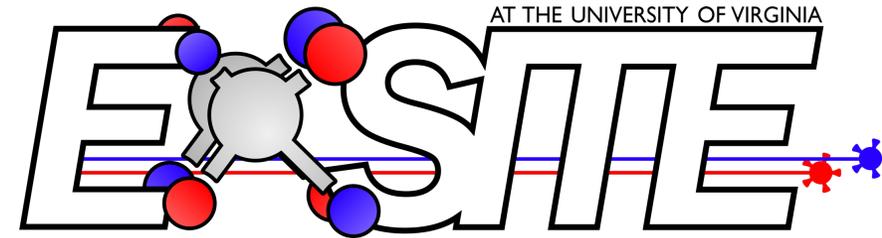




UVA



# Pump-probe thermoreflectance: then and now

**Patrick E. Hopkins**

Co-Founder, Laser Thermal

[patrick@laserthermal.com](mailto:patrick@laserthermal.com)

Whitney Stone Professor, University of Virginia

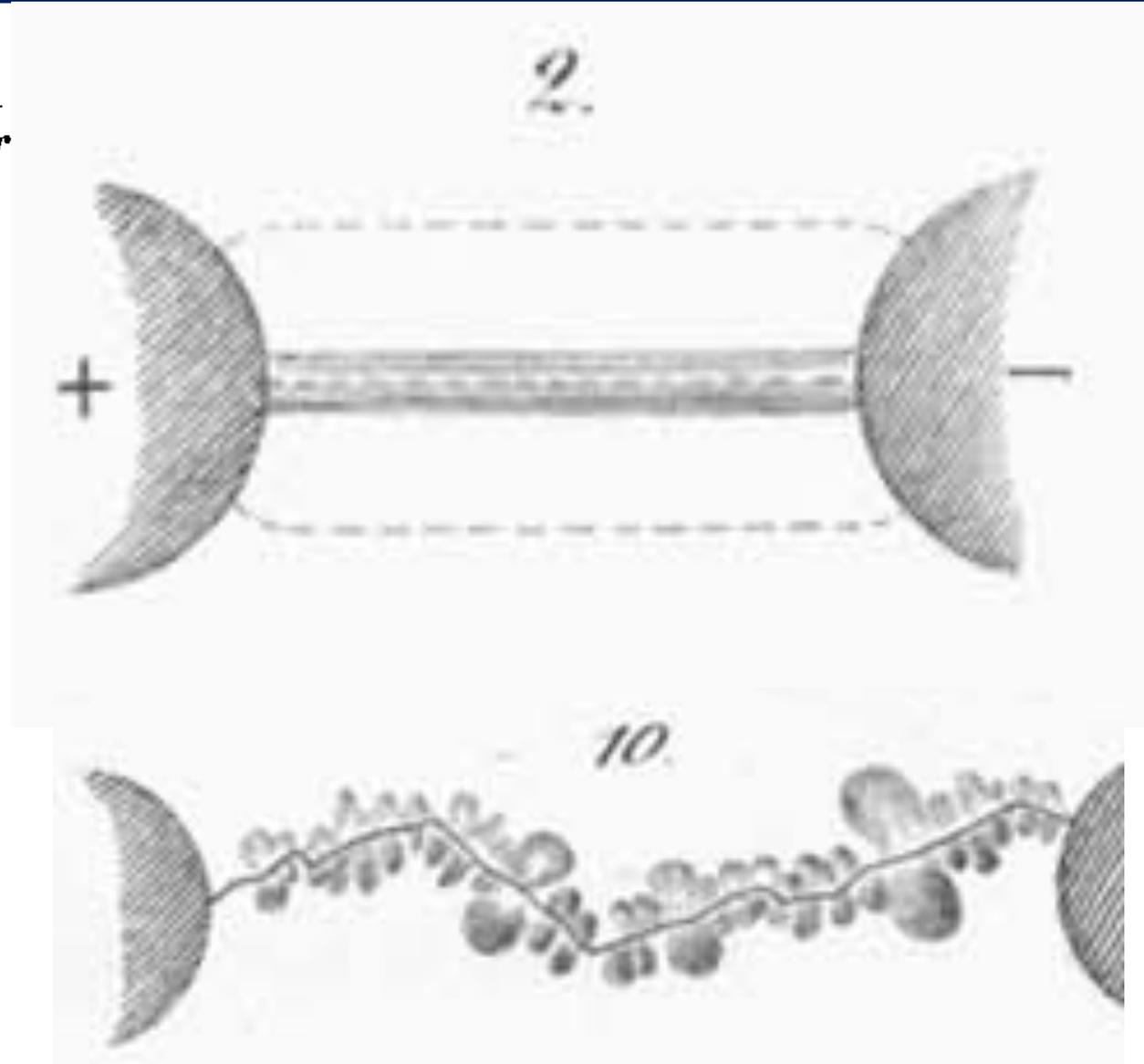
[phopkins@virginia.edu](mailto:phopkins@virginia.edu)

# The beginning: Transient light sparks

## II. *Optische Studien nach der Methode der Schlierenbeobachtung;* *von A. Töpler.*

(Fortsetzung von Bd. 131, S. 215.)

- “Pump” light sparks of less than 2 microseconds
- Observe transient changes in refractive index of liquids



# Thermomodulation spectroscopy and thermorelectance

Modulation Spectroscopy  
(Solid state physics)



Cardona, Manuel

Note: This is not the actual book cover

PHYSICAL REVIEW B

VOLUME 5, NUMBER 10

15 MAY 1972

## Thermomodulation Spectra of Al, Au, and Cu<sup>†</sup>

R. Rosei\* and D. W. Lynch

*Institute for Atomic Research and Department of Physics, Iowa State University, Ames, Iowa 50010*

(Received 10 January 1972)

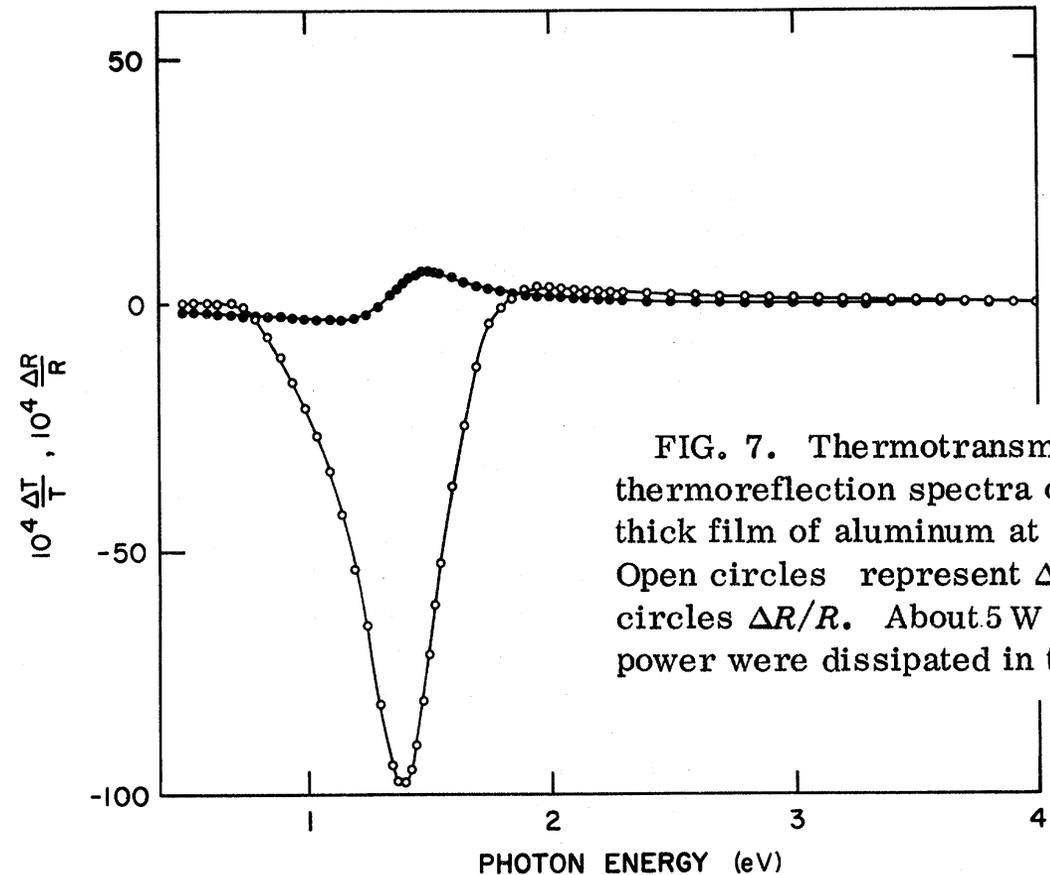


FIG. 7. Thermotransmission and thermorelection spectra of a 310-Å-thick film of aluminum at about 370 K. Open circles represent  $\Delta T/T$  and closed circles  $\Delta R/R$ . About 5 W of modulating power were dissipated in the sample.

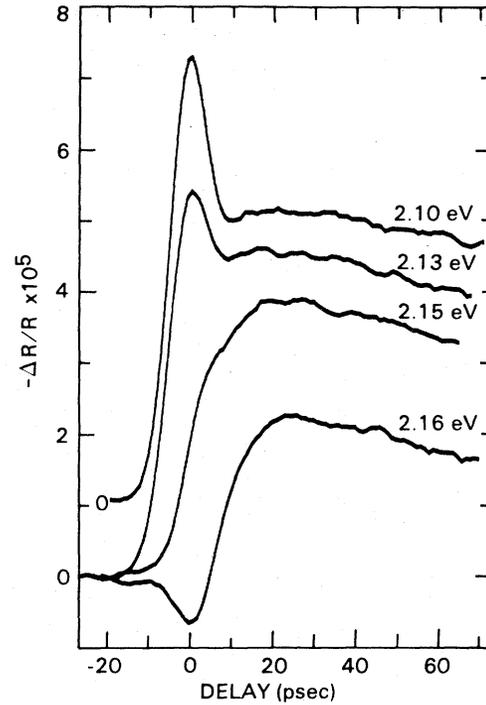
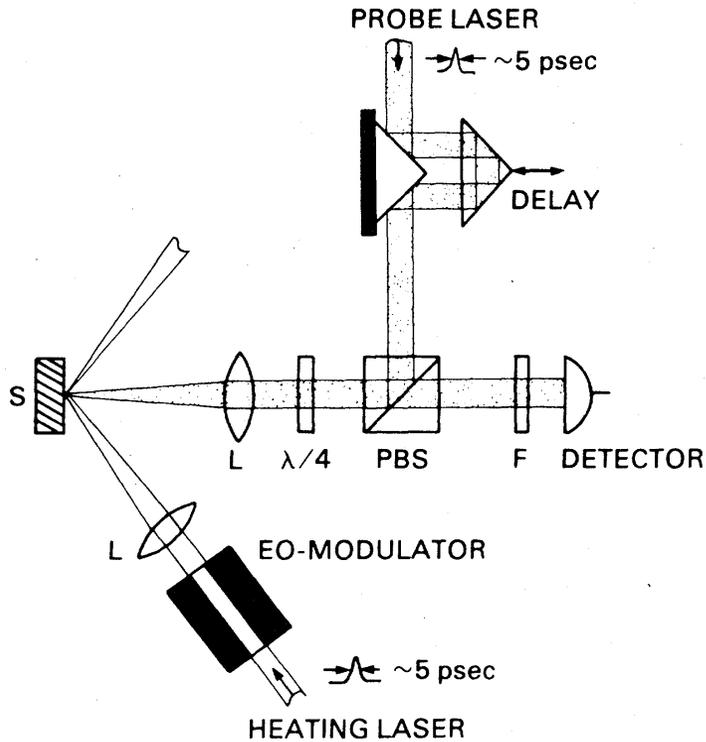
# “Modulate power with laser”: Pump-probe

## Observation of Nonequilibrium Electron Heating in Copper

G. L. Eesley

Physics Department, General Motors Research Laboratories, Warren, Michigan 48090

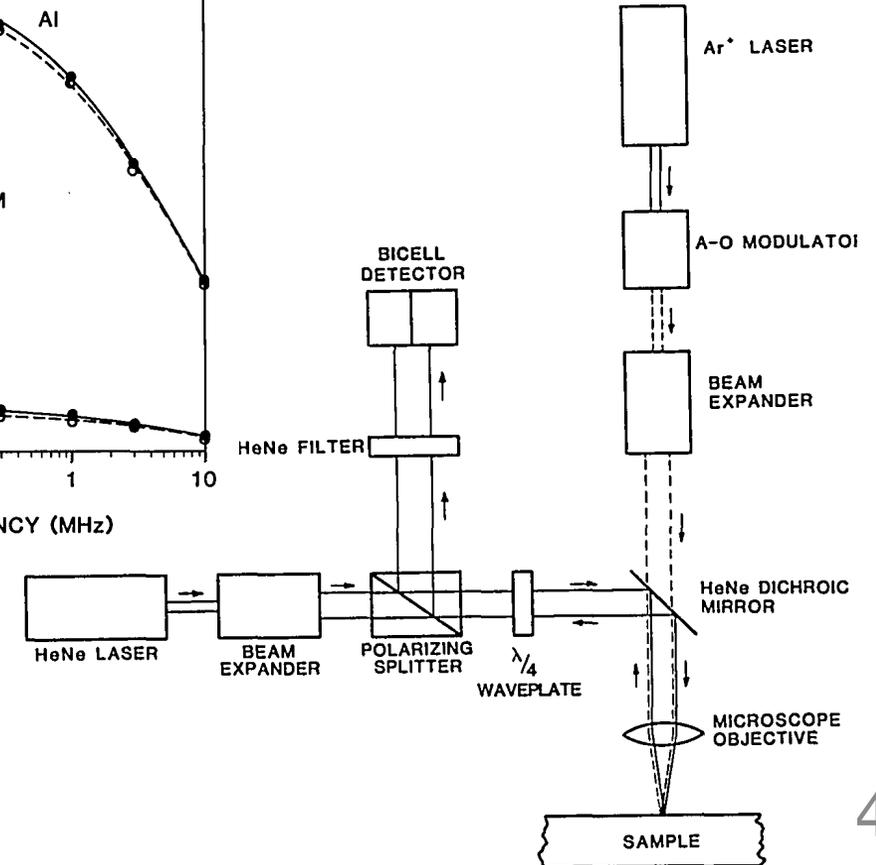
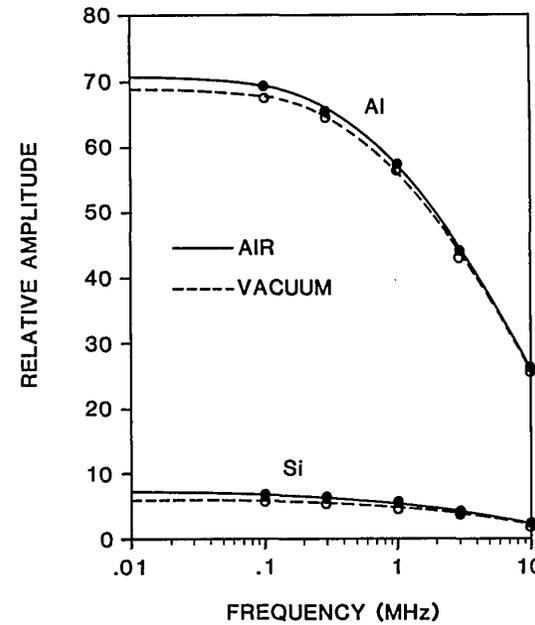
(Received 26 September 1983)



## Thermal-wave detection and thin-film thickness measurements with laser beam deflection

15 October 1983 / Vol. 22, No. 20 / APPLIED OPTICS 3169

Jon Opsal, Allan Rosencwaig, and David L. Willenborg



# TDTR by Cahill: Simplifying, standardizing & embracing out of phase signals

## Thermometry and Thermal Transport in Micro/Nanoscale Solid-State Devices and Structures

Journal of Heat Transfer

APRIL 2002, Vol. 124 / 223

REVIEW OF SCIENTIFIC INSTRUMENTS

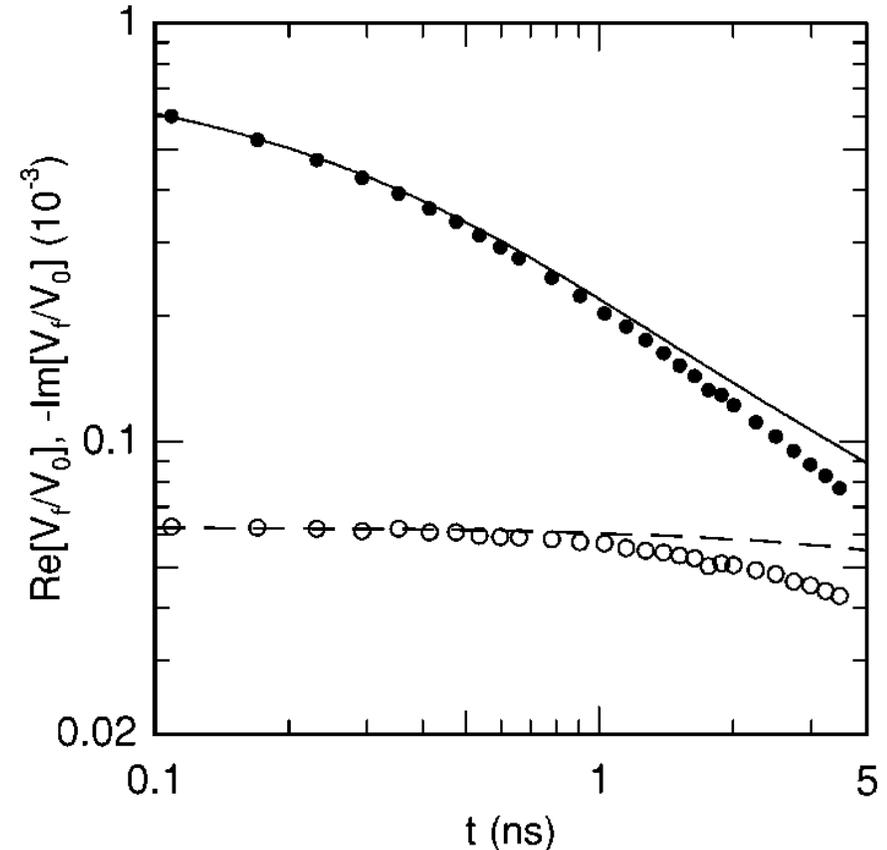
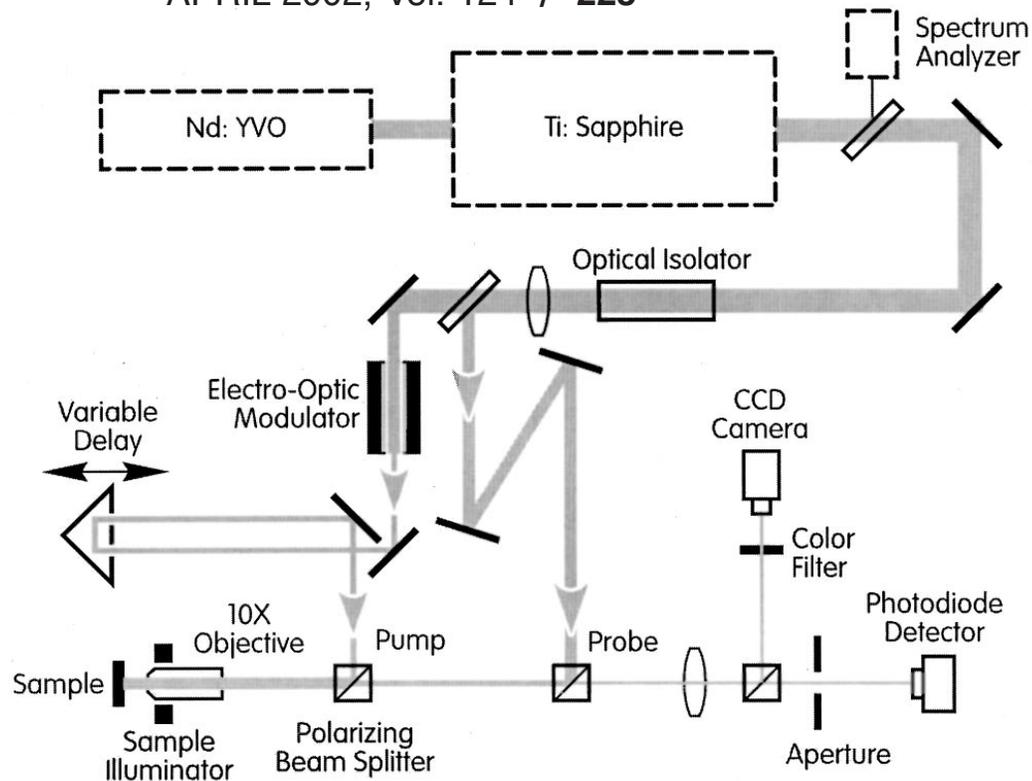
VOLUME 75, NUMBER 12

DECEMBER 2004

### Analysis of heat flow in layered structures for time-domain thermoreflectance

David G. Cahill<sup>(a)</sup>

Department of Materials Science and Engineering and Frederick Seitz Materials Research Laboratory, University of Illinois, Urbana, Illinois 61801



**David G. Cahill**

Department of Materials Science and Engineering, and the Frederick Seitz Materials Research Laboratory, University of Illinois, Urbana, IL 61801

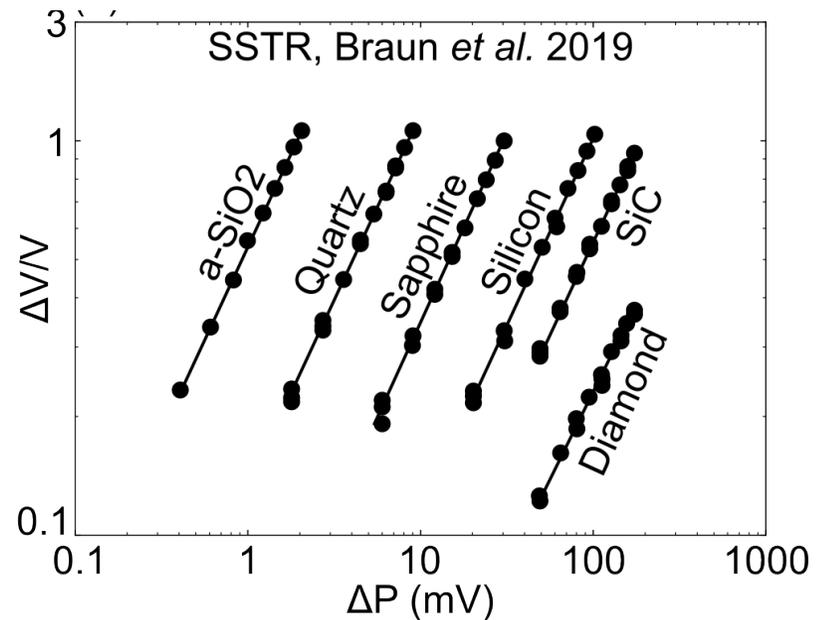
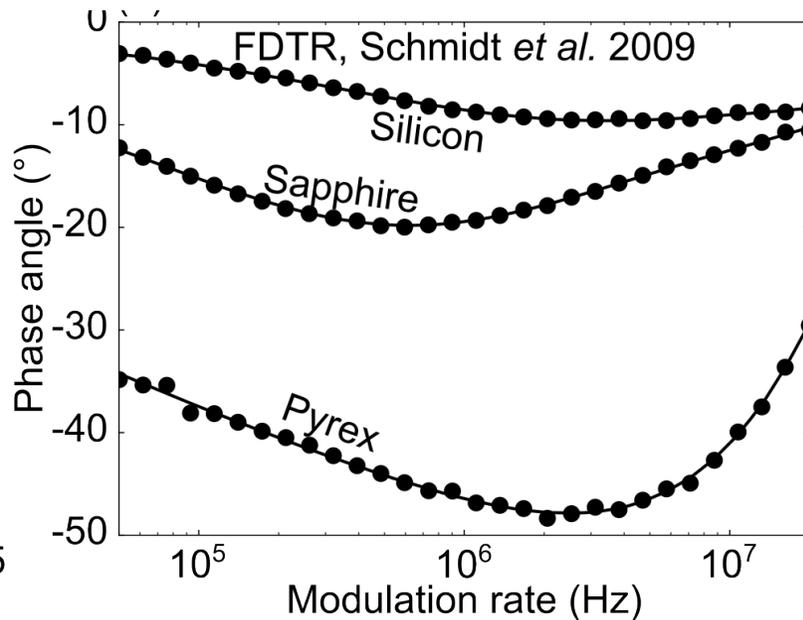
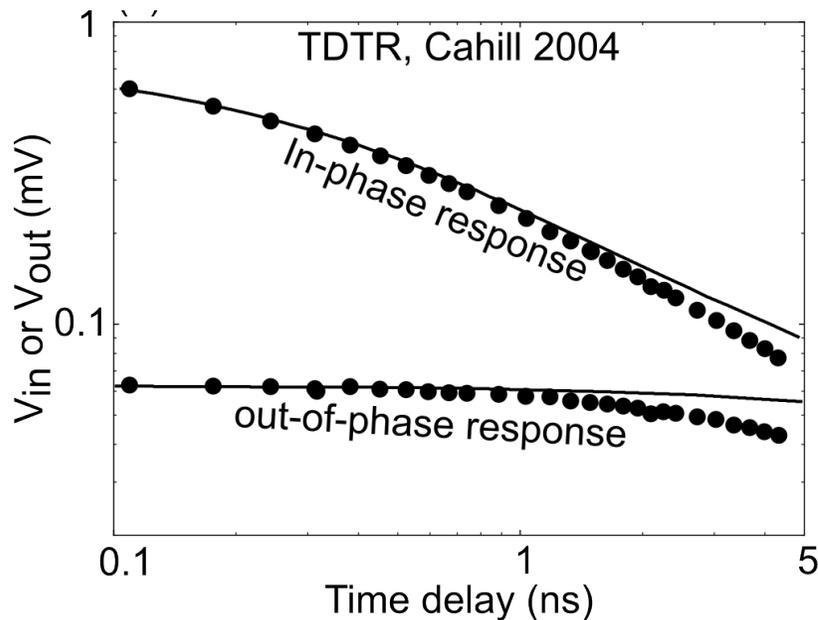
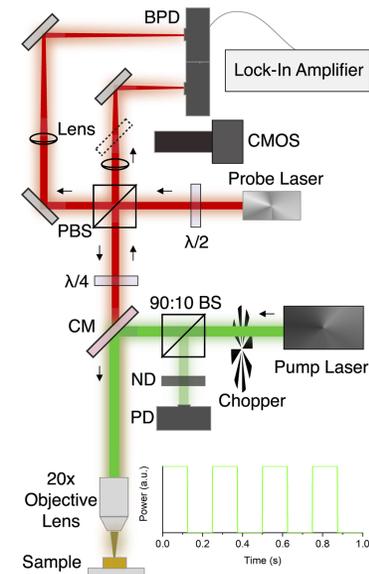
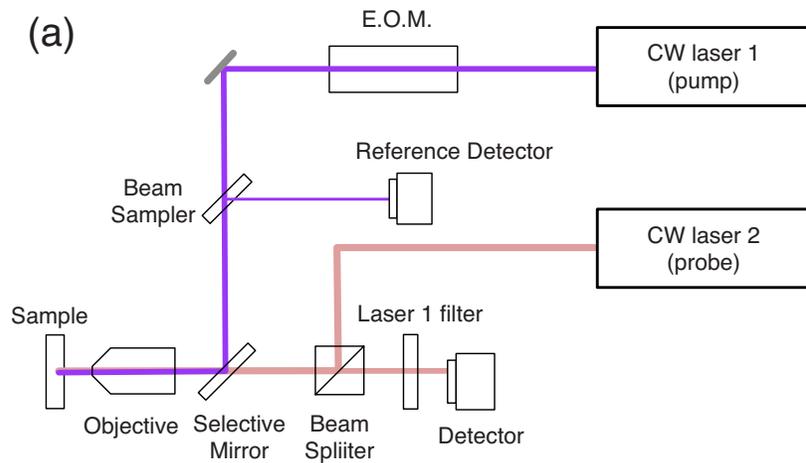
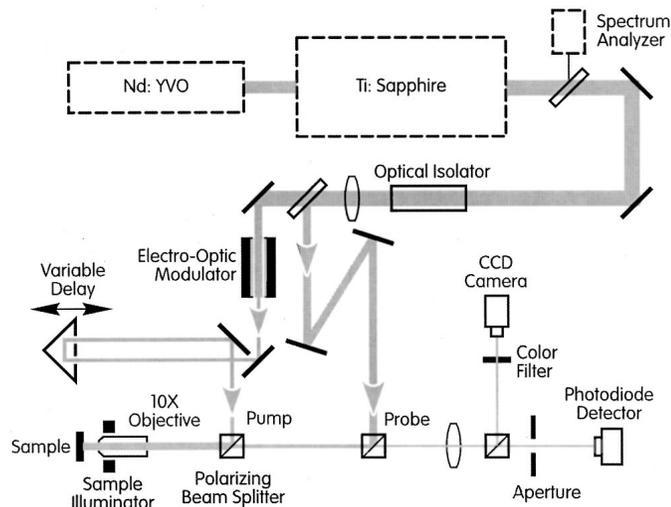
**Kenneth Goodson**

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e-mail: majumdar@me.berkeley.edu

# The “basic flavors” of thermoreflectance



# Some “how to” papers

## TDTR

JOURNAL OF APPLIED PHYSICS 124, 161103 (2018)



### Tutorial: Time-domain thermoreflectance (TDTR) for thermal property characterization of bulk and thin film materials

Puqing Jiang, Xin Qian, and Ronggui Yang<sup>a)</sup>  
*Department of Mechanical Engineering, University of Colorado, Boulder, Colorado 80309, USA*

the transducer. A commercial fiber-based SSTR (SSTR-F) has now been developed while turnkey FDTR or TDTR instruments do not yet exist.

## FDTR

An instrumentation guide to measuring thermal conductivity using frequency domain thermoreflectance (FDTR)

Cite as: Rev. Sci. Instrum. 95, 103006 (2024); doi: 10.1063/5.0213738  
Submitted: 12 April 2024 • Accepted: 19 September 2024 •  
Published Online: 14 October 2024



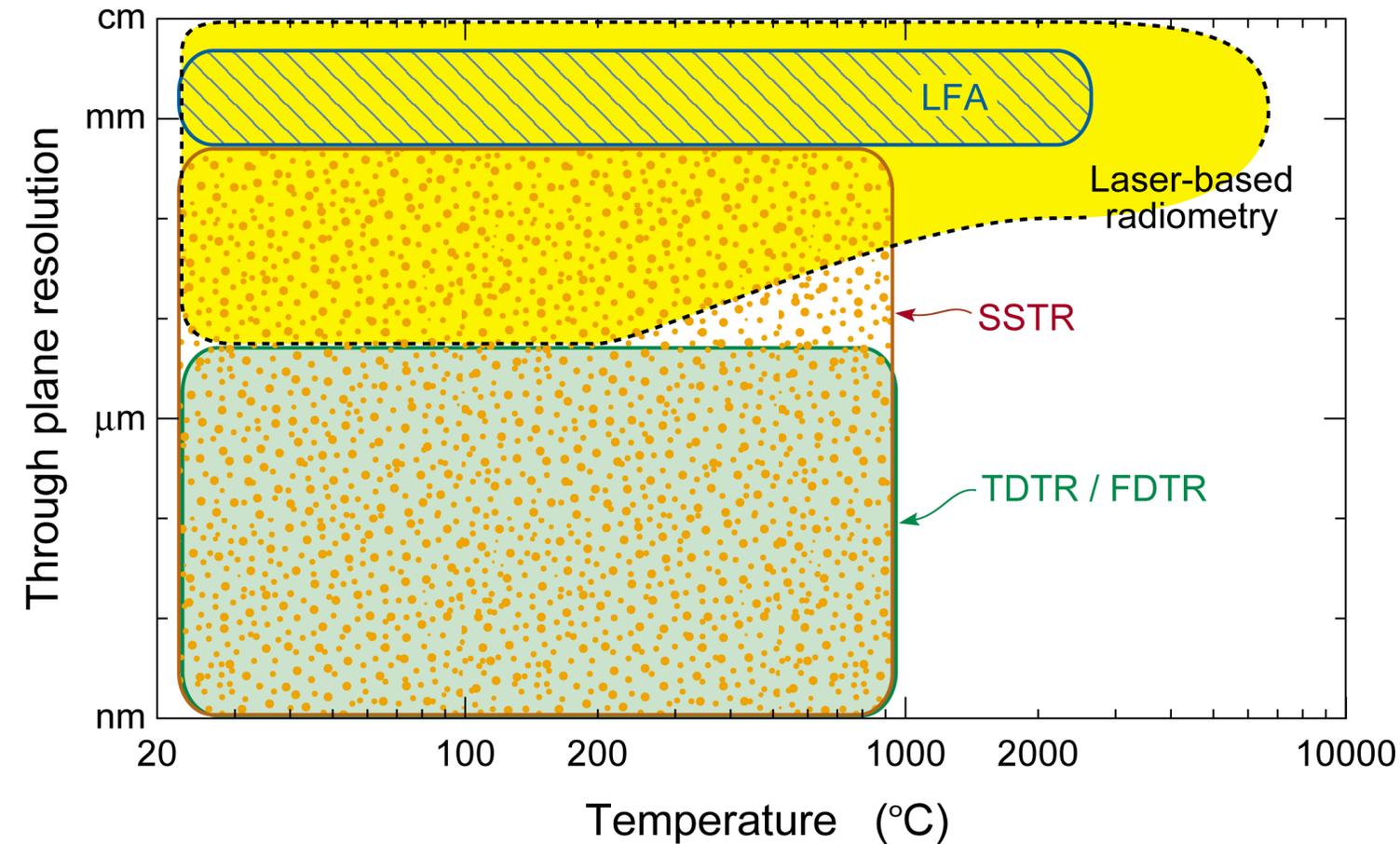
Dylan J. Kirsch,<sup>1,2,a)</sup> Joshua Martin,<sup>1,b)</sup> Ronald Warzoha,<sup>3,c)</sup> Mark McLean,<sup>1,d)</sup> Donald Windover,<sup>1,e)</sup> and Ichiro Takeuchi<sup>2,f)</sup>

Quote  
from  
paper



COI Statement: Hopkins' co-founder of LT

# But what about the limitations? And tips and tricks?



Limitations and advances in optical thermometry: nanoscale resistances, high thermal conductivity materials, and ultrahigh temperatures

Thomas W. Pfeifer,<sup>\*</sup> Hunter B. Schonfeld,<sup>†</sup> and Ethan A. Scott<sup>‡</sup>  
*Department of Mechanical and Aerospace Engineering,  
University of Virginia, Charlottesville, Virginia 22904, USA*

Henry Aller<sup>§</sup> and Samuel Graham<sup>¶</sup>  
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University of Maryland, College Park, Maryland 20742, USA*

John T. Gaskins,<sup>\*\*</sup> David H. Olson,<sup>††</sup> and Jeffrey Braun<sup>‡‡</sup>  
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Patrick E. Hopkins<sup>§§</sup>  
*Department of Mechanical and Aerospace Engineering, University of Virginia,  
Charlottesville, Virginia 22904, USA*  
*Department of Physics, University of Virginia,  
Charlottesville, Virginia 22904, USA*  
*Department of Materials Science and Engineering,  
University of Virginia, Charlottesville, Virginia 22904, USA and  
Laser Thermal, Charlottesville, Virginia 22904, USA*

# But what about the limitations? And tips and tricks?

## Unwrapping a full temporal cycle in time domain thermoreflectance for enhanced measurement sensitivity in thermally insulating materials

Cite as: Rev. Sci. Instrum. 93, 084904 (2022); doi: 10.1063/5.0089075  
 Submitted: 22 February 2022 • Accepted: 14 July 2022 •  
 Published Online: 19 August 2022



Brian F. Donovan,<sup>1</sup> Taylor L. Gray,<sup>1</sup> Adam A. Wilson,<sup>2</sup> and Ronald J. Warzoha<sup>3</sup>

## An instrumentation guide to measuring thermal conductivity using frequency domain thermoreflectance (FDTR)

Cite as: Rev. Sci. Instrum. 95, 103006 (2024); doi: 10.1063/5.0213738  
 Submitted: 12 April 2024 • Accepted: 19 September 2024 •  
 Published Online: 14 October 2024



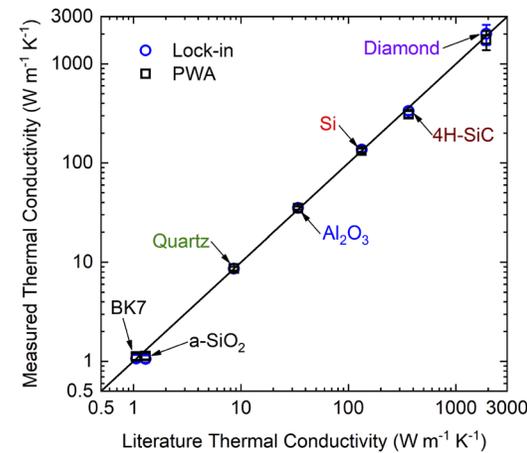
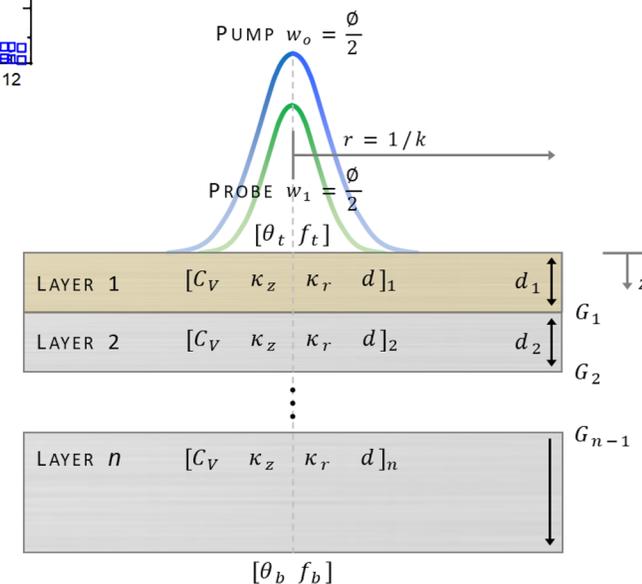
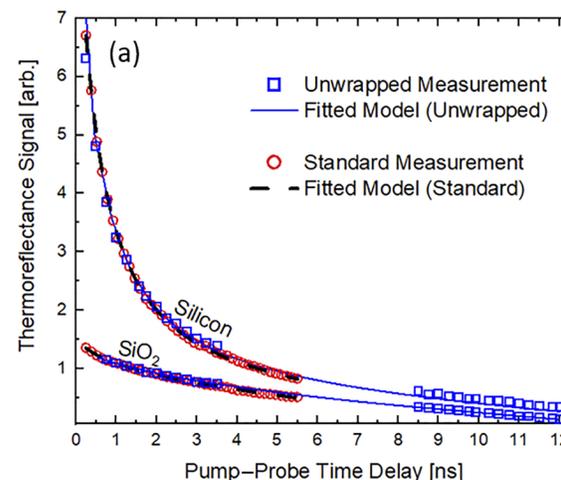
Dylan J. Kirsch,<sup>1,2,a)</sup> Joshua Martin,<sup>1,b)</sup> Ronald Warzoha,<sup>3,c)</sup> Mark McLean,<sup>1,d)</sup> Donald Windover,<sup>1,e)</sup> and Tomo Takeuchi<sup>2,f)</sup>

## A steady-state thermoreflectance method to measure thermal conductivity

Cite as: Rev. Sci. Instrum. 90, 024905 (2019); doi: 10.1063/1.5056182  
 Submitted: 12 September 2018 • Accepted: 9 February 2019 •  
 Published Online: 28 February 2019



Jeffrey L. Braun,<sup>1</sup> David H. Olson,<sup>1</sup> John T. Gaskins,<sup>1</sup> and Patrick E. Hopkins<sup>1,2,3,a)</sup>



# But what about the limitations? And tips and tricks?

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Research Article

## Measurements of Thermal Resistance Across Buried Interfaces with Frequency-Domain Thermoreflectance and Microscale Confinement

Ronald J. Warzoha,\* Adam A. Wilson, Brian F. Donovan, Andy Clark, Xuemei Cheng, Lu An, and Gang Peng

Cite This: <https://doi.org/10.1021/acsami.4c05258>

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*Letters*

Letter

[pubs.acs.org/JPL](https://pubs.acs.org/JPL)

## Time-Resolved Magneto-Optical Kerr Effect of Magnetic Thin Films for Ultrafast Thermal Characterization

Jun-Yang Chen,<sup>†</sup> Jie Zhu,<sup>‡,§</sup> Delin Zhang,<sup>†</sup> Dustin M. Lattery,<sup>‡</sup> Mo Li,<sup>†</sup> Jian-Ping Wang,<sup>†</sup> and Xiaojia Wang<sup>\*,‡</sup>

