Senior Laboratory

PHYC 493L, Spring 2020

Classes: MW, 8:00-10:50 am

Location: PAIS 1417

Instructor: Tara Drake
Email: drakete@unm.edu
Office: PAIS 2234 and CHTM 118B

Teaching Assistant: Xuefeng Li
Email: xuefengli@unm.edu

Office Hours: arrange meeting with instructor or TA via email

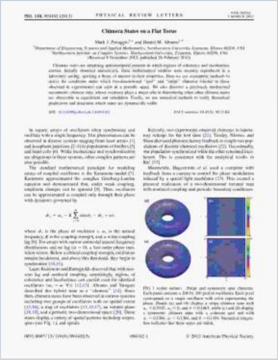
Lab Reports

Each student produces a **separate** formal report based on experiment.

Should follow the style of a scientific journal (Typed, one or two columns)

- See Optics Letters or Physical Review Letters

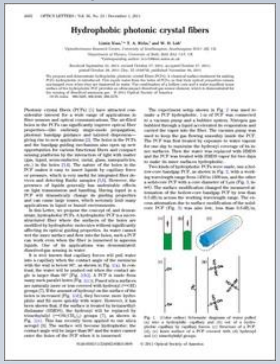
Phys. Rev. Lett.



PHYSICAL REVIEW LETTERS

Chimera States on a Flat Torus

Opt. Lett.



Hydrophobic photonic crystal fibers

Next lab report is due **Wednesday**, Feb 19, **before class**. (8 am)
Please submit **by email**. (If you also bring in a hard copy, I will be appreciative!)

Figures

IMO, the make-or-break of a paper.

1. All axes have labels and units.
2. Figure caption
   - Separated from main text (standard journal format)
   - Enough detail that the main concept is clear without reference to text. A reader should be able to answer, “what measurement is this showing?”
3. Figures have numbers (Fig. 1, Fig. 2) and at least one referral in text.
   - If there is Fig. 1a and Fig 1b, both appear in text separately.
4. Text in figure (labels, etc.) is big enough to read (8 pt or larger).
5. If figure is taken from somewhere, “Reproduced from []” must be in caption.

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Abstract

How reader decides if your paper is worth their time!

The abstract contains a summary of your manuscript:

- It is short (~250 words).
- Briefly state the motivation and give context for the work (~ one-two sentences)
- Problem statement/statement of work (~one sentence)
- Statement of methodology and results (with errors)
- Relevance of results to your field, other disciplines, or general public (depending on the journal's audience)

- Completely encapsulates your paper

Example Abstract

High-harmonic generation (HHG) is a signature optical phenomenon of strongly driven, nonlinear optical systems. Specifically, the understanding of the HHG process in rare gases has played a key role in the development of attosecond science. Recently, HHG has also been reported in solids, providing novel opportunities such as controlling strong-field and attosecond processes in dense optical media down to the nanoscale. Here, we report HHG from a low-loss, indium-doped cadmium oxide thin film by leveraging the epsilon-near-zero (ENZ) effect, whereby the real part of the material's permittivity in certain spectral ranges vanishes, as well as the associated large resonant enhancement of the driving laser field. We find that ENZ-assisted harmonics exhibit a pronounced spectral redshift as well as linewidth broadening, resulting from the photo induced electron heating and the consequent time-dependent ENZ wavelength of the material. Our results provide a new platform to study strong-field and ultrafast electron dynamics in ENZ materials, reveal new degrees of freedom for spectral and temporal control of HHG, and open up the possibilities of compact solid-state attosecond light sources.

Yang, Y., Lu, J., Manjavacas, A. *et al.* High-harmonic generation from an epsilon-near-zero material. *Nat. Phys.* **15,** 1022–1026 (2019).

Abstract: Motivation (broad)

High-harmonic generation (HHG) is a signature optical phenomenon of strongly driven, nonlinear optical systems. Specifically, the understanding of the HHG process in rare gases has played a key role in the development of attosecond science. Recently, HHG has also been reported in solids, providing novel opportunities such as controlling strong-field and attosecond processes in dense optical media down to the nanoscale. Here, we report HHG from a low-loss, indium-doped cadmium oxide thin film by leveraging the epsilon-near-zero (ENZ) effect, whereby the real part of the material's permittivity in certain spectral ranges vanishes, as well as the associated large resonant enhancement of the driving laser field. We find that ENZ-assisted harmonics exhibit a pronounced spectral redshift as well as linewidth broadening, resulting from the photo induced electron heating and the consequent time-dependent ENZ wavelength of the material. Our results provide a new platform to study strong-field and ultrafast electron dynamics in ENZ materials, reveal new degrees of freedom for spectral and temporal control of HHG, and open up the possibilities of compact solid-state attosecond light sources.

Yang, Y., Lu, J., Manjavacas, A. *et al.* High-harmonic generation from an epsilon-near-zero material. *Nat. Phys.* **15,** 1022–1026 (2019).

Abstract: Motivation/Context (more specific)*

High-harmonic generation (HHG) is a signature optical phenomenon of strongly driven, nonlinear optical systems. Specifically, the understanding of the HHG process in rare gases has played a key role in the development of attosecond science. **Recently, HHG has also been reported in solids, providing novel opportunities such as controlling strong-field and attosecond processes in dense optical media down to the nanoscale.** Here, we report HHG from a low-loss, indium-doped cadmium oxide thin film by leveraging the epsilon-near-zero (ENZ) effect, whereby the real part of the material's permittivity in certain spectral ranges vanishes, as well as the associated large resonant enhancement of the driving laser field. We find that ENZ-assisted harmonics exhibit a pronounced spectral redshift as well as linewidth broadening, resulting from the photo induced electron heating and the consequent time-dependent ENZ wavelength of the material. Our results provide a new platform to study strong-field and ultrafast electron dynamics in ENZ materials, reveal new degrees of freedom for spectral and temporal control of HHG, and open up the possibilities of compact solid-state attosecond light sources.

*Your motivation might not be so long.

Abstract: statement of work/problem

High-harmonic generation (HHG) is a signature optical phenomenon of strongly driven, nonlinear optical systems. Specifically, the understanding of the HHG process in rare gases has played a key role in the development of attosecond science. Recently, HHG has also been reported in solids, providing novel opportunities such as controlling strong-field and attosecond processes in dense optical media down to the nanoscale. **Here, we report HHG from a low-loss, indium-doped cadmium oxide thin film by leveraging the epsilon-near-zero (ENZ) effect, whereby the real part of the material's permittivity in certain spectral ranges vanishes, as well as the associated large resonant enhancement of the driving laser field.** We find that ENZ-assisted harmonics exhibit a pronounced spectral redshift as well as linewidth broadening, resulting from the photo induced electron heating and the consequent time-dependent ENZ wavelength of the material. Our results provide a new platform to study strong-field and ultrafast electron dynamics in ENZ materials, reveal new degrees of freedom for spectral and temporal control of HHG, and open up the possibilities of compact solid-state attosecond light sources.

Yang, Y., Lu, J., Manjavacas, A. *et al.* High-harmonic generation from an epsilon-near-zero material. *Nat. Phys.* **15,** 1022–1026 (2019).

Abstract: Results

High-harmonic generation (HHG) is a signature optical phenomenon of strongly driven, nonlinear optical systems. Specifically, the understanding of the HHG process in rare gases has played a key role in the development of attosecond science. Recently, HHG has also been reported in solids, providing novel opportunities such as controlling strong-field and attosecond processes in dense optical media down to the nanoscale. Here, we report HHG from a low-loss, indium-doped cadmium oxide thin film by leveraging the epsilon-near-zero (ENZ) effect, whereby the real part of the material's permittivity in certain spectral ranges vanishes, as well as the associated large resonant enhancement of the driving laser field. **We find that ENZ-assisted harmonics exhibit a pronounced spectral redshift as well as linewidth broadening, resulting from the photo induced electron heating and the consequent time-dependent ENZ wavelength of the material.** Our results provide a new platform to study strong-field and ultrafast electron dynamics in ENZ materials, reveal new degrees of freedom for spectral and temporal control of HHG, and open up the possibilities of compact solid-state attosecond light sources.

Yang, Y., Lu, J., Manjavacas, A. *et al.* High-harmonic generation from an epsilon-near-zero material. *Nat. Phys.* **15,** 1022–1026 (2019).

Abstract: Relevance/Impact

High-harmonic generation (HHG) is a signature optical phenomenon of strongly driven, nonlinear optical systems. Specifically, the understanding of the HHG process in rare gases has played a key role in the development of attosecond science. Recently, HHG has also been reported in solids, providing novel opportunities such as controlling strong-field and attosecond processes in dense optical media down to the nanoscale. Here, we report HHG from a low-loss, indium-doped cadmium oxide thin film by leveraging the epsilon-near-zero (ENZ) effect, whereby the real part of the material's permittivity in certain spectral ranges vanishes, as well as the associated large resonant enhancement of the driving laser field. We find that ENZ-assisted harmonics exhibit a pronounced spectral redshift as well as linewidth broadening, resulting from the photo induced electron heating and the consequent time-dependent ENZ wavelength of the material. **Our results provide a new platform to study strong-field and ultrafast electron dynamics in ENZ materials, reveal new degrees of freedom for spectral and temporal control of HHG, and open up the possibilities of compact solid-state attosecond light sources.**

Abstract: Relevance/Impact

…"Our results provide a new platform to study strong-field and ultrafast electron dynamics in ENZ materials, reveal new degrees of freedom for spectral and temporal control of HHG, and open up the possibilities of compact solid-state attosecond light sources."

For this lab:

Each lab in senior lab comes from the first stages of a larger research lab. (Absorption spectroscopy of Rubidium is used in many Bose-Einstein-Condensation experiments, for example.)

Think about this is experiment relevant to a future experiment or a bigger research program. What could be done with these results?

The relevance of the experiment you are writing up could be framed in terms of future new research made possible by this preliminary setup.

Lab Reports

- **Main sections (see guide in class website for specific details)**
  - **Abstract**: concise description of methods and results.
  - **Introduction**: motivation, background and summary of experiment
  - **Methods**: description of experimental methods and **calibrations**
  - **Data**: present the data, use plots or/and tables
  - **Results and data analysis**: describe how the data analysis was done and present your results with errors
  - **Discussion**
  - **Conclusion**
  - **References:** Pick a consistent format. If you don't know one, use this:

    A. Author, B. Coauthor, C. Lastauthor, "Title," *Journal using standard abbreviation such as Nat. Phys.* **Volume,** first page–last page (year published).
  - **Appendix if necessary**

Error Analysis

When applicable, you must give the uncertainty in your results.

This comes from various sources:

- The error bar on a fit. (A fit to (the expected function) gives a rate of 4.0(1) liters/s.)
- The resolution of an instrument you used to measure. ("The analyzer had a resolution bandwidth of 100 kHz.")
- The standard deviation on repeated measurements. (We measure 100(9) counts per minute.)

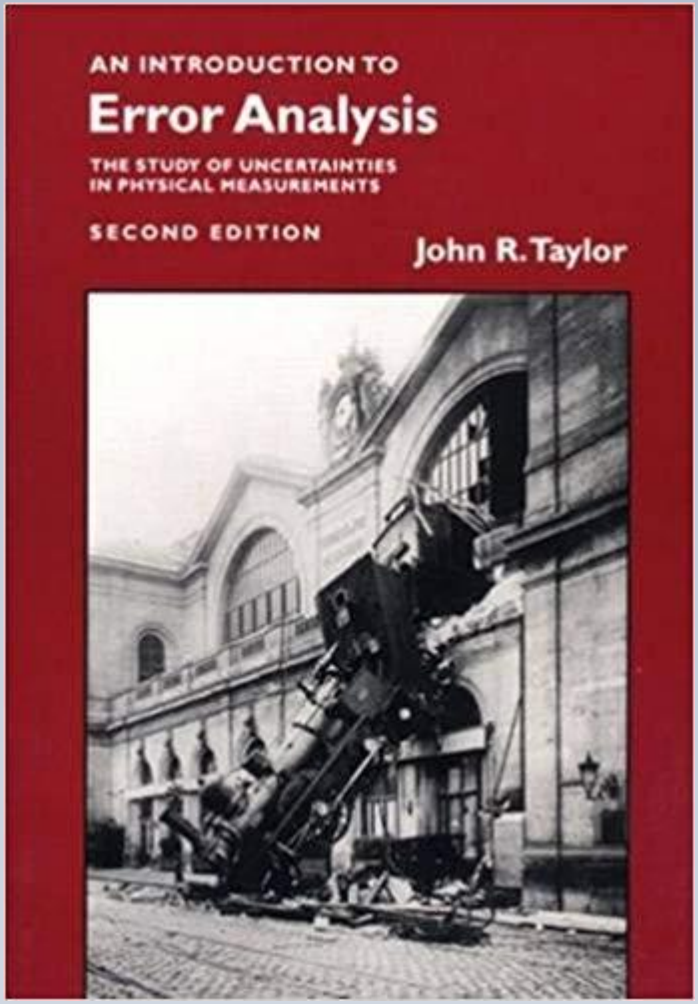
In general, different sources of error are reported separately.

When errors are combined, they generally add in quadrature:

$$\text{Error reported} = \sqrt{(error1)^2 + (error2)^2}$$

When reporting errors, tell the reader where they come from. (You do not need to include the calculations in the report—but it needs to be in your lab notebook.)

Error Analysis: an excellent reference



Announcement:

With the exception of the Machine Shop Module:

Monday Labs will now be 8-10:50.

The extra hour (11-12) is optional for you to use if you need extra time to finish.

(Machine shop module will still meet 8-11:50 on Mondays.)