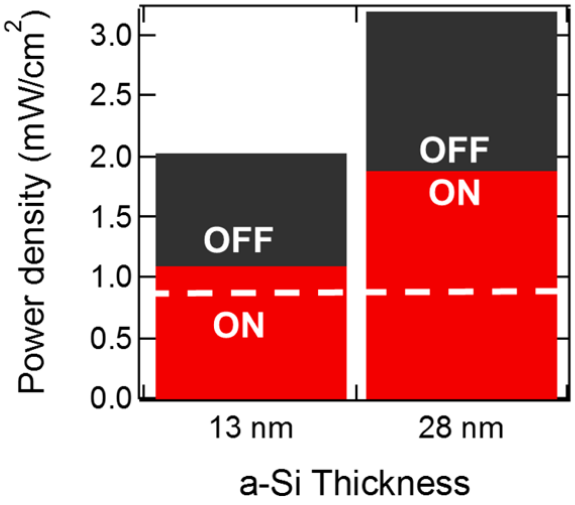
Murray, Ma, and Munday *ACS Photonics* (in press) DOI: 10.1021/acsphotonics.6b00518

Measured and modeled absorption



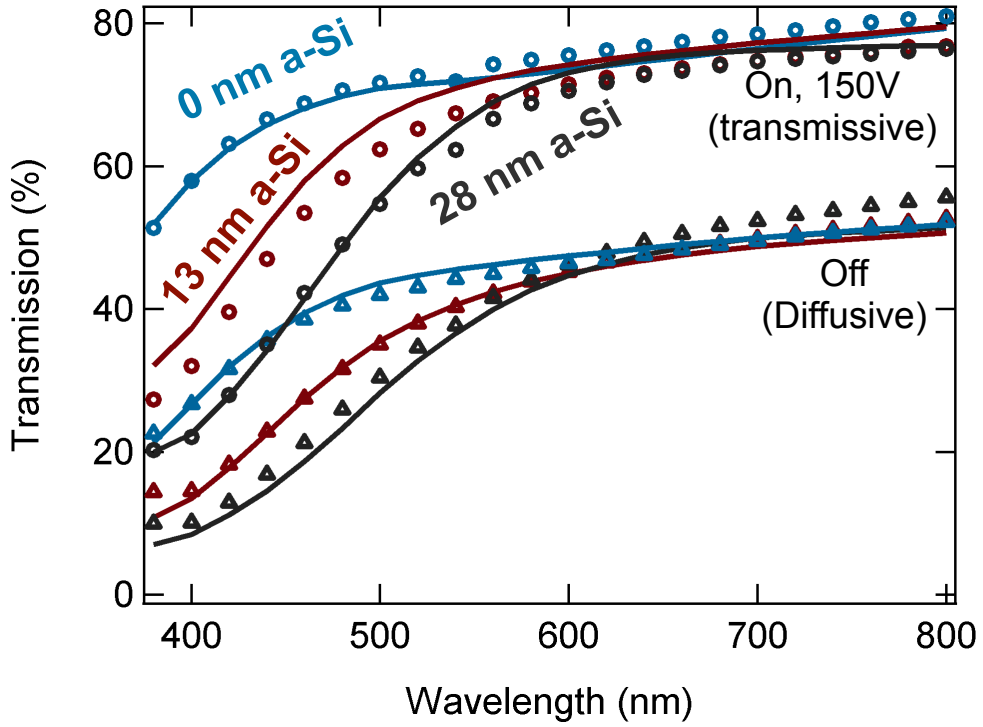


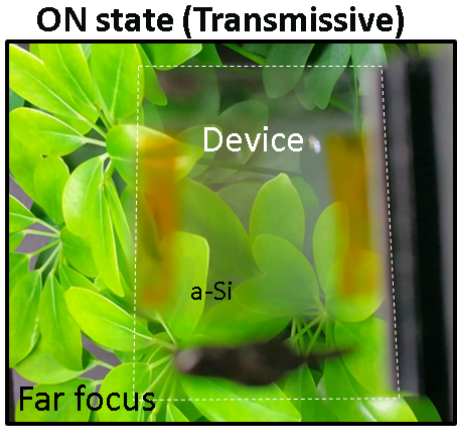


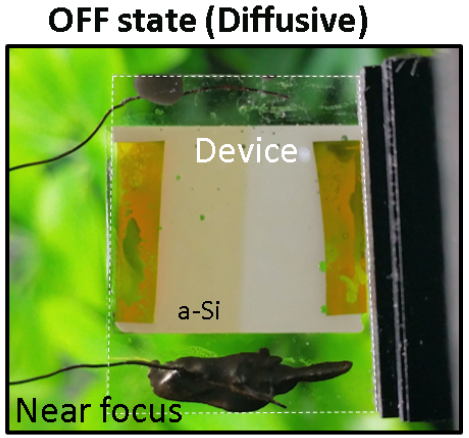


Self-powering threshold (0.79 mW/cm^2)

Transmission characteristics show excellent operation as a smart window

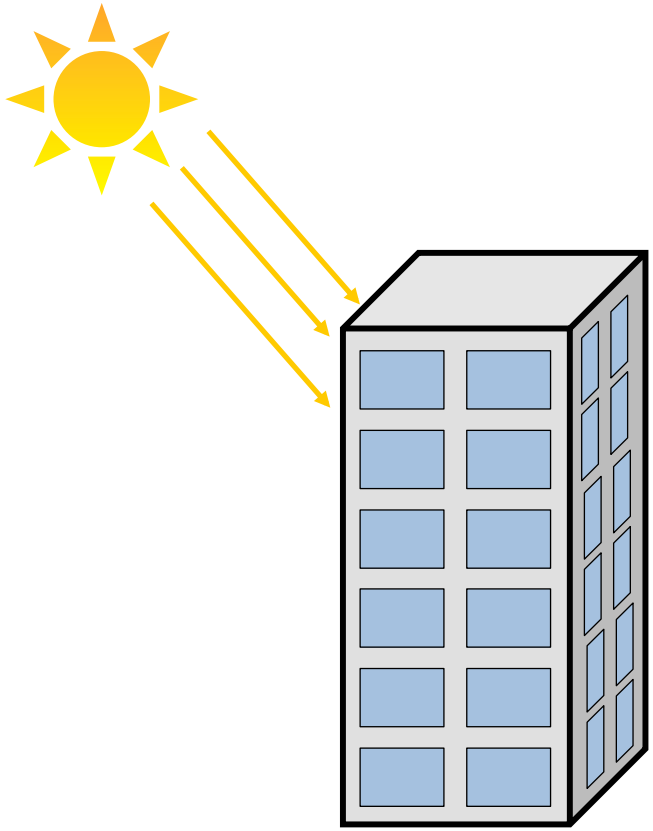


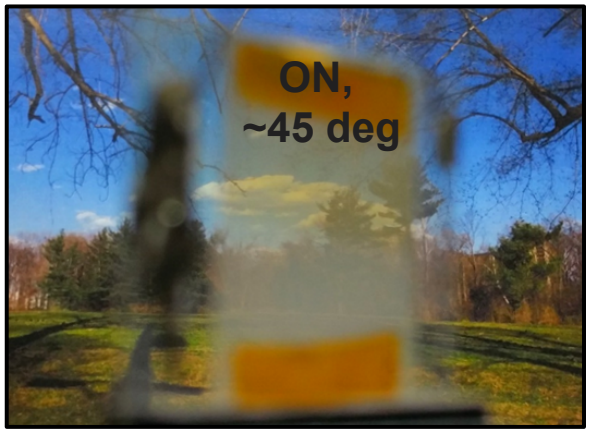




Murray, Ma, and Munday *ACS Photonics* (in press) DOI: 10.1021/acsphotonics.6b00518

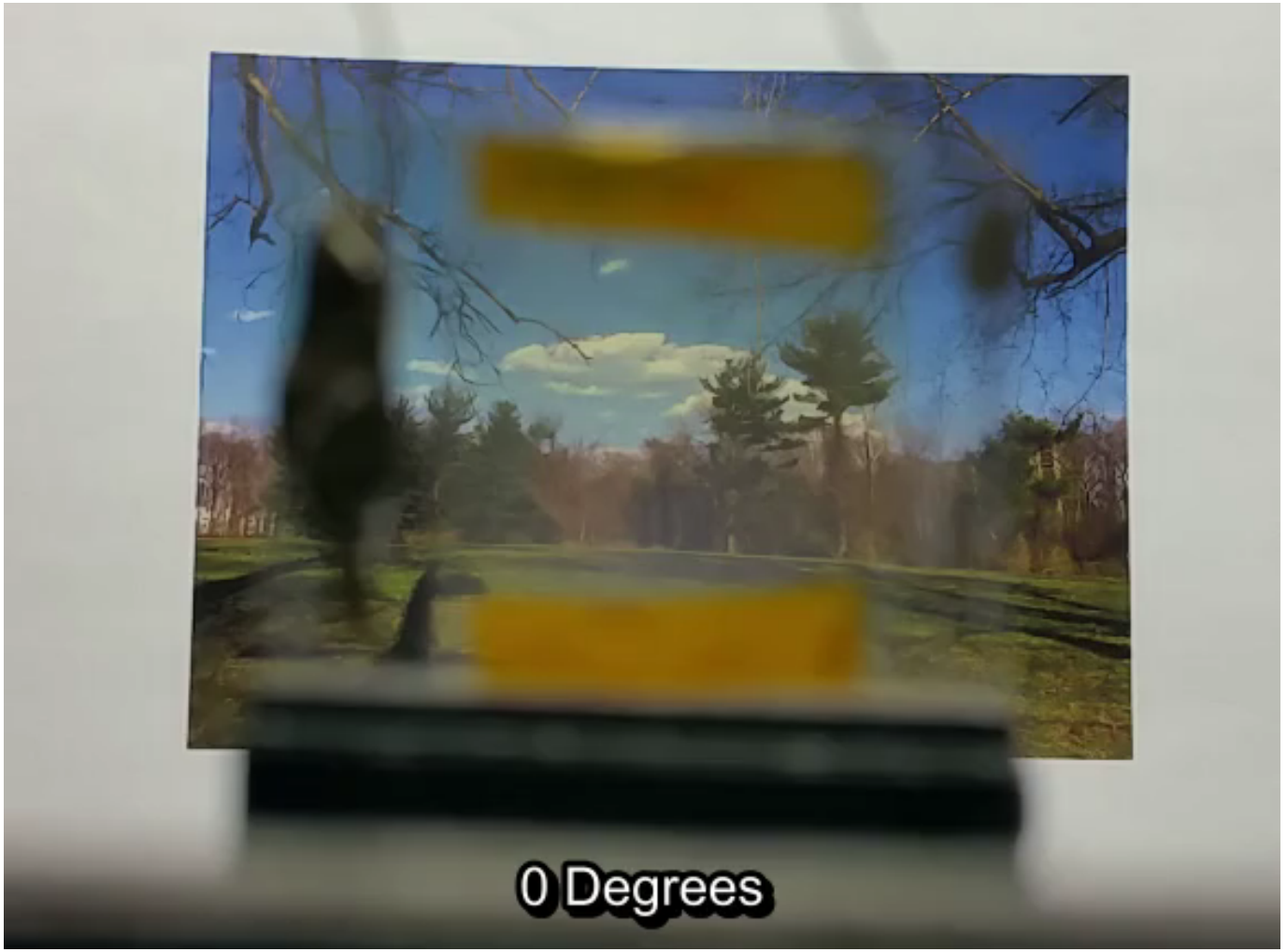
Scattering for non-normal incidence improves power generation, while keeping normal incidence transmission





Murray, Ma, and Munday *ACS Photonics* (in press) DOI: 10.1021/acsphotonics.6b00518

Video of viewing angle dependence



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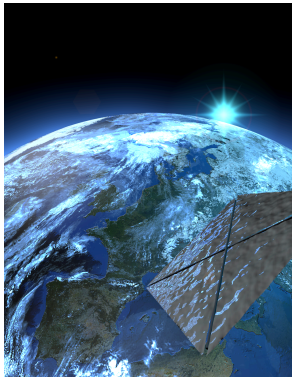

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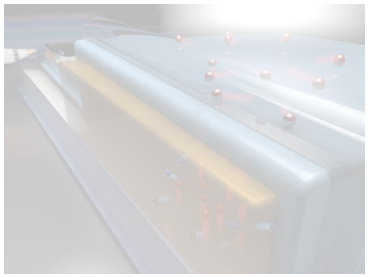
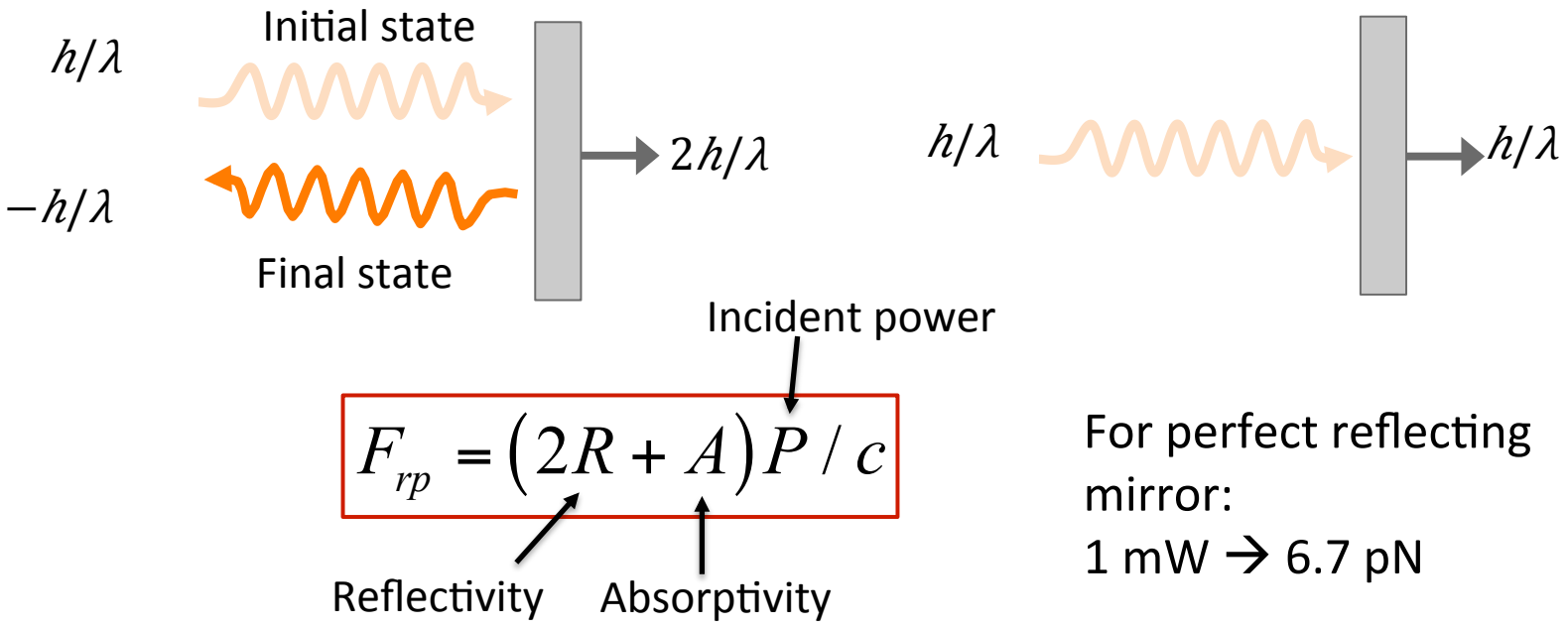
  Gong and Munday, *Nano Lett.* 15, 147–152 (2015)



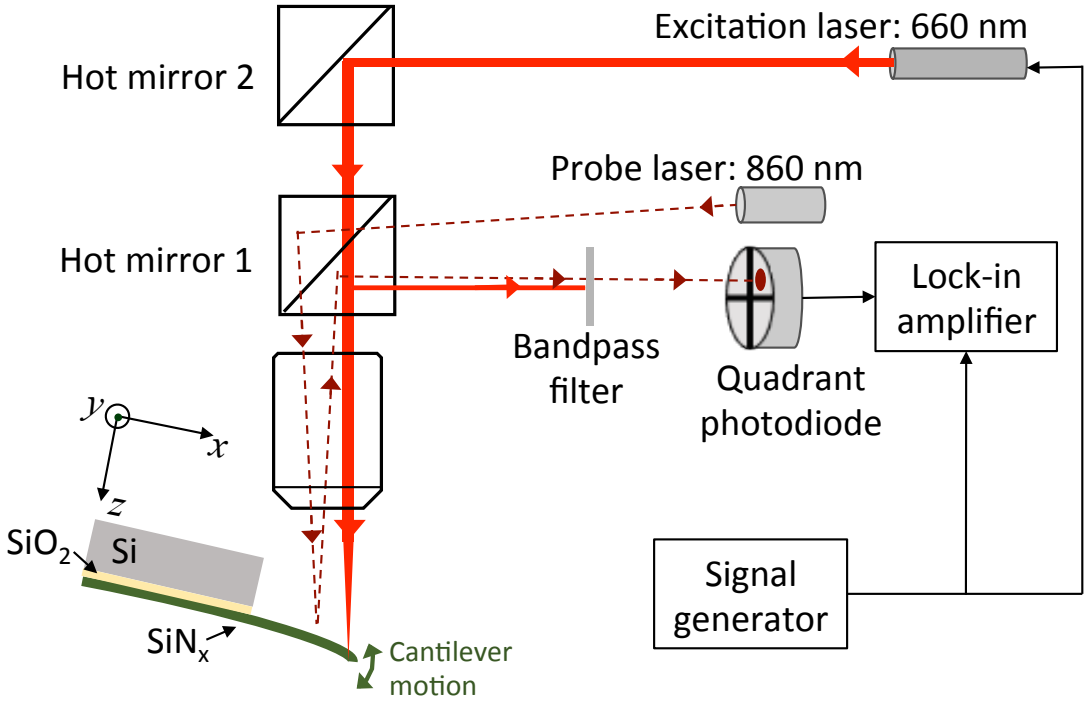
Radiation pressure

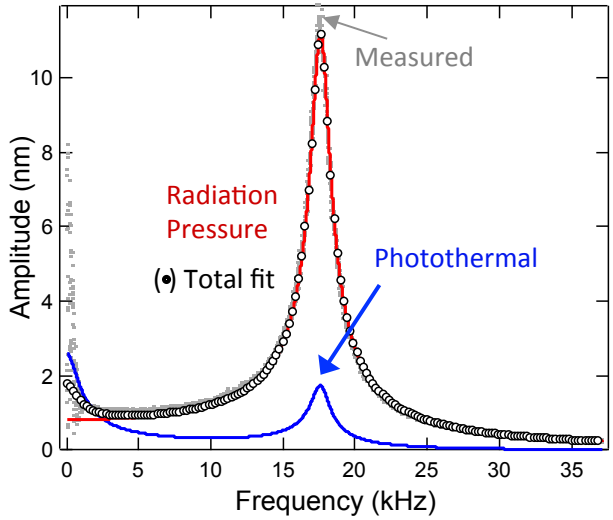
- Each photon carries momentum $p_{photon} = \frac{h}{\lambda}$
- Generates a force when it's reflected or absorbed

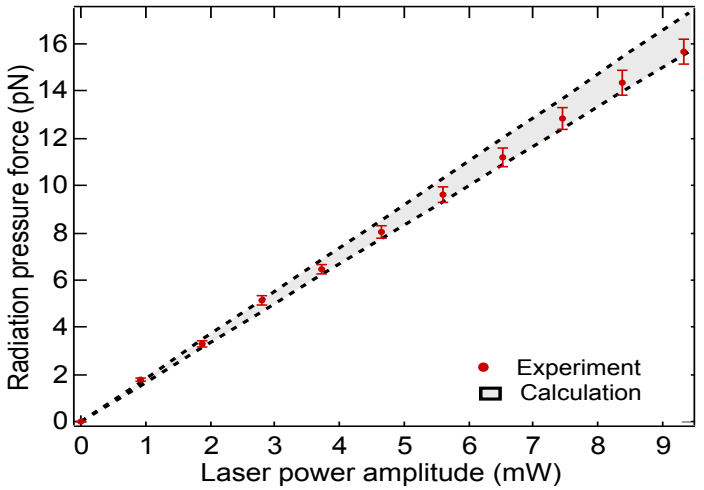


For perfect reflecting mirror:
1 mW → 6.7 pN

Measurement of radiation pressure



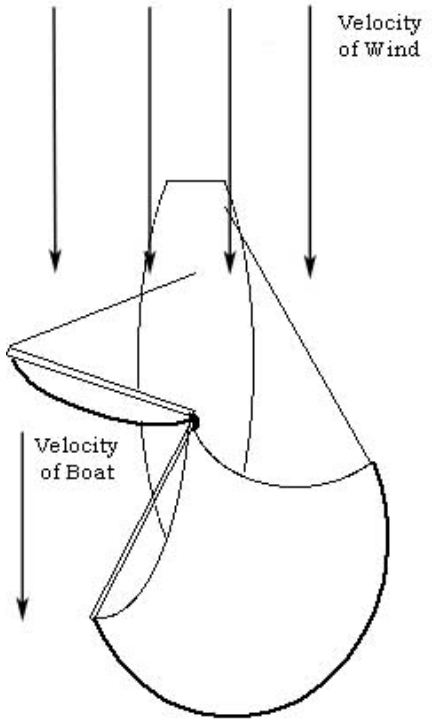




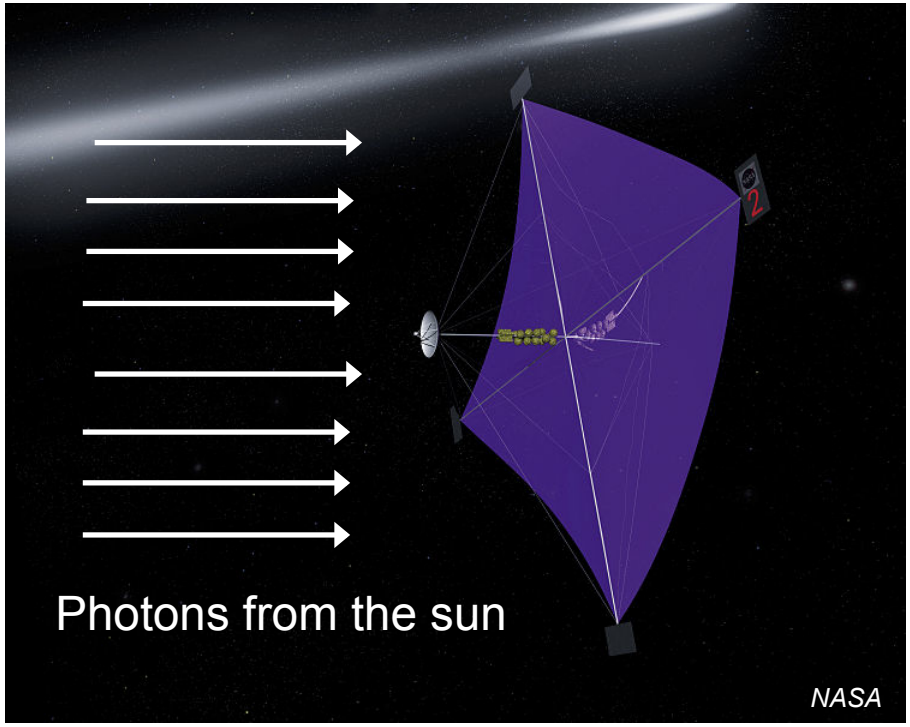
D. Ma, J.L. Garrett, and J.N. Munday, Appl. Phys. Lett. **091107**, 4 (2015).

Application of radiation pressure: Solar sailing

Basic "wind" sail



Solar sail (wind ➔ photons)

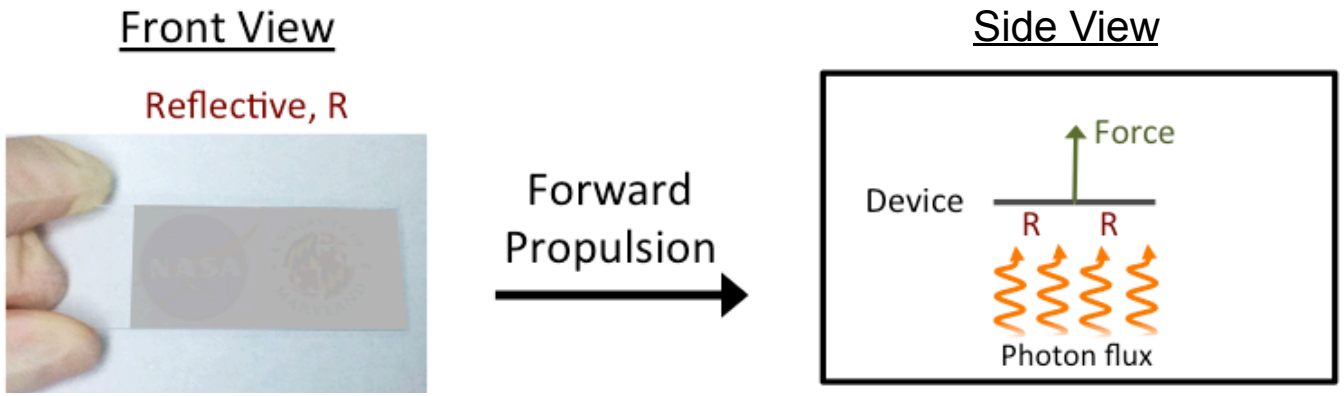


Benefits and limitations of current solar sails

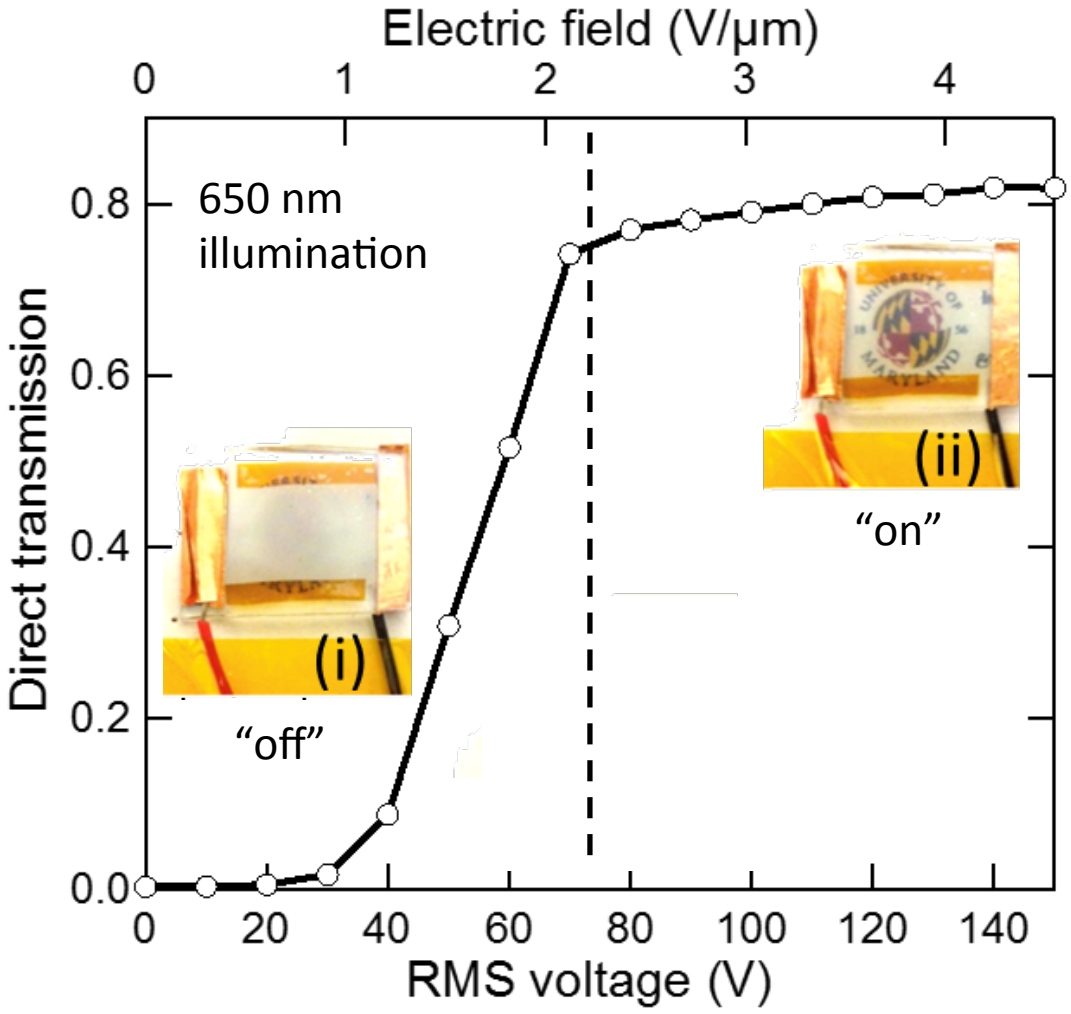
- Benefits
  - No fuel/propellant
  - Small constant force (acceleration) can lead to large velocities
- Limitations
  - Currently attitude control still requires propellant or mechanical motion

Solution: Steering and attitude control via switchable reflectivity

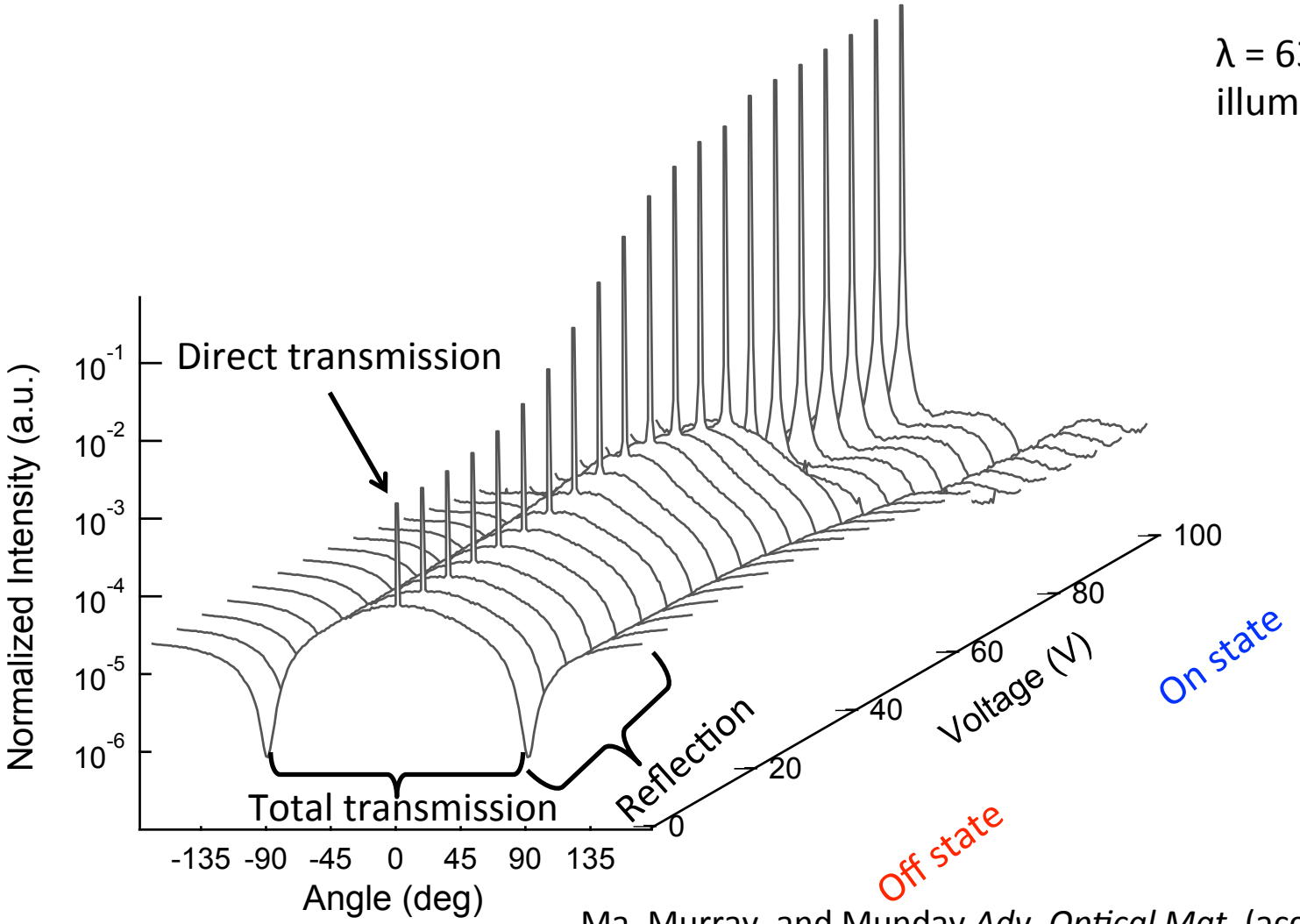
The idea: Radiation pressure for steering



Determination of direct transmission as a function of voltage

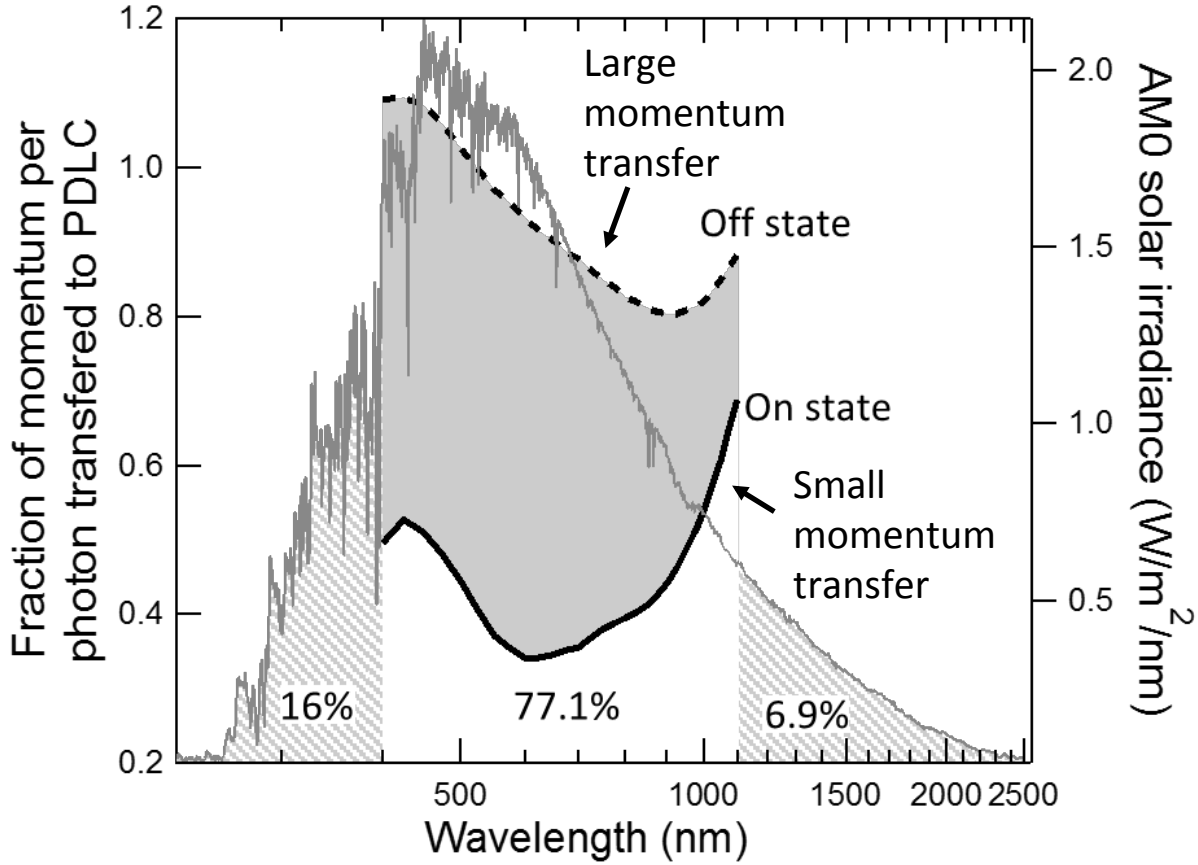


Angular distribution measurement



Ma, Murray, and Munday *Adv. Optical Mat.* (accepted 2017)

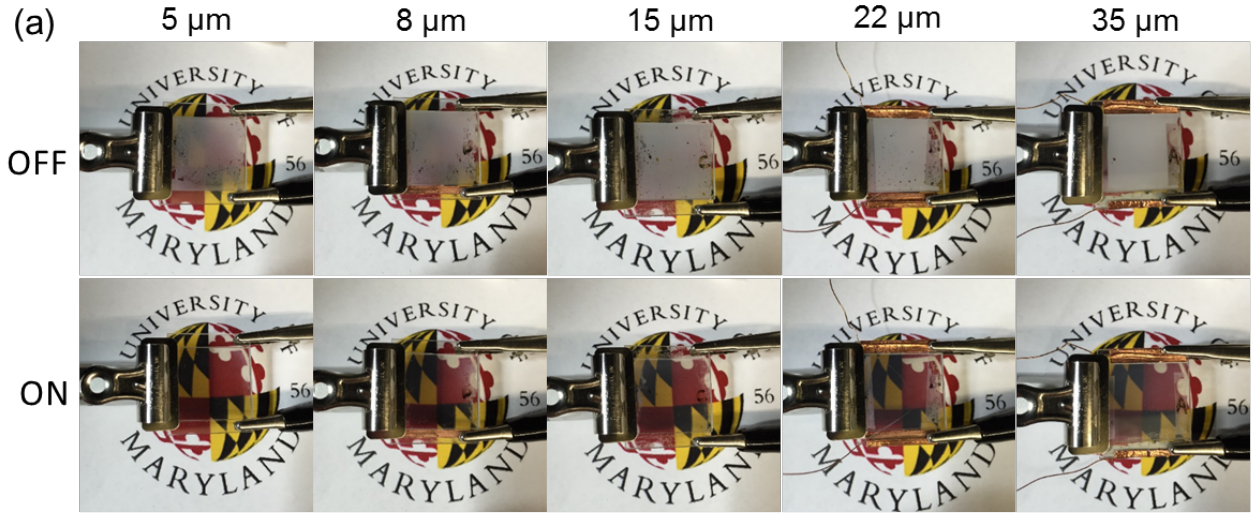
Large switchability of momentum transfer throughout the solar spectrum

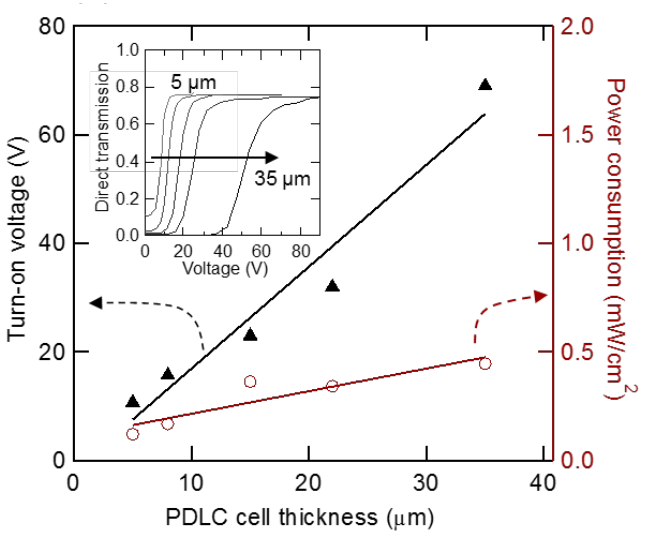


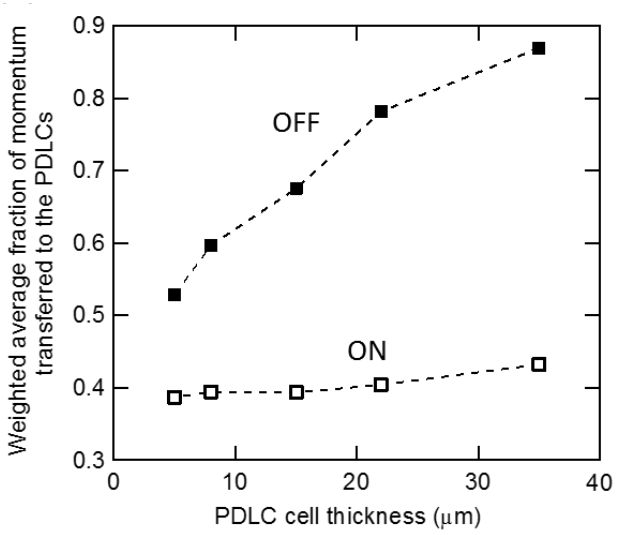
Weighted average momentum switchability: $\Delta p \approx 0.5\ p_0$

Ma, Murray, and Munday *Adv. Optical Mat.* (accepted 2017)

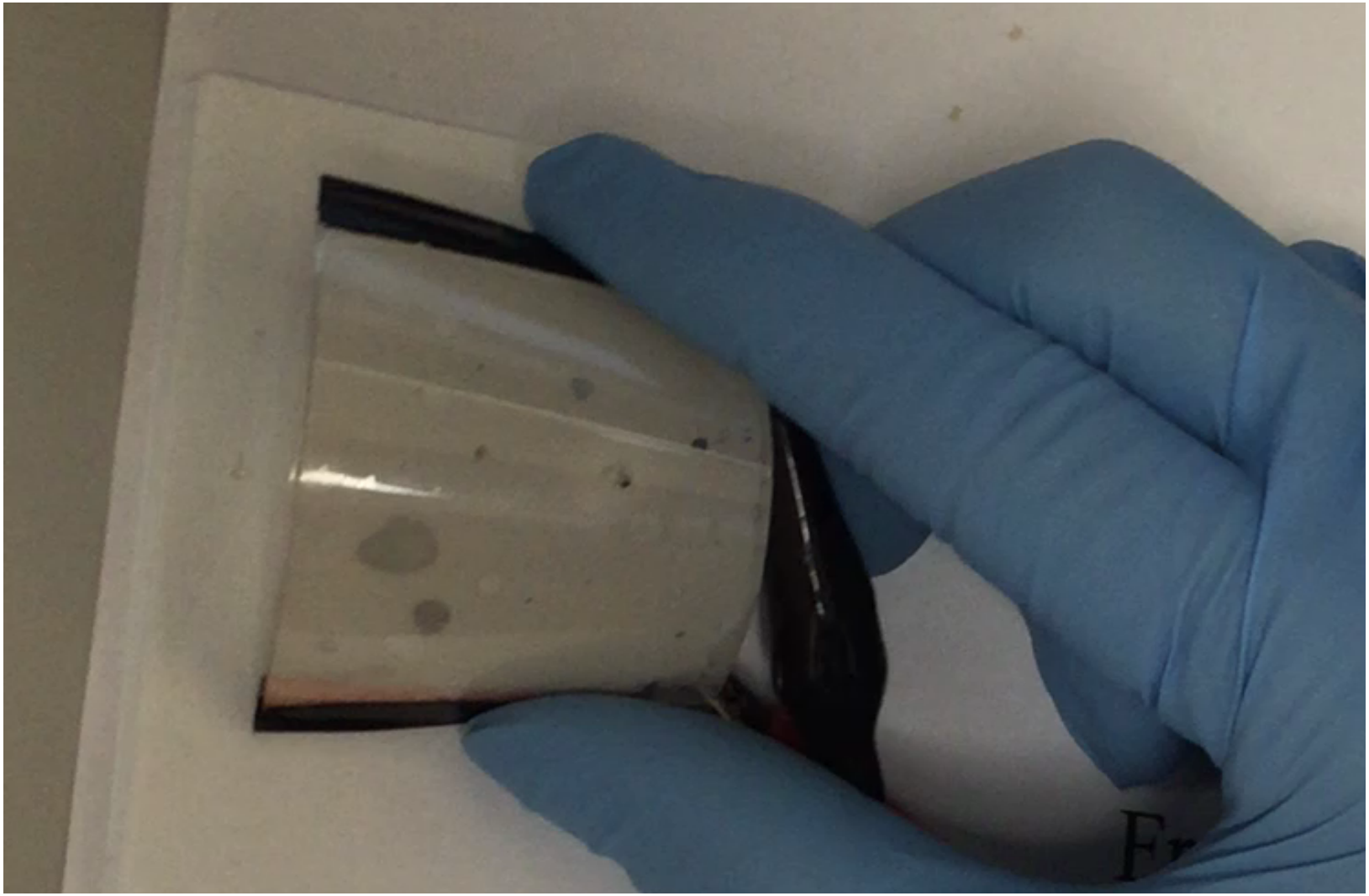
Thinner devices consume less power and require less voltage, but have less switchability







Next step: flexible devices



Solar sail in deployment testing room (NASA)

Outline

- Active control of light trapping for a smart solar window

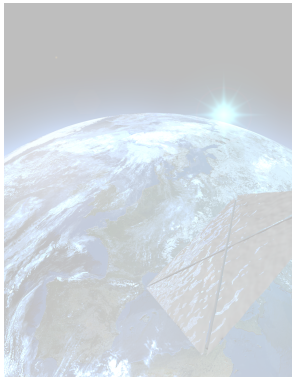
  Murray, Ma, and Munday *ACS Photonics* (in press 2017)
  DOI: 10.1021/acsphotonics.6b00518

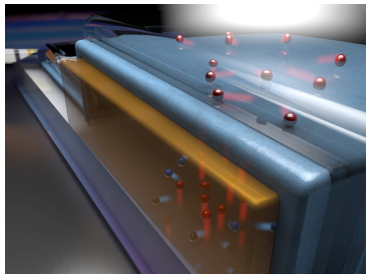
- Tunable radiation pressure for space propulsion

  Ma, Murray, and Munday *Advanced Optical Materials* (accepted 2017)

- Hot carrier detectors and energy converters

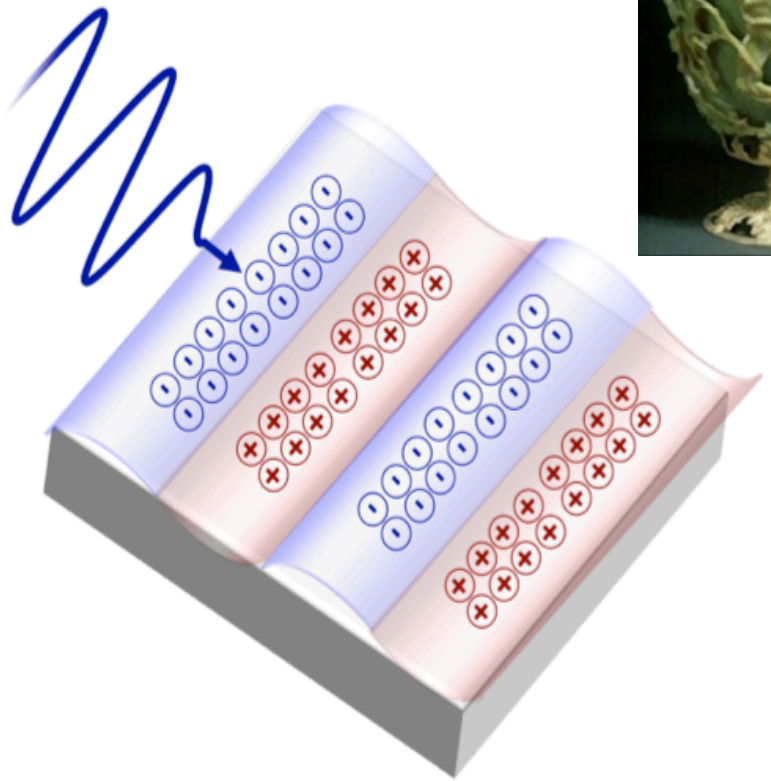
  Gong and Munday, *Nano Lett.* 15, 147–152 (2015)



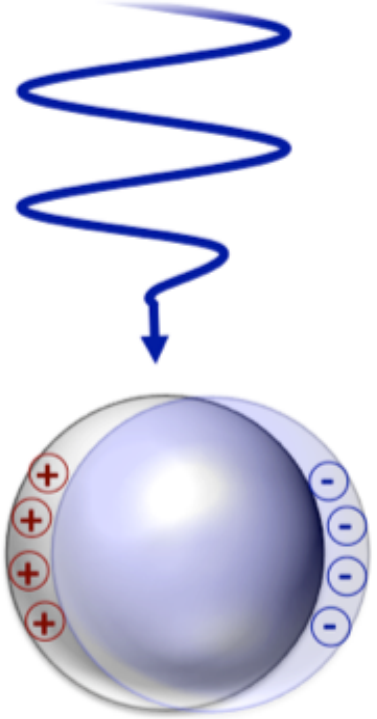


Surface plasmons for light confinement

Propagating Plasmon

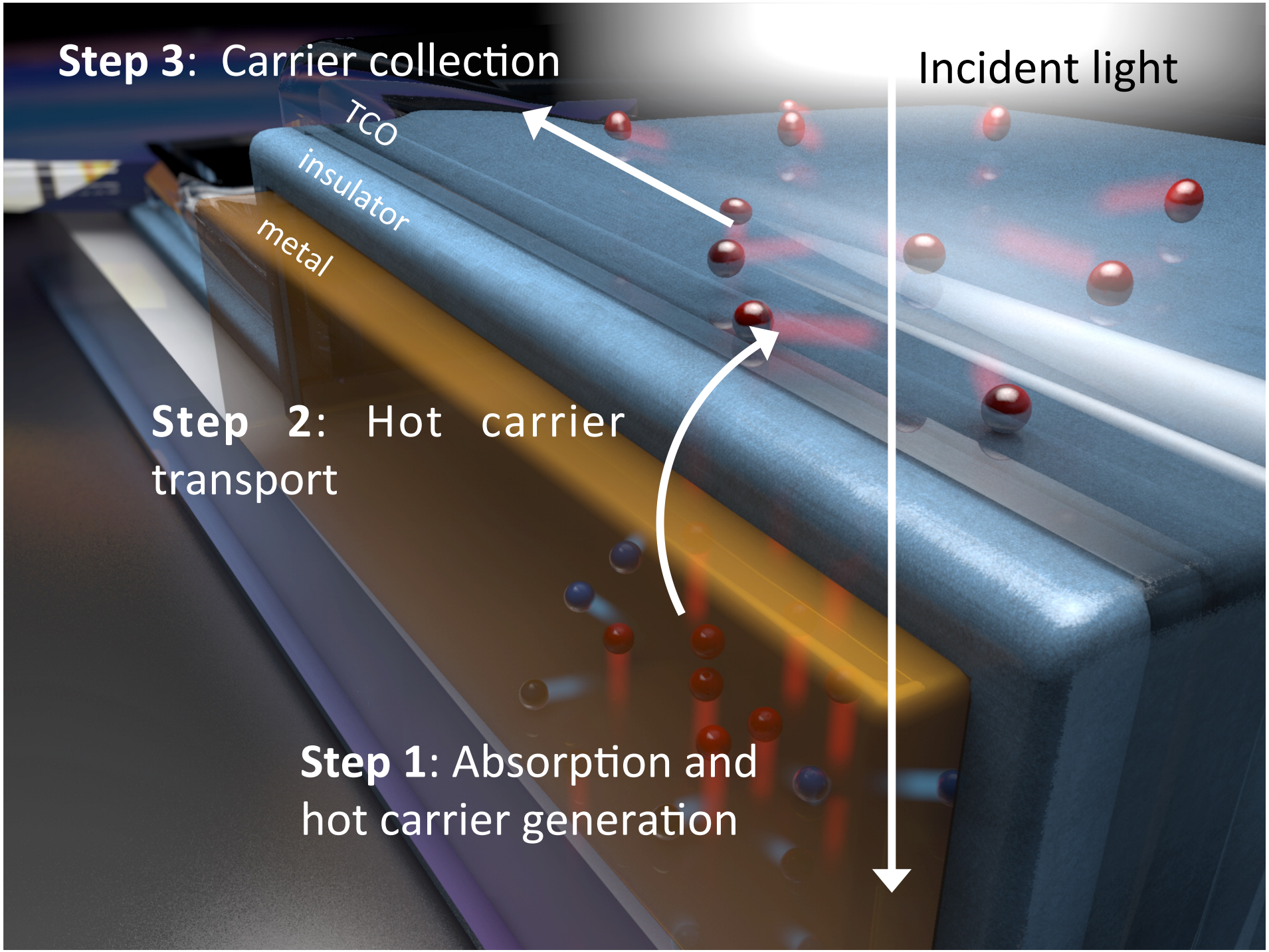


Localized Plasmon



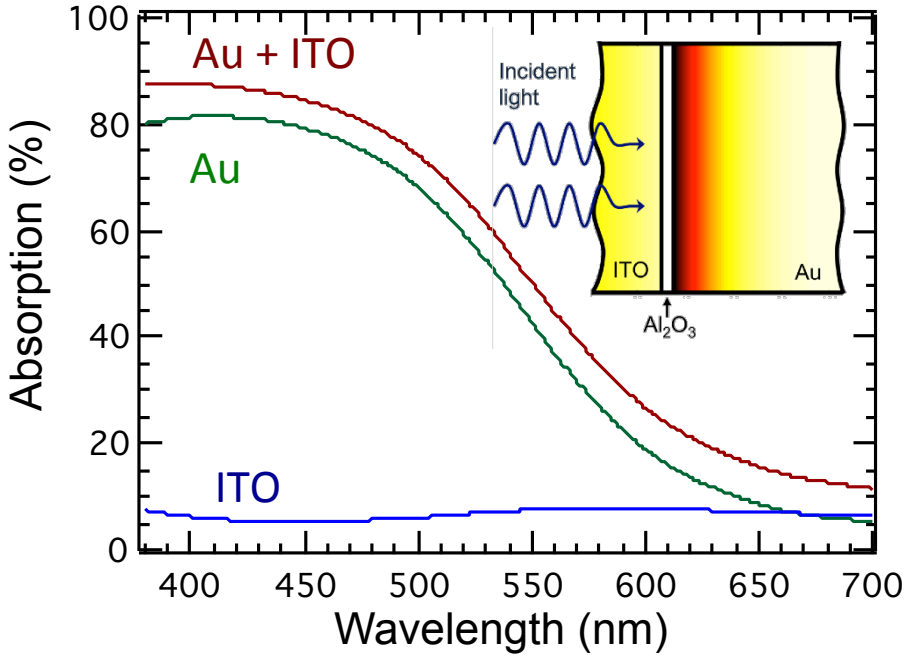
Benefits of plasmonics: high field intensities
Problems: Strong optical loss

Can we take advantage of the strong optical loss?

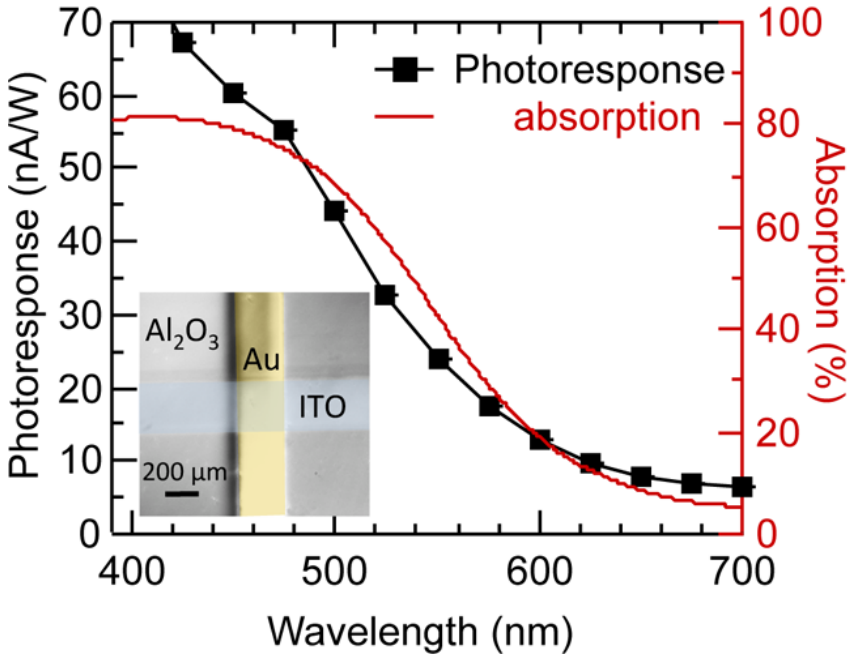

Step 3: Carrier collection
Incident light
TCO
insulator
metal
Step 2: Hot carrier transport
Step 1: Absorption and hot carrier generation

Simulation of a planar TCO hot carrier device

Absorption predominantly in Au layer



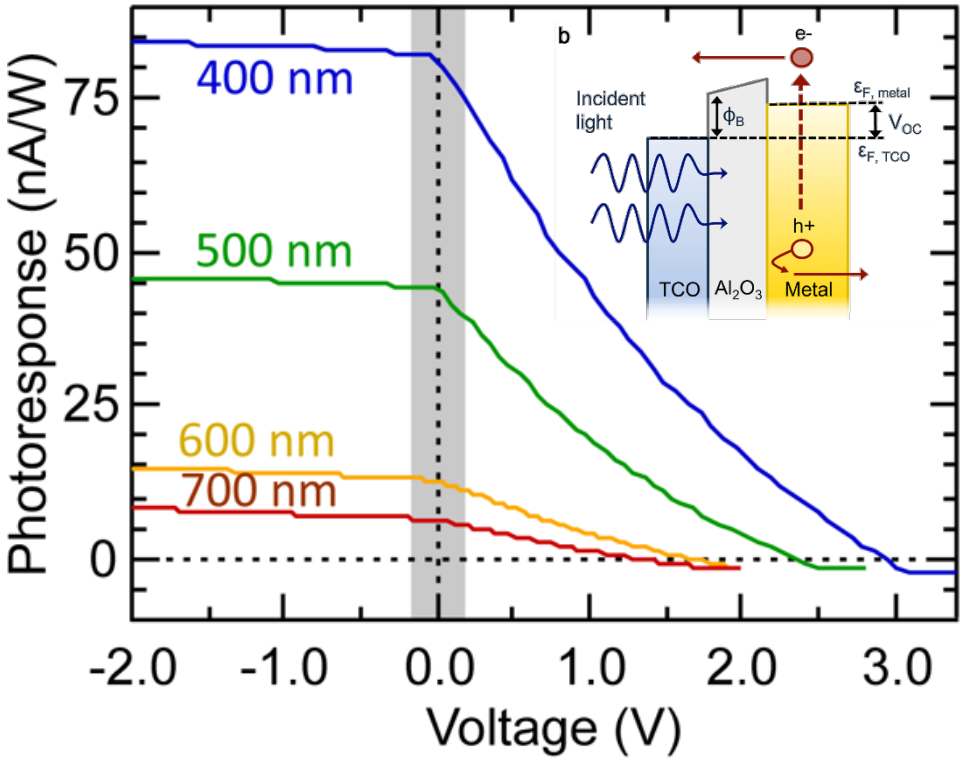
Experiments



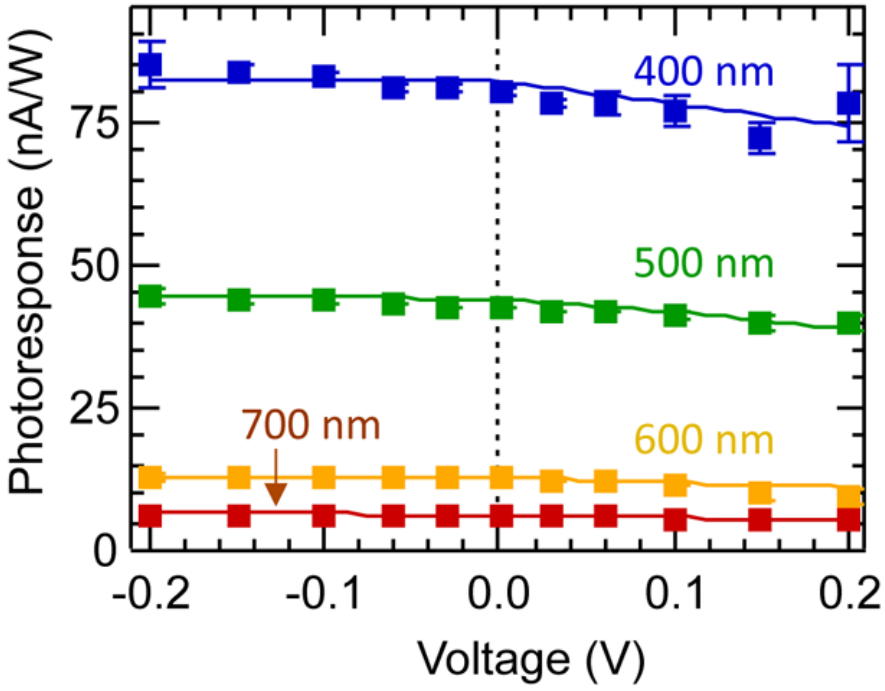
Gong and Munday, *Nano Lett.* 15, 147–152 (2015)

Power generation: Photoresponse under monochromatic light illumination and bias

Calculations



Experiments

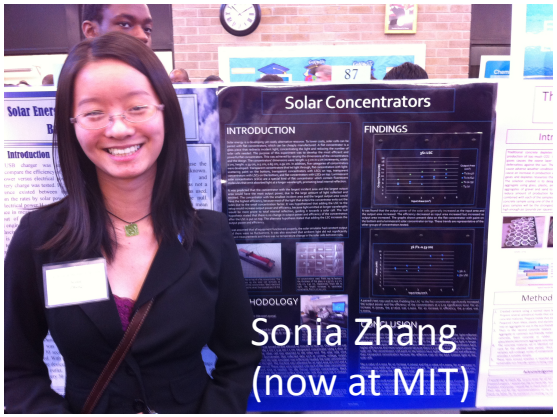


$$I(V) = I_e^{Au-ITO}(V) - I_e^{ITO-Au}(V) - I_h^{Au-ITO}(V) + I_h^{ITO-Au}(V)$$

Gong and Munday, *Nano Lett.* 15, 147–152 (2015)

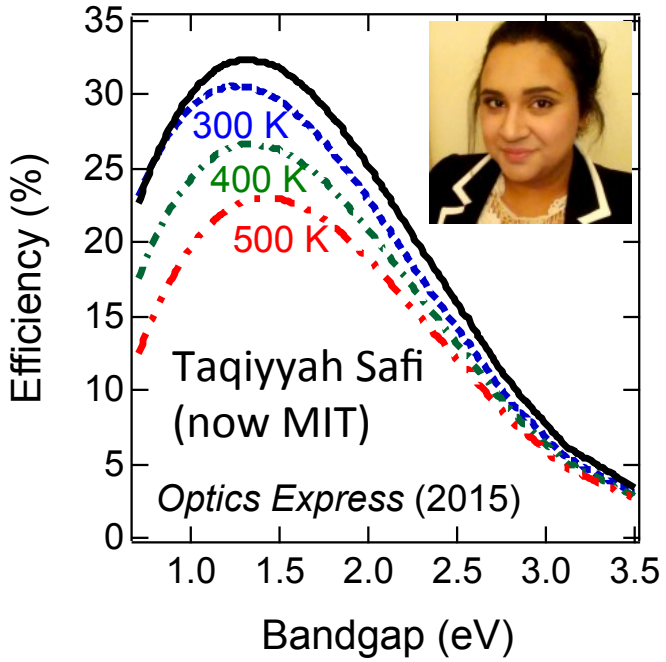
Outreach and broader impacts of research from the Munday Lab

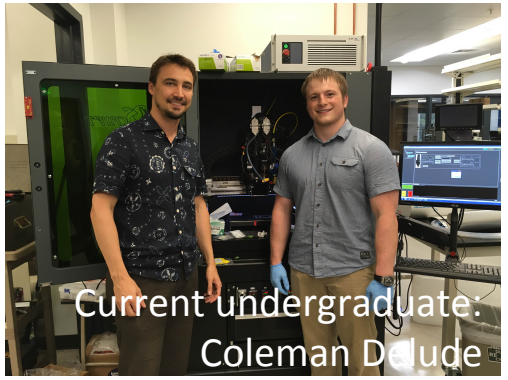
High School Students



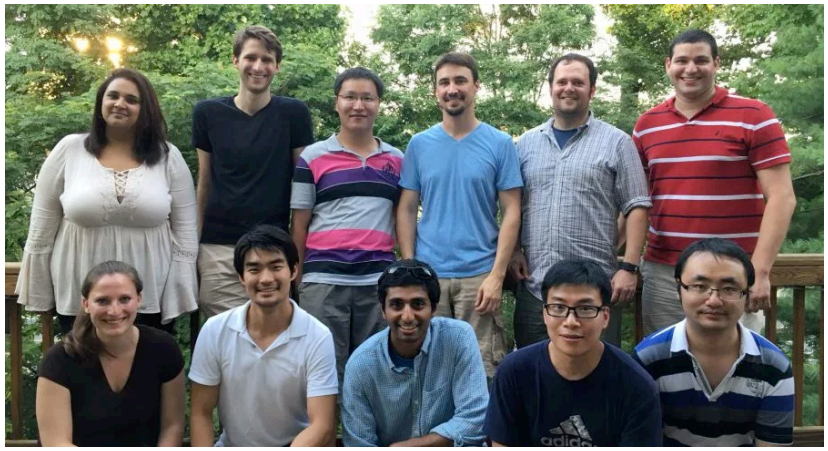
Undergraduates

Carlos Biaou
(now UC Berkley)

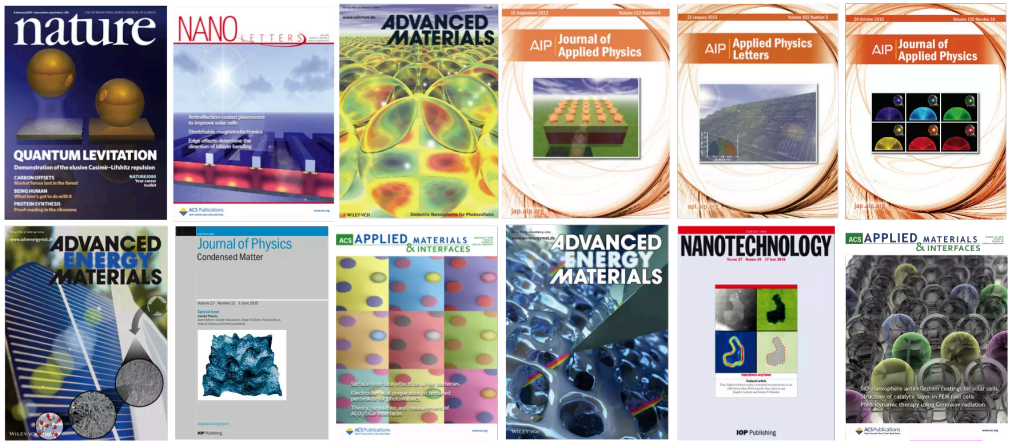




Conclusions



Highlights from the Munday lab



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Google

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