Uncovering Material Charge Dynamics with Ultrafast Terahertz Spectroscopy

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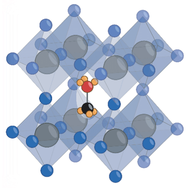
Motivation

Ultrafast terahertz spectroscopy provides a non-damaging probe of fundamental charge dynamics in novel photovoltaic materials. New insights drive development of powerful, globally accessible energy technology.

New Photovoltaic Materials



NREL

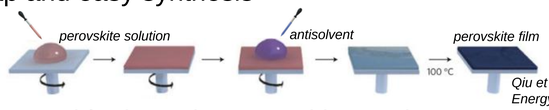
Hybrid perovskites[1,2] belong to perovskite family:

ABX_3 — A^+, B^{2+} = cations; X^- = anion

Hybrid perovskites mix organic and inorganic components.

Advantages

- Competitive efficiency with commercial technology
- Cheap and easy synthesis



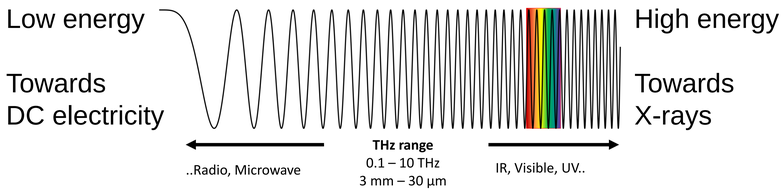
Qiu et al. 2018, Materials Energy Today.

- Highly tunable through composition and structure

Obstacles

- Unstable in excess heat, air, water, light, etc.
- Scale-up process difficult
- *Incomplete picture of fundamental photophysics*

Terahertz (THz) Frequency



6.2 THz ~ 298 K (room temperature)

Advantages

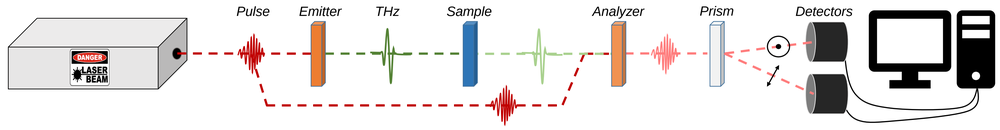
- Non-damaging (non-ionizing)
- Sensitive to many-particle interactions (e.g. room temperature vibrations)
- Full electric field is measurable

Obstacles

- Lack of strong emitters and sensitive detectors
- Expensive setup
- Steep learning curve

Ultrafast Terahertz Spectroscopy

Our laser system generates light pulses shorter than 1-trillionth of a second.



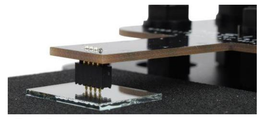
By measuring how our samples absorb THz light, we resolve ultrafast phenomena.

Probing Charge Carrier Behavior

Ground State

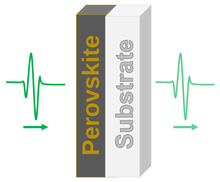
Challenge:

Measure inherent electrical properties. Typical techniques can be invasive and damaging to the sample.

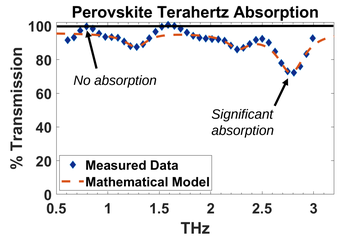


Four Point Probe

Approach:

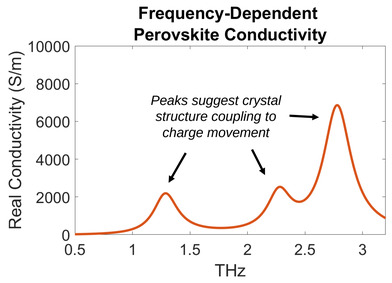


We measure absorption of THz and analyze with model.



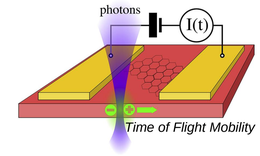
Result:

From model fit we quantify strength of charge movement (i.e. conductivity) *non-invasively*.

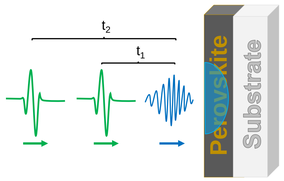


Excited State

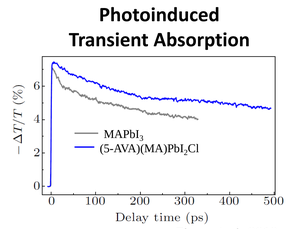
Investigate photoexcited charge movement. Typical techniques require metal contact deposition which influences measurement.



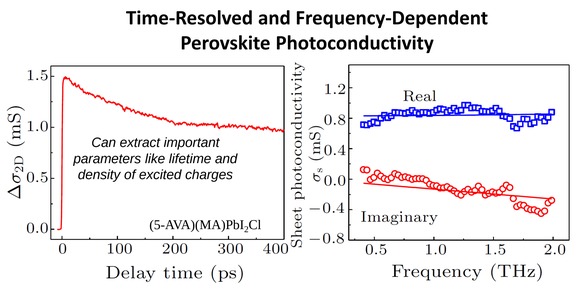
Time of Flight Mobility



We can measure *change* in THz absorption *over time.*



Zhao et al. 2019, Chin. Phys. Lett.



Zhao et al. 2019, Chin. Phys. Lett.

Outlook:

Study influence of practical device conditions and components to enhance technological development,

including:

- Stellar radiation
- Charge transport interface
- Quantum confinement

Additional References

1. Huang, J., Yuan, Y., Shao, Y., Yan, Y. (2017). Understanding the physical properties of hybrid perovskites for photovoltaic applications. *Nature Reviews Materials*, *2*, 17042.
2. Herz, L. (2017). Charge-Carrier Mobilities in Metal Halide Perovskites: Fundamental Mechanisms and Limits. *ACS Energy Letters*, *2*, 1535-1548.

Acknowledgements

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