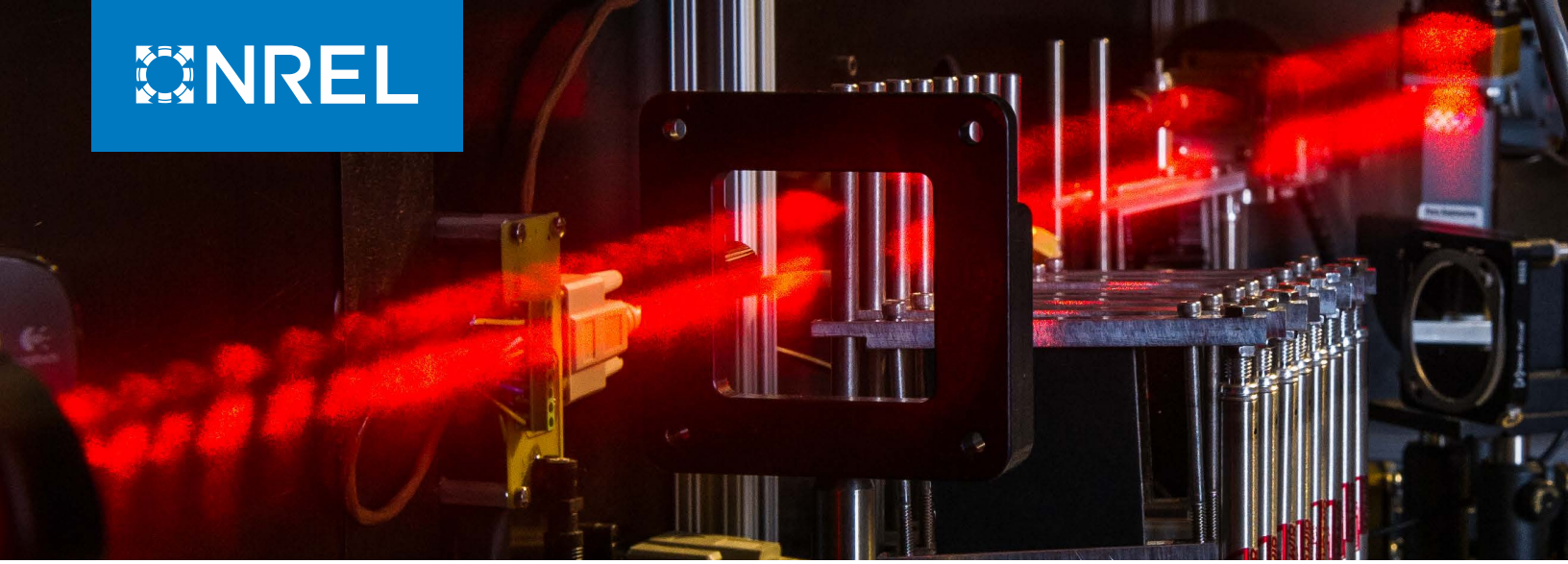
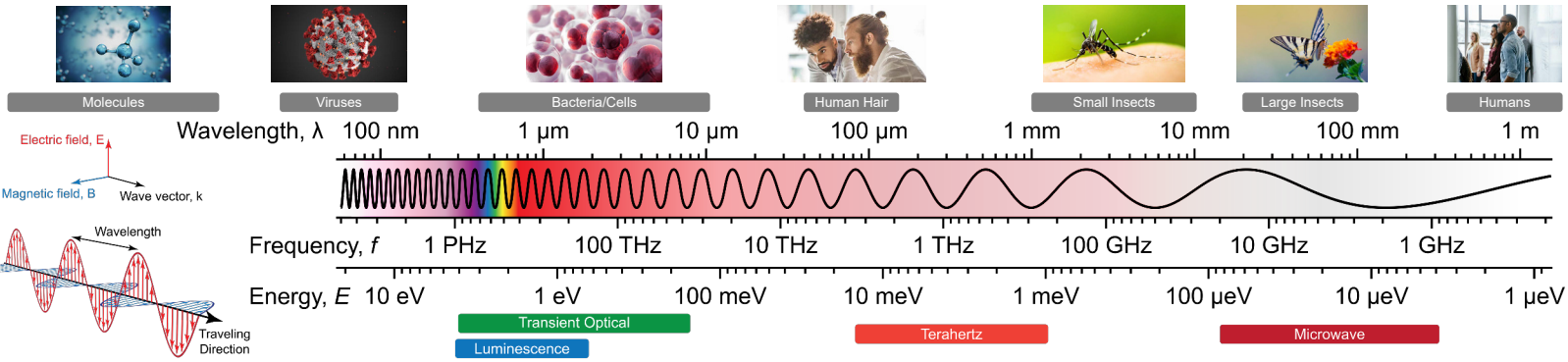


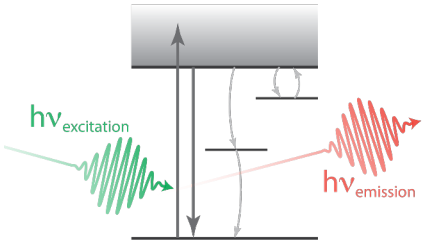
Image 35789 – Credit: Dennis Schroeder / NREL

Electro-Optical Measurement Techniques

Utilize the unique characteristics of photons across different regions of the electromagnetic spectrum to probe the optical and electronic properties of chemical systems, materials and devices for energy conversion technologies

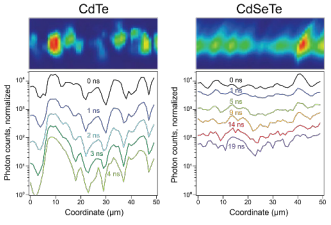


Luminescence Spectroscopy



- Emission upon excitation by photon absorption (photoluminescence, PL) or carrier injection (electroluminescence, EL)
- Photon emission probes electronic transitions, in either visible or near-infrared
- Steady-state and temporal information, with resolution spanning picoseconds to minutes
- Amenable to imaging or microscopy for spatial information

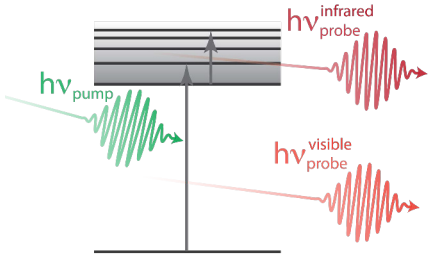
Time-resolved Photoluminescence Imaging in Thin-film Photovoltaics



Time-resolved PL images and intensity profiles showing greater spatial variation in the CdTe region of a graded CdTe/CdSeTe absorber, suggesting an order of magnitude larger contribution of grain boundary recombination in. the CdTe layer.

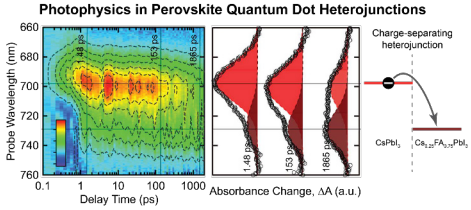
Image adapted from:
X. Zheng, D. Kuciauskas, *et al.* "Recombination and bandgap engineering in CdSeTe/CdTe solar cells." *APL Materials* **7**, 071112 (2019).

Transient Optical Spectroscopy



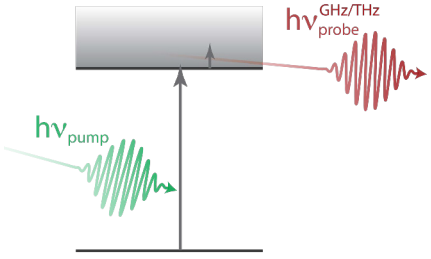
- Pump-probe techniques; pump photon generates excited state, delayed photon probes excited-state dynamics
- Sensitive to electronic (UV/visible/near-IR) and vibrational (mid-IR) transitions
- Time resolution spanning femtoseconds to microseconds
- Technique variations can probe bulk, surface, and interfacial dynamics of excitons, charges, and spin carriers, including transport.

Photophysics in Perovskite Quantum Dot Heterojunctions



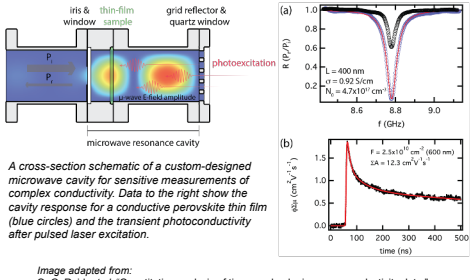
Spectro-temporal transient absorption map illustrating charge separation at a perovskite-perovskite heterojunction, enabling enhanced photovoltaic performance.
Image adapted from:
Q. Zhao, *et al.* "High efficiency perovskite quantum dot solar cells with charge separating heterostructure." *Nat. Commun.* **10**, 1–8 (2019).

High-frequency Spectroscopy



- Pump-probe techniques, using THz (terahertz spectroscopy) or GHz (microwave conductivity) probes
- Sensitive to complex conductivity or dielectric function, providing information about carrier generation, transport, and losses
- THz: time resolution spanning femtoseconds to nanoseconds; GHz: time resolution spanning nanoseconds to milliseconds

Time-resolved Microwave Conductivity of Thin-film Semiconductors



A cross-section schematic of a custom-designed microwave cavity for sensitive measurements of complex conductivity. Data to the right show the cavity response for a conductive perovskite thin film (blue circles) and the transient photoconductivity after pulsed laser excitation.

Image adapted from:
O. G. Reid, *et al.* "Quantitative analysis of time-resolved microwave conductivity data." *J. Phys. D: Appl. Phys.* **50**, 493002 (2017).

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