UVA SCHOOL of ENGINEERING & APPLIED SCIENCE

Assessment of defects and quality of thin films and interfaces with laser-based thermoreflectance thermal conductivity measurements

Patrick E. Hopkins

Professor, University of Virginia

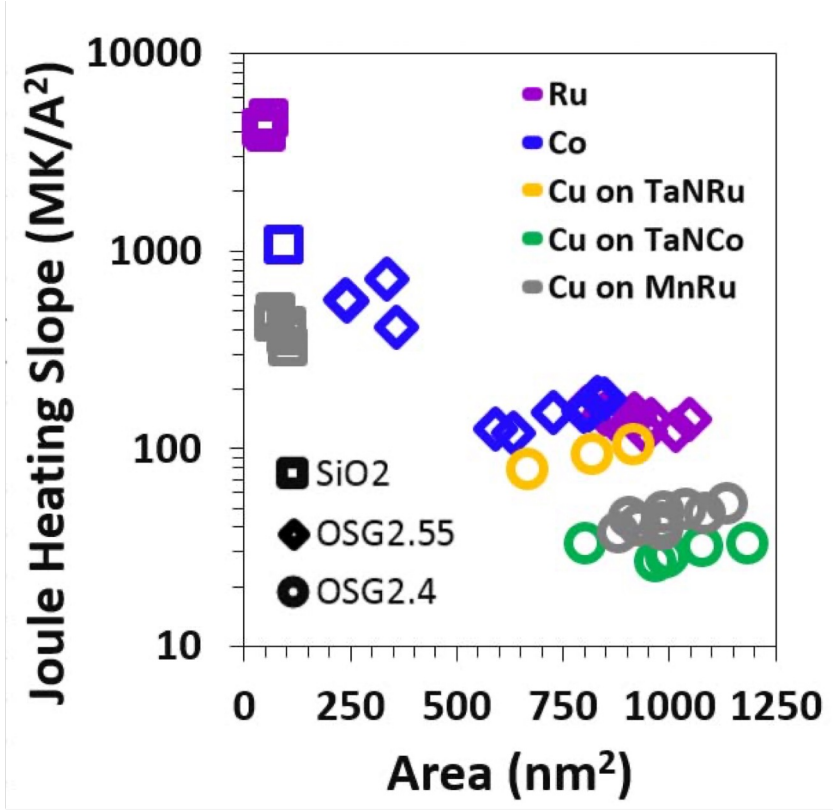
Co-Founder, Laser Thermal

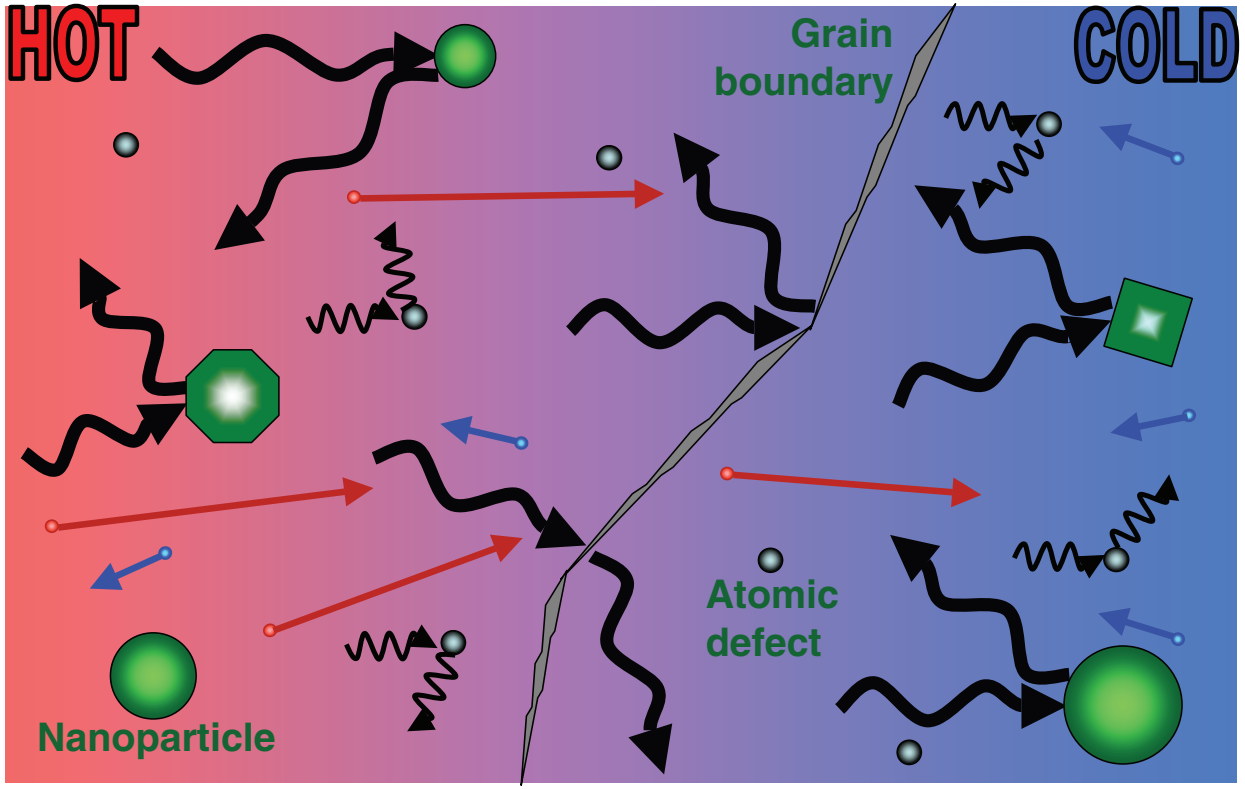
phopkins@virginia.edu

patrickehopkins.com

The problem w/ high electrical and thermal resistances

High electrical and thermal resistivities from reduced dimensionality and interface scattering lead to self heating & deleterious device performance

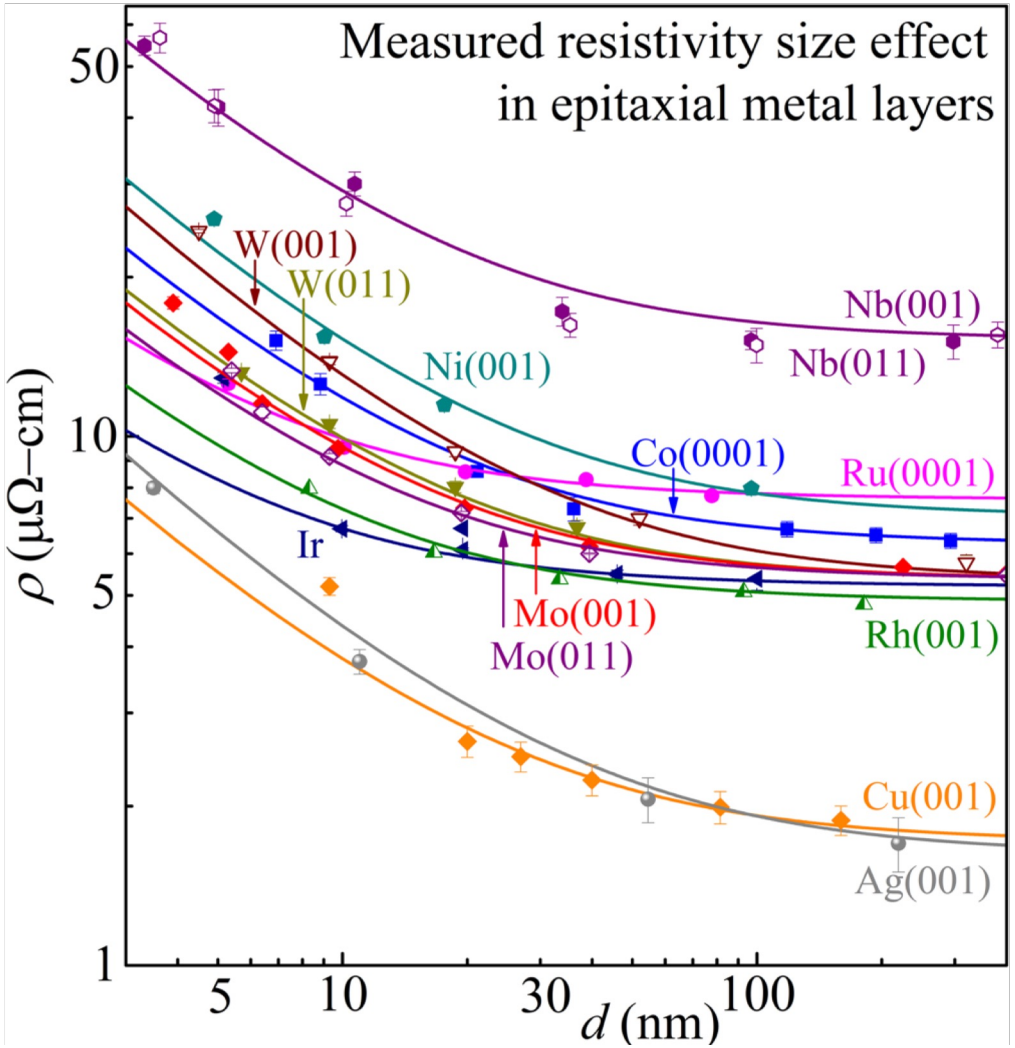




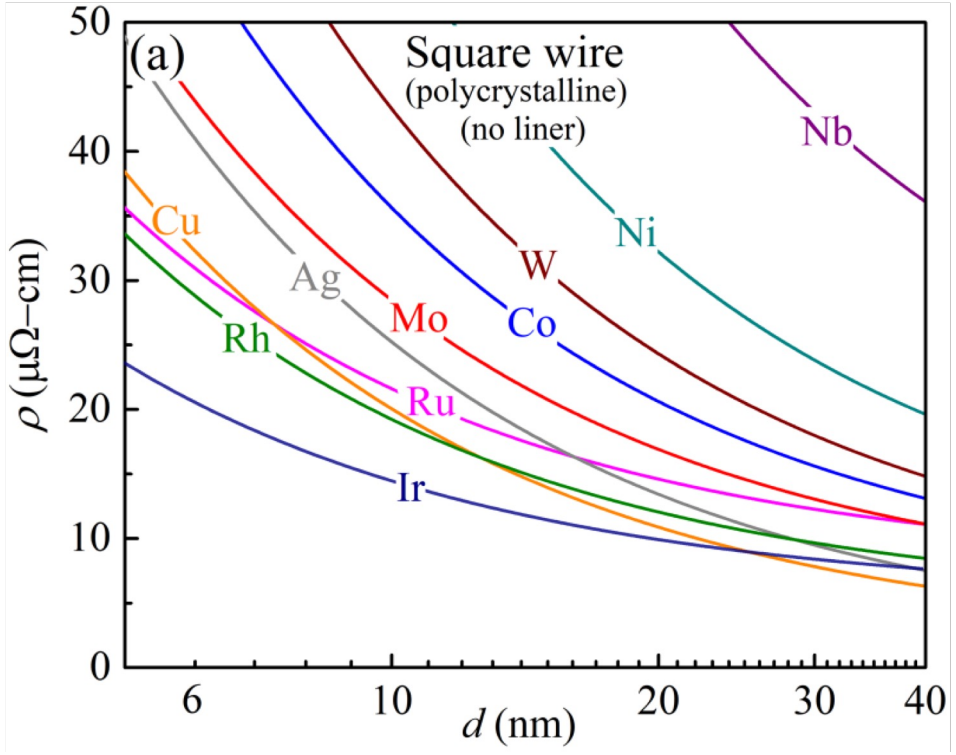
2018 IEEE IEDM 5.3.1-5.3.4
doi: 10.1109/IEDM.2018.8614695

Adv. Mat. **22**, 3970

Electrical resistivity scaling



On the nanoscale, copper may not have the lowest resistivity compared to other metals



JAP **127**, 050901

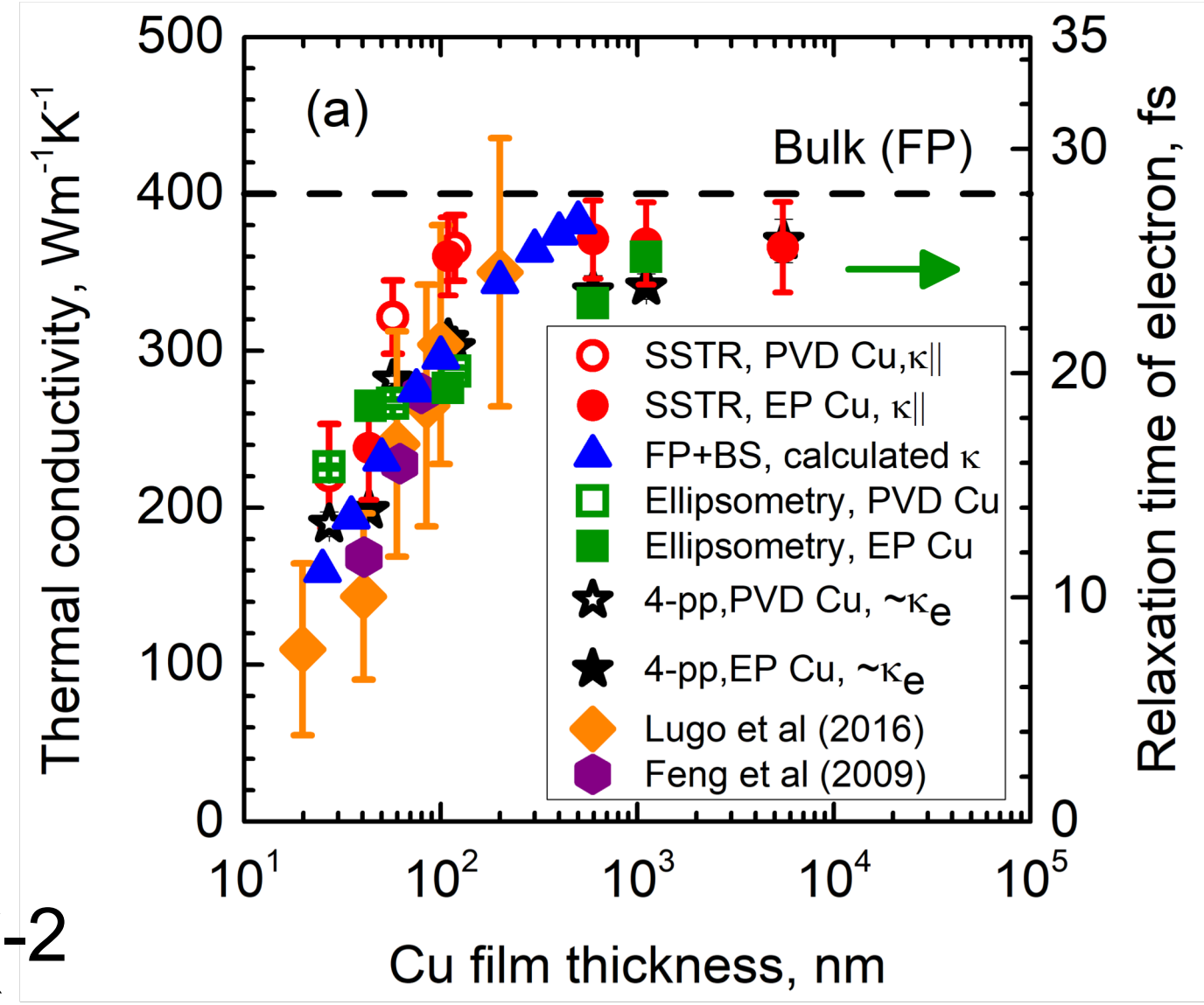
Thermal conductivity scaling and the Wiedemann-Franz Law

Electron thermal conductivity

$$\kappa = L\sigma T$$

Electrical conductivity

$$L_0 = 2.45 \times 10^{-8}\ \mathrm{W\ \Omega\ K^{-2}}$$



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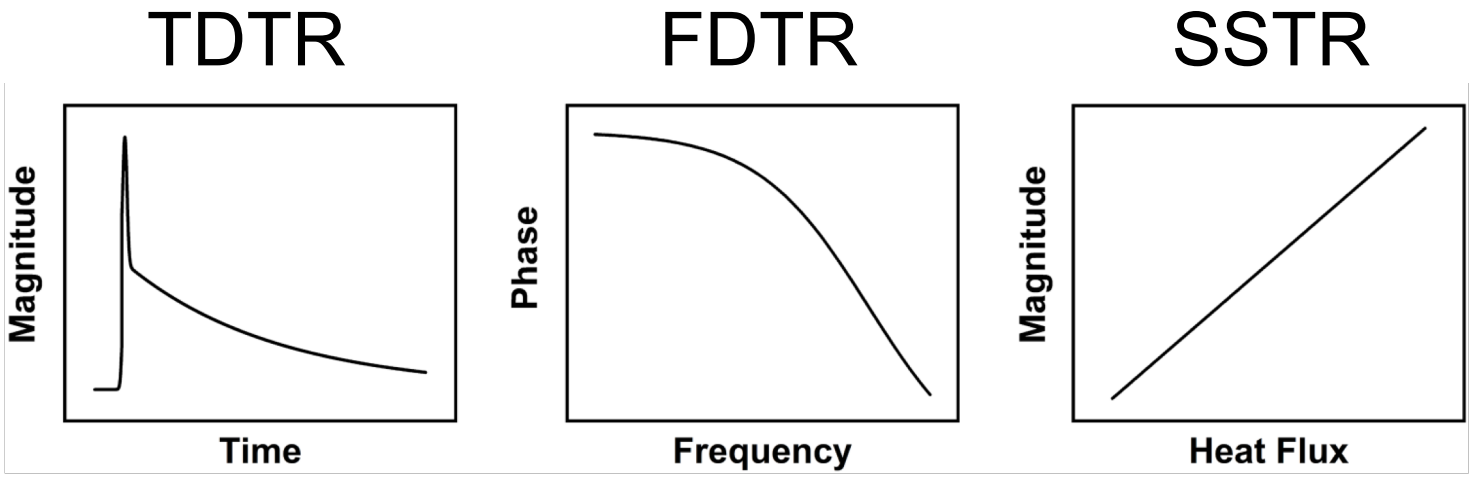
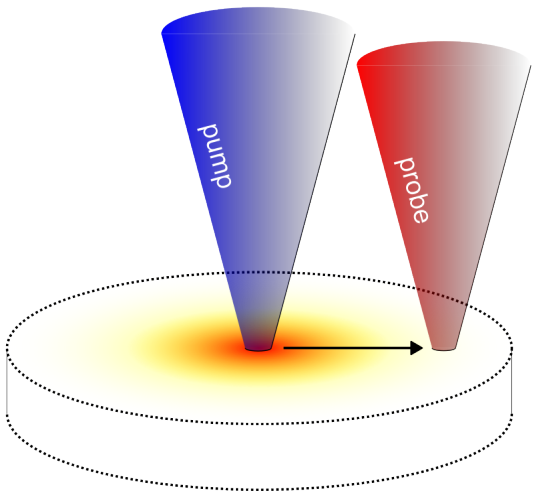
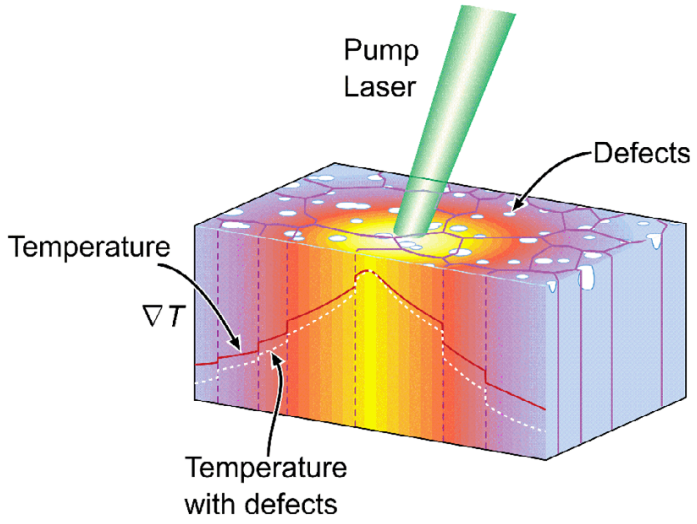
Need methods to measure thermal conductivity of thin films and thermal resistance at interfaces so we do not rely on the Wiedemann-Franz law to evaluate thermal properties of interconnects

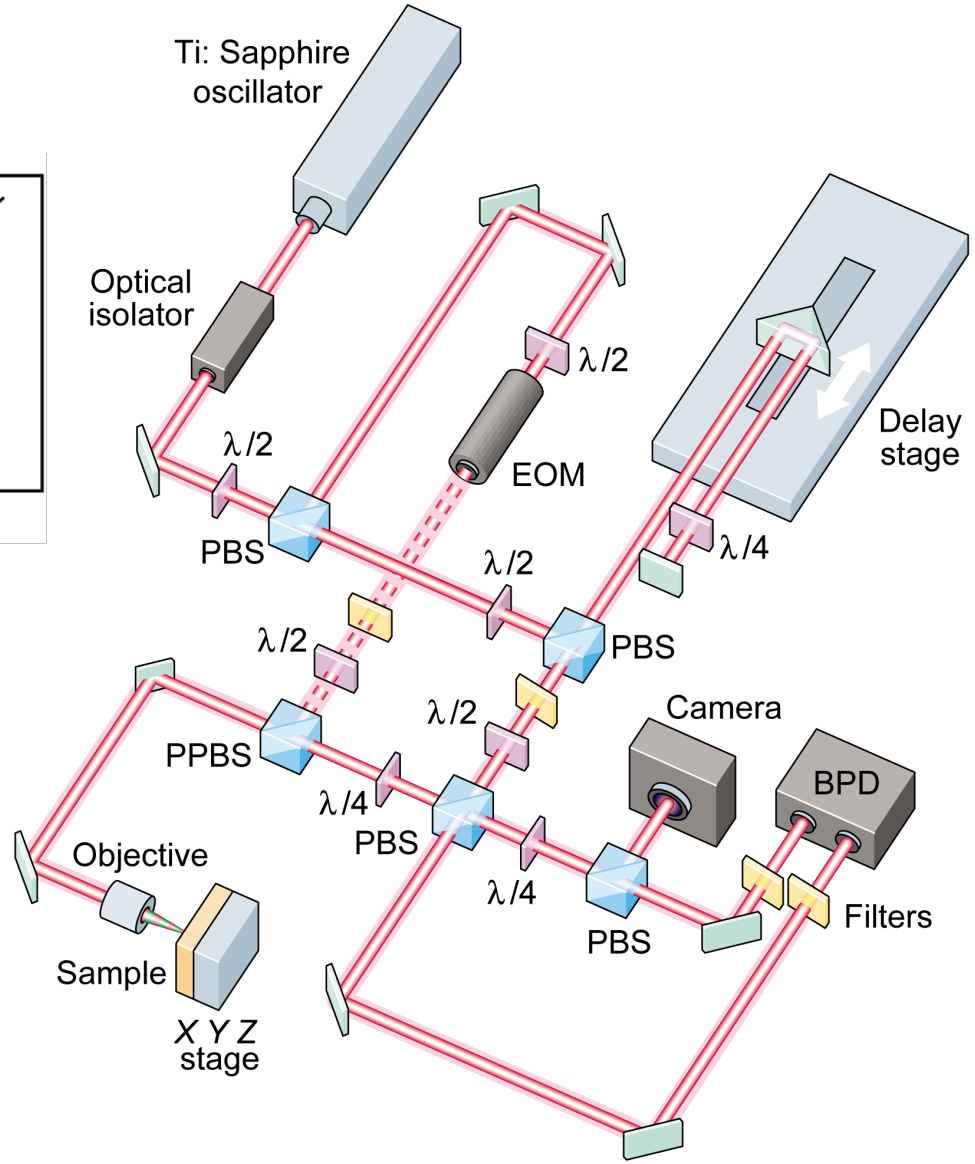
- Pump-probe thermoreflectance to measure thermal conductivity
  - TDTR, FDTR, SSTR
- Metal thin films, failure of the WF Law, and potential for layered 2D delafossite films with exceptionally high thermal conductivities
- Cohesive energy of thin metals evaluated w/ short pulsed laser ablation

Measuring the thermal conductivity of thin films

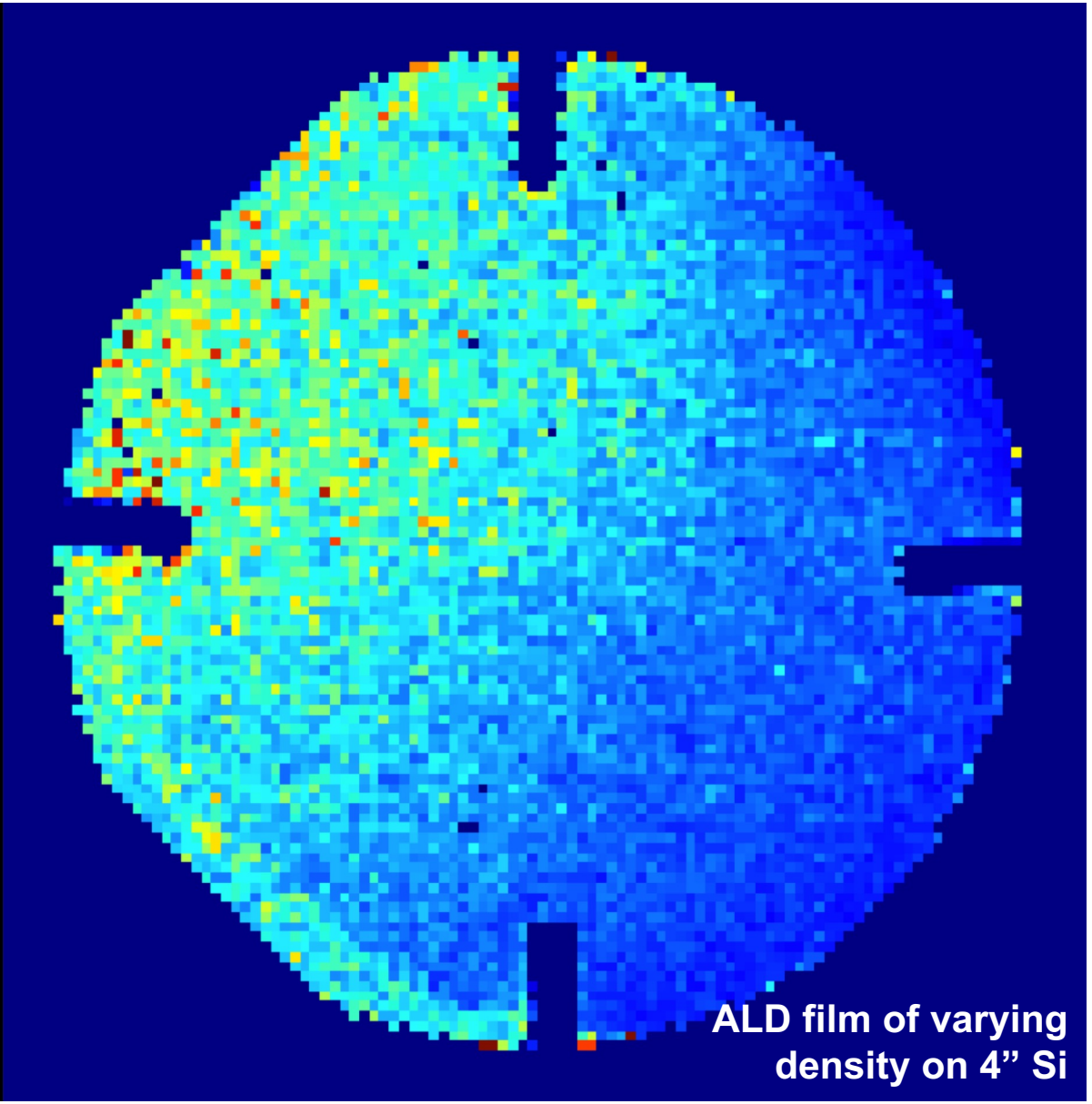


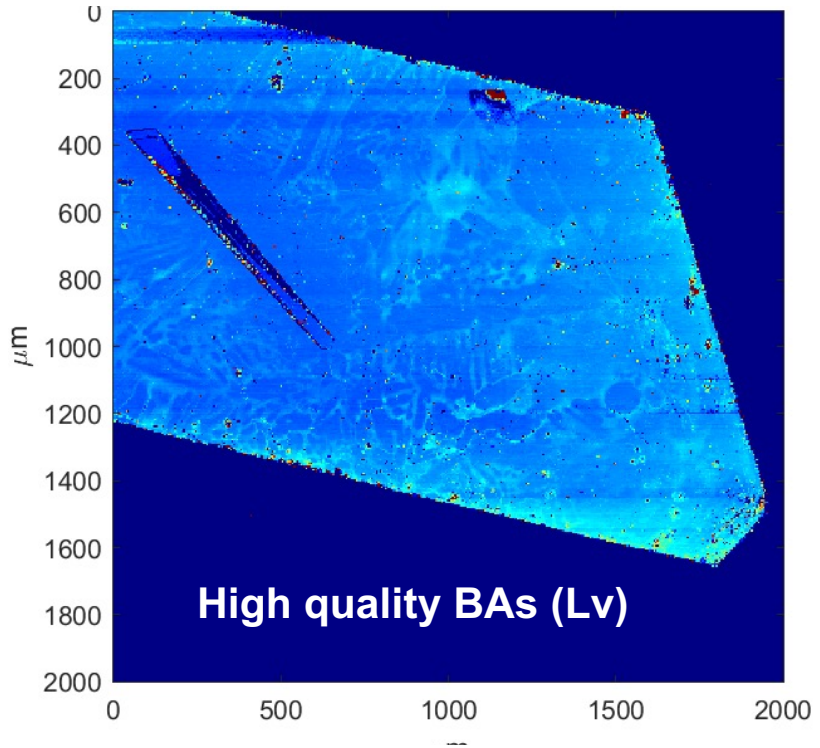


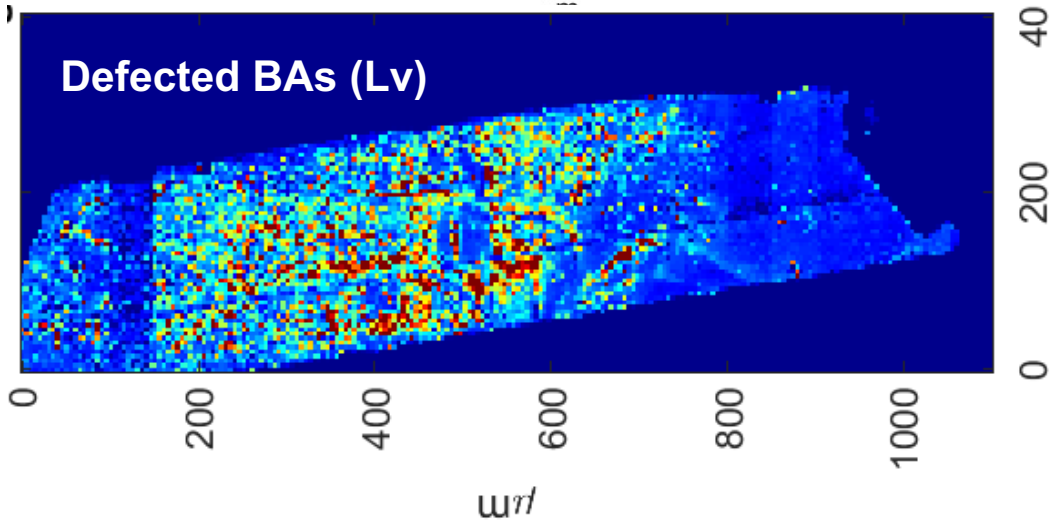




Evaluating spatial inhomogeneities in film/crystal growth

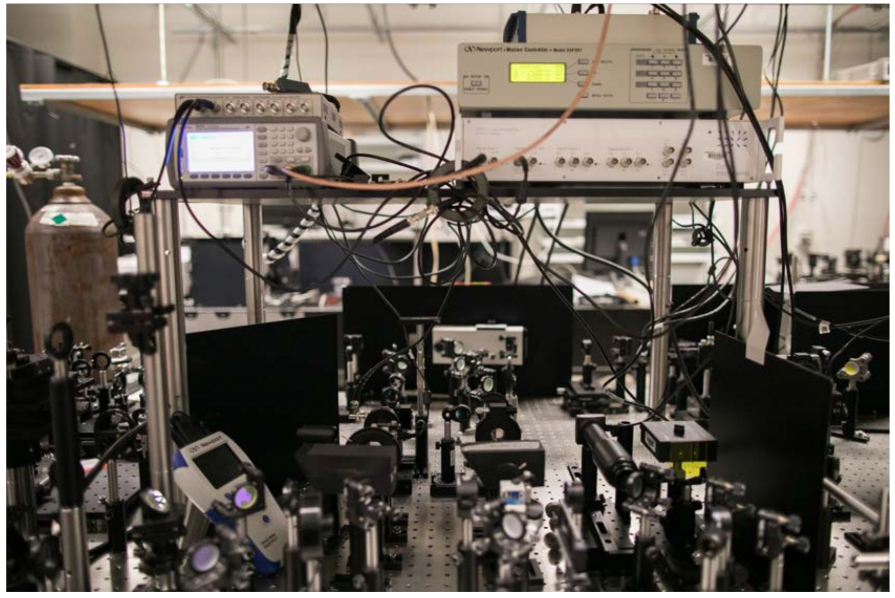






Commercializing FDTR/SSTR: Laser Thermal

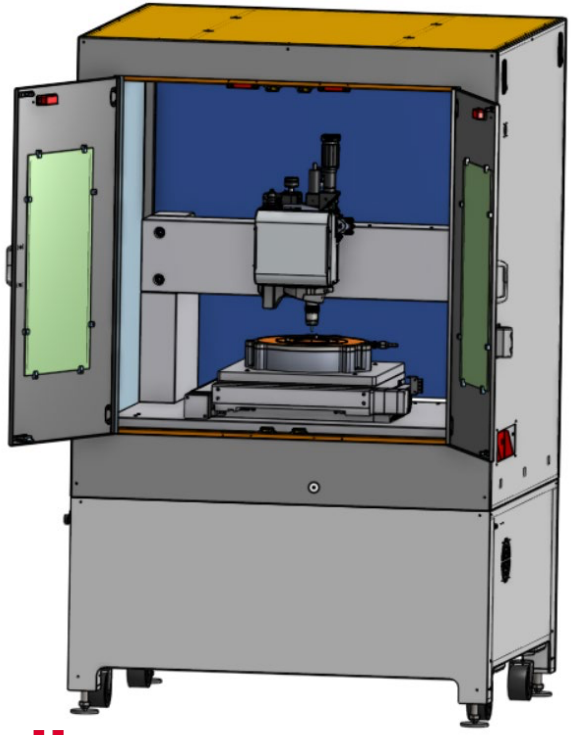
AT THE UNIVERSITY OF VIRGINIA



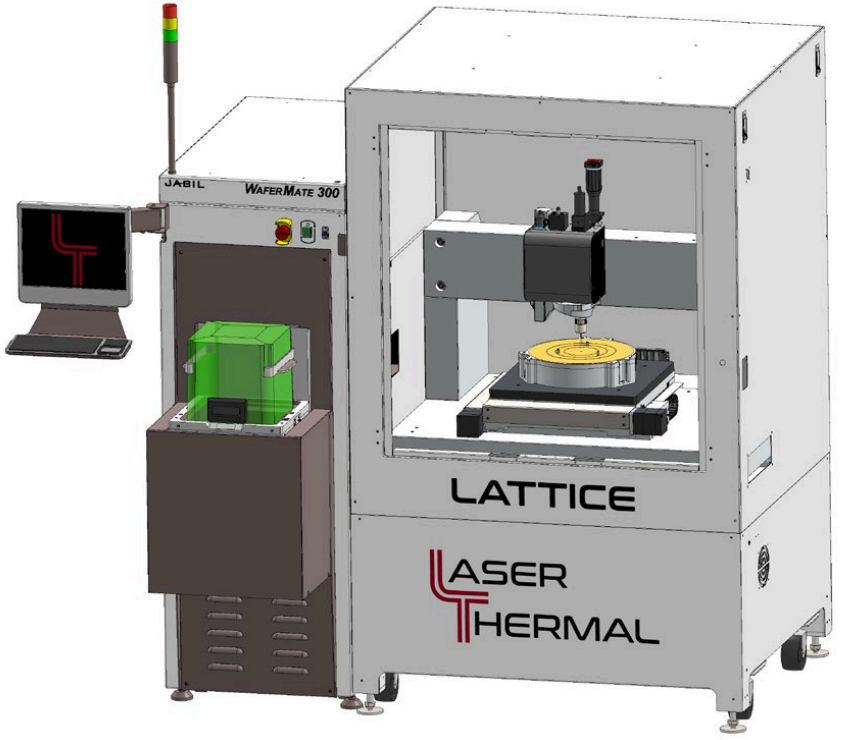
Commercializing FDTR/SSTR: Laser Thermal

Currently Available (150 mm)

300 mm automated scanning available late 2026



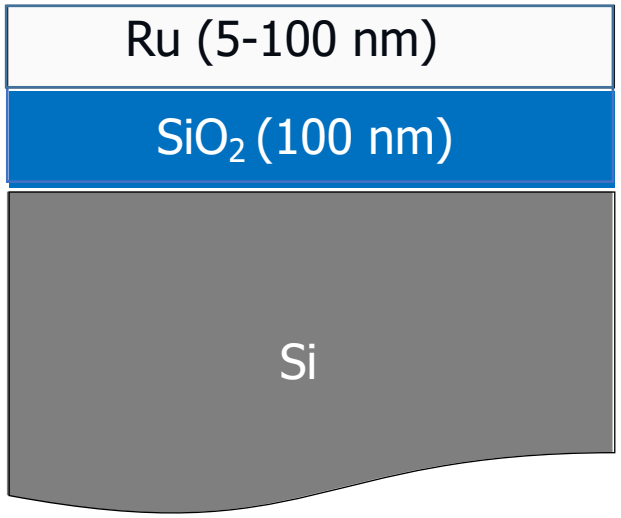
Automated 300 mm wafer handling (EFEM tool) 2027



LASER THERMAL

In-plane thermal conductivity of Ru

In-plane κ slightly higher than WF-derived κ, phonon effects



RESEARCH ARTICLE

ADVANCED FUNCTIONAL MATERIALS
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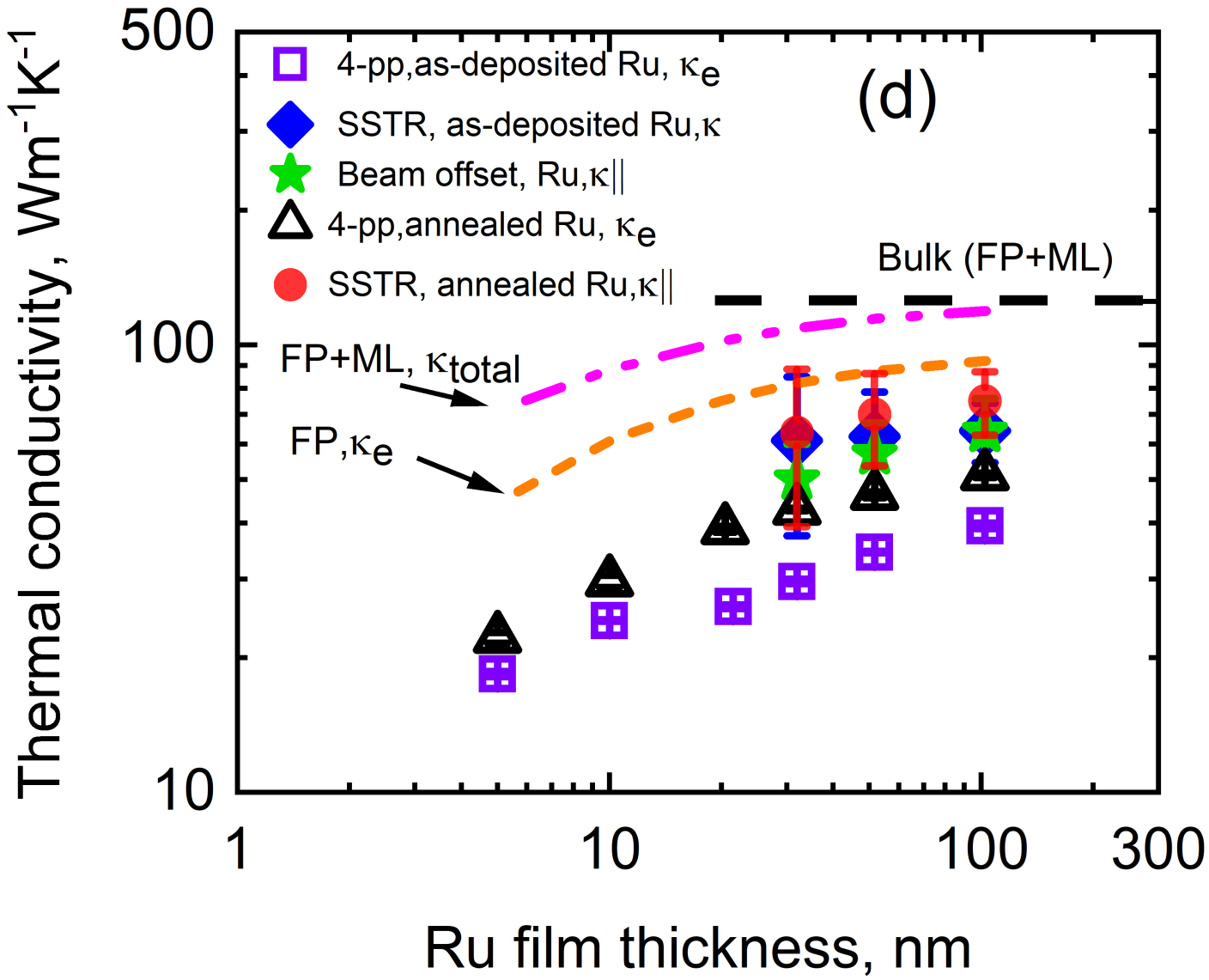
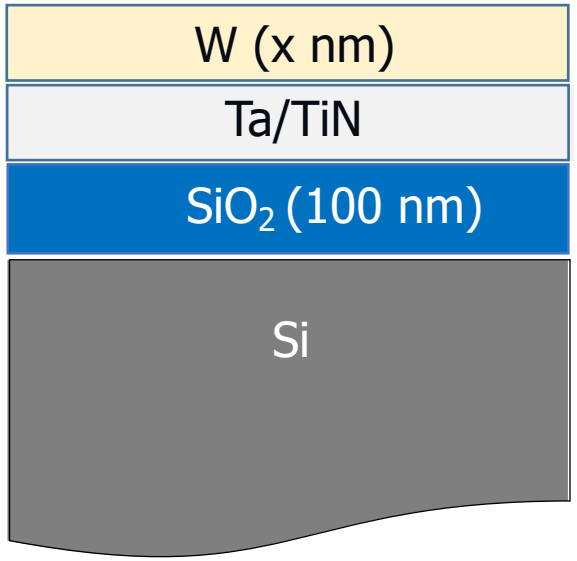
Unveiling Phonon Contributions to Thermal Conductivity and the Applicability of the Wiedemann—Franz Law in Ruthenium and Tungsten Thin Films

*Md. Rafiqul Islam, Pravin Karna, Niraj Bhatt, Sandip Thakur, Helge Heinrich, Daniel M. Hirt, Saman Zare, Christopher Jezewski, Rinus T.P. Lee, Kandabara Tapily, John T. Gaskins, Colin D. Landon, Sean W. King, Ashutosh Giri, and Patrick E. Hopkins**



In-plane thermal conductivity of W

In-plane κ much higher than WF-derived κ, phonon effects



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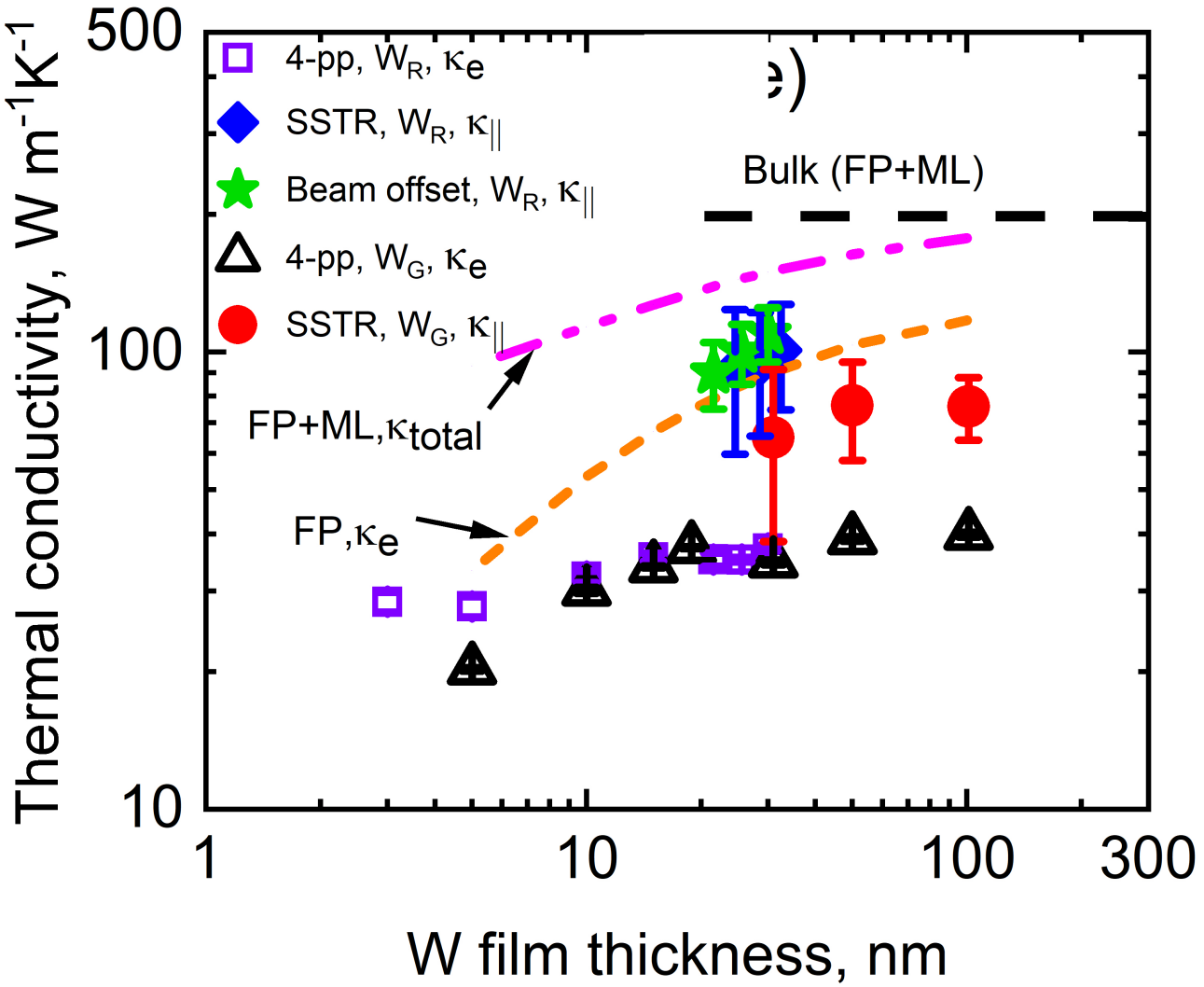
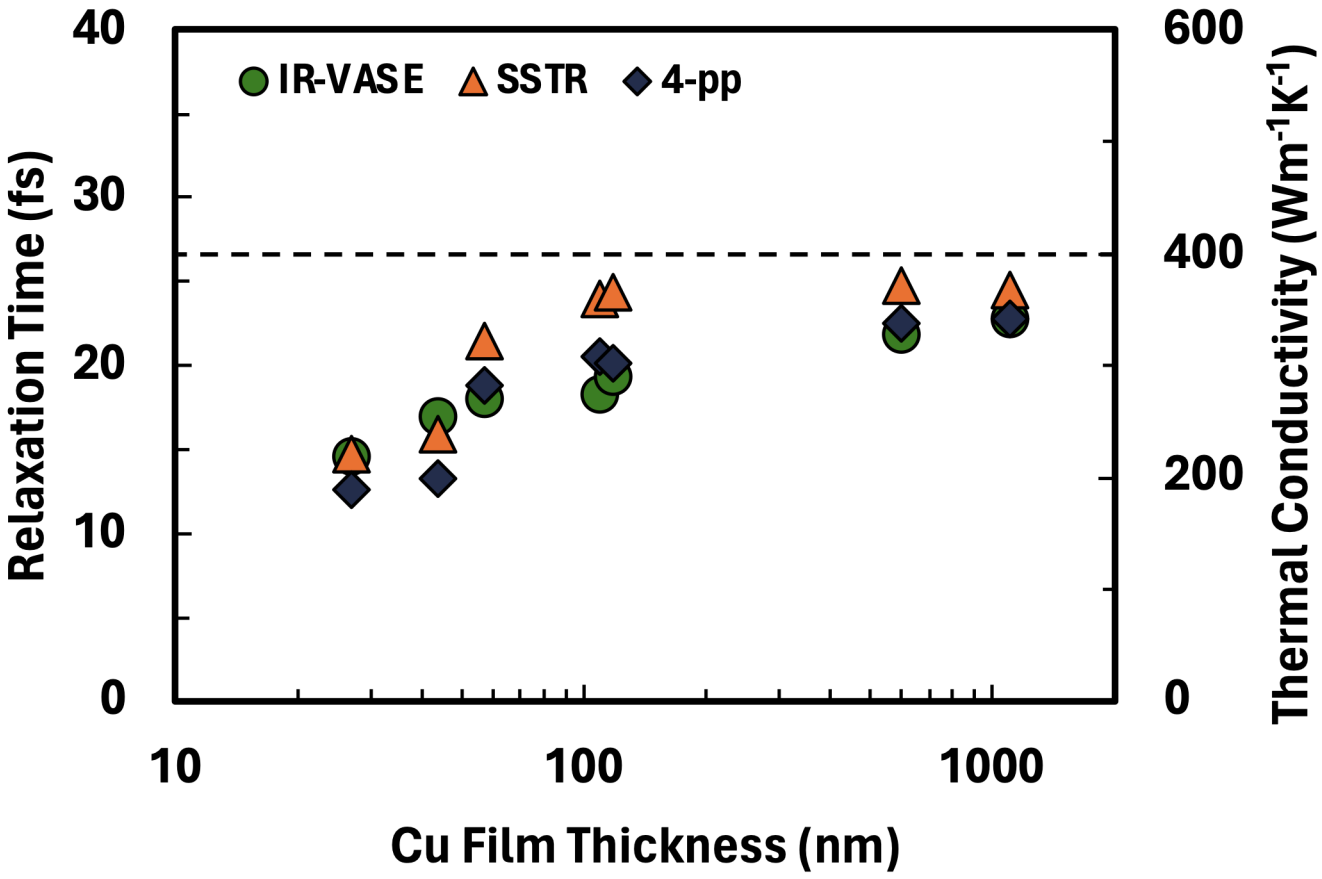


IR-VASE for electron relaxation time

$$\kappa \propto Cv^2\tau$$



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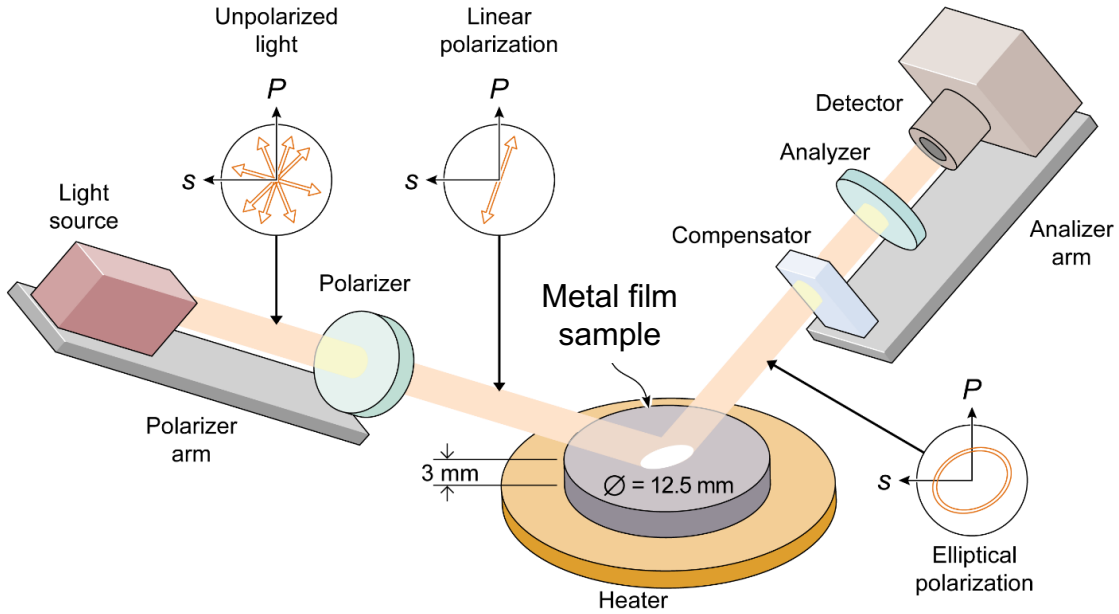
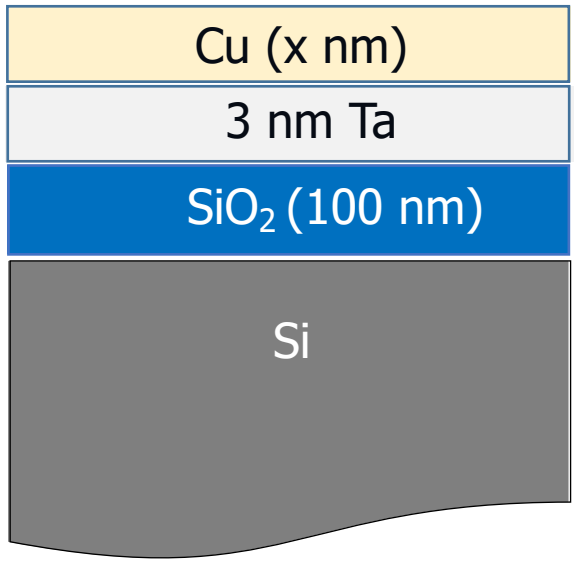
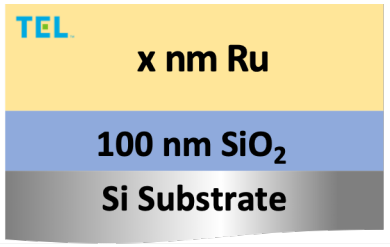
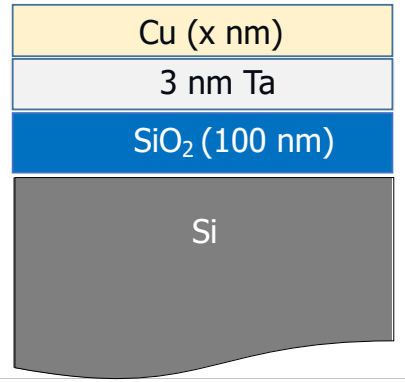
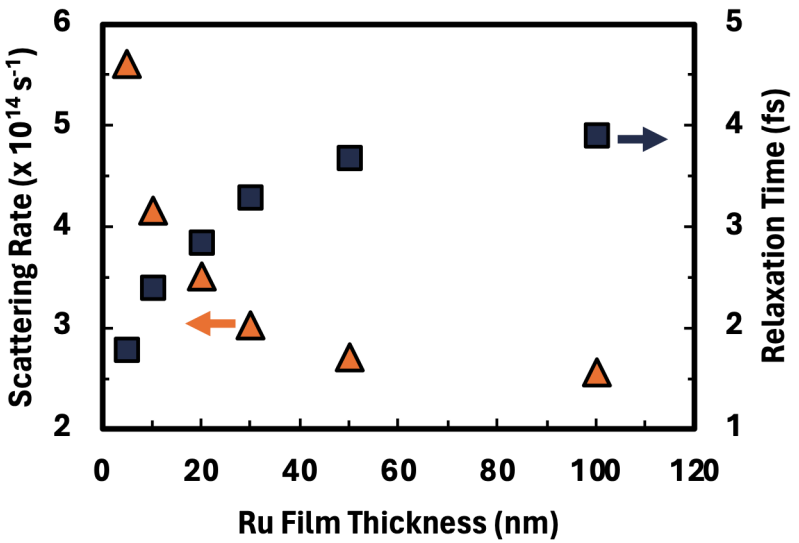


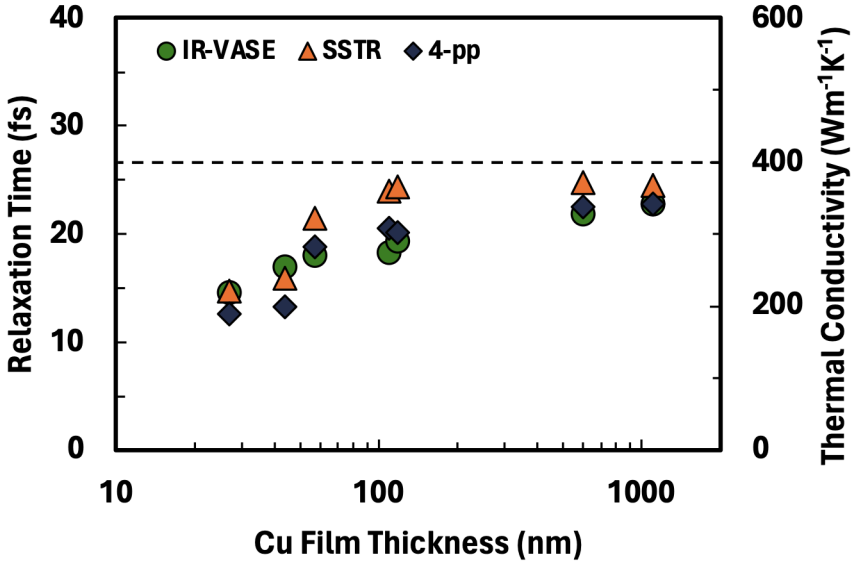


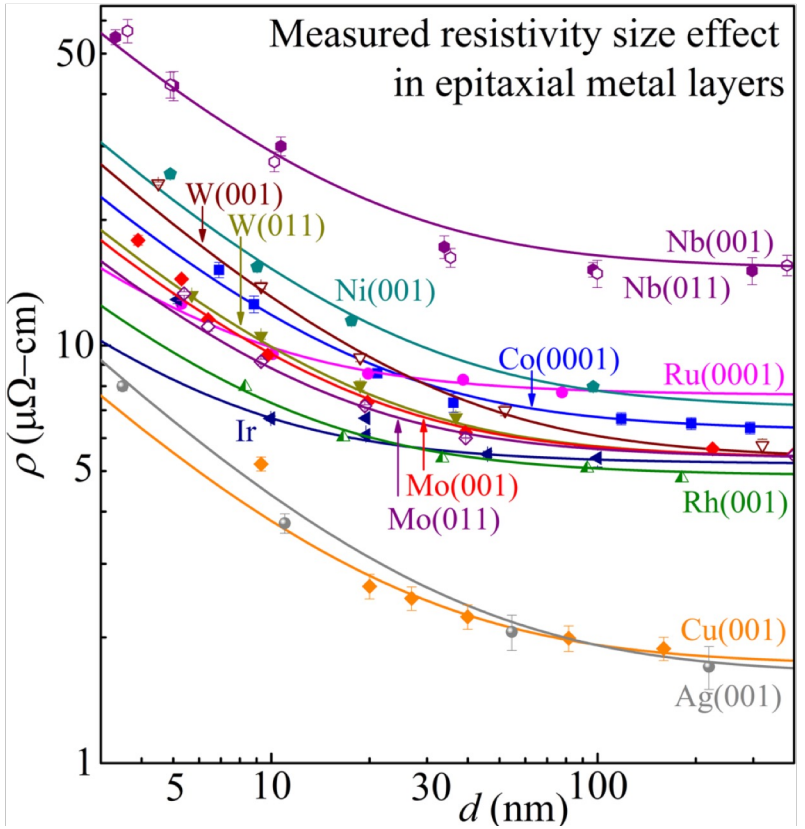
Scattering rates to evaluate scaling of σ and κ with thickness





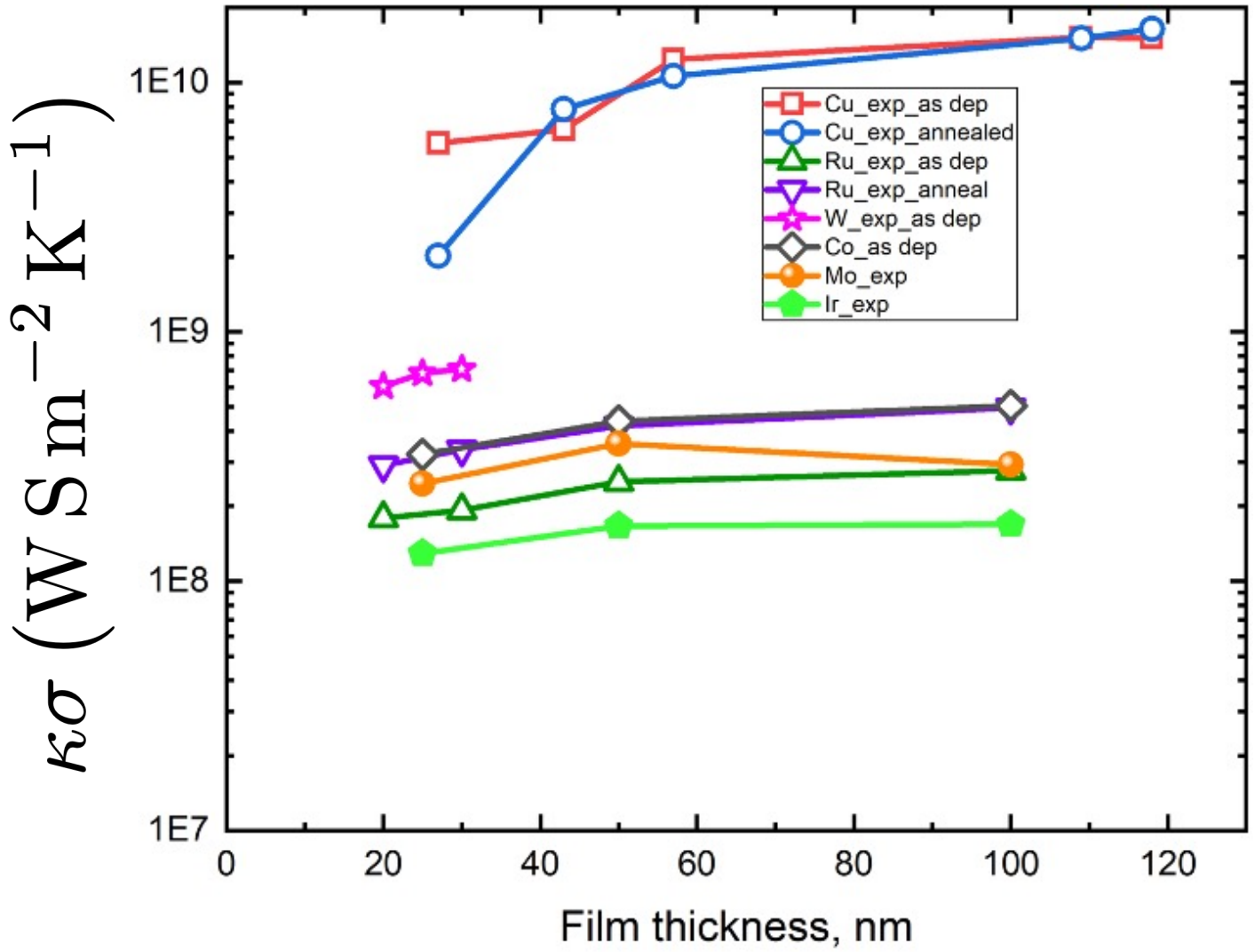






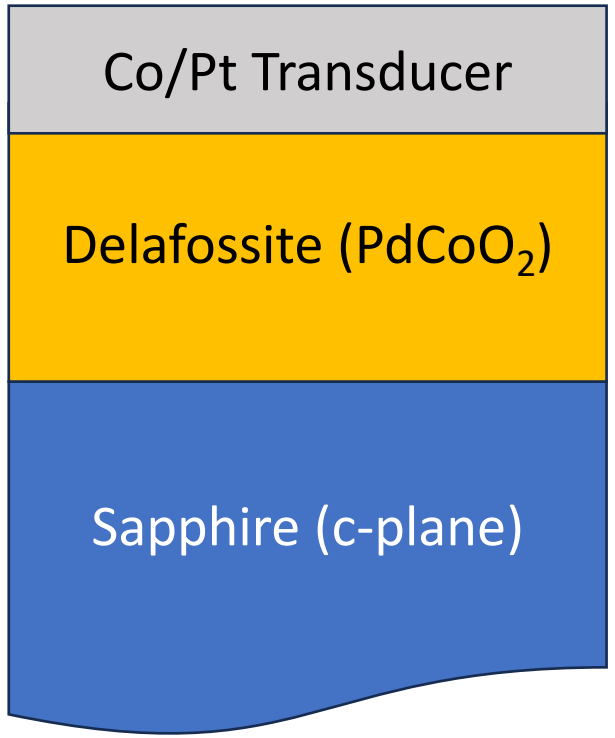
FOM for metals: Looking beyond Cu

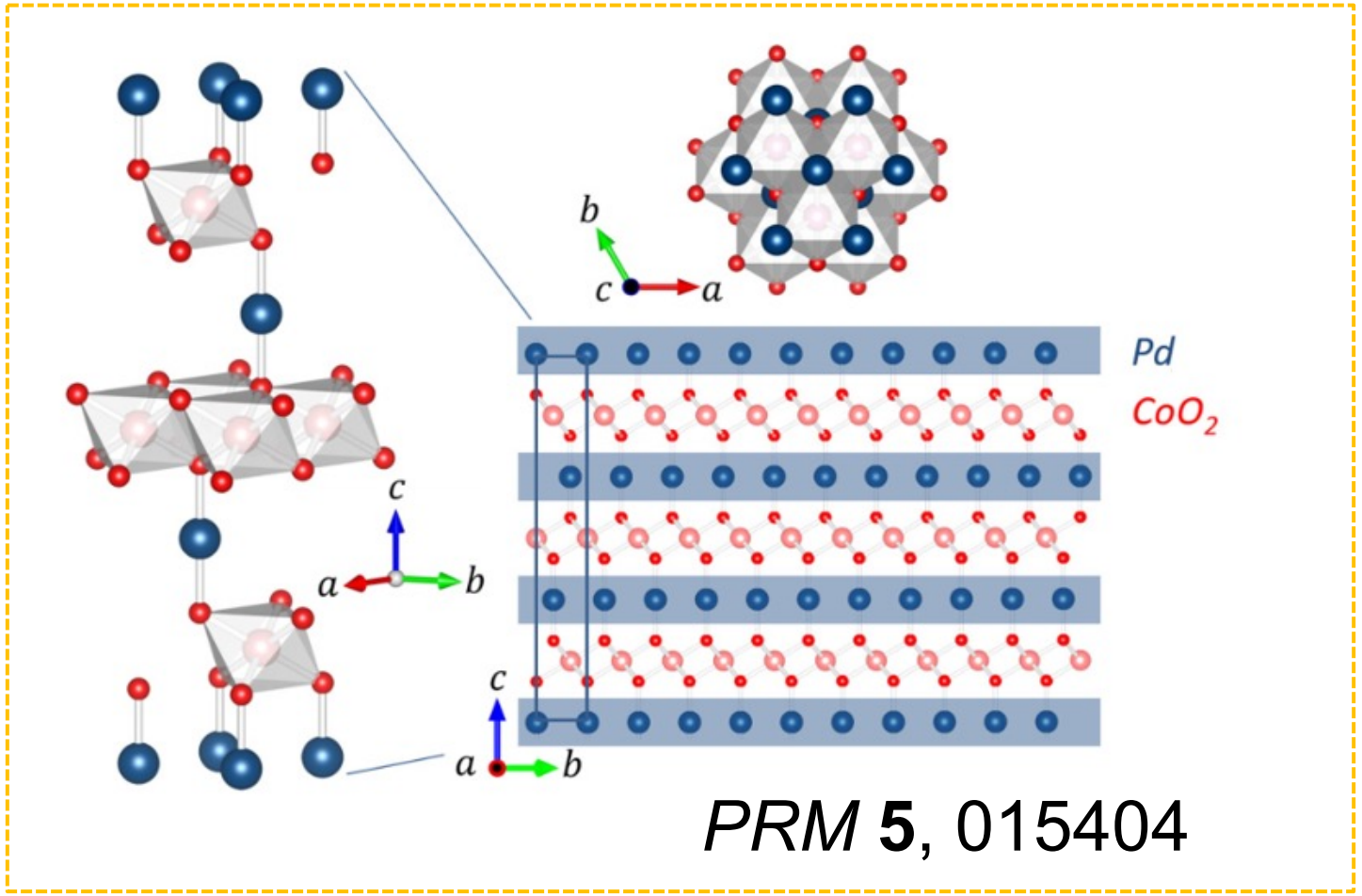
Reality for film measured (> 20 nm): Cu still has better properties



TR-MOKE to realize extremes of metallic heat conduction

- Thin film $PdCoO_2$ delafossite, grown on sapphire substrates
- Extremely anisotropic metallic oxides

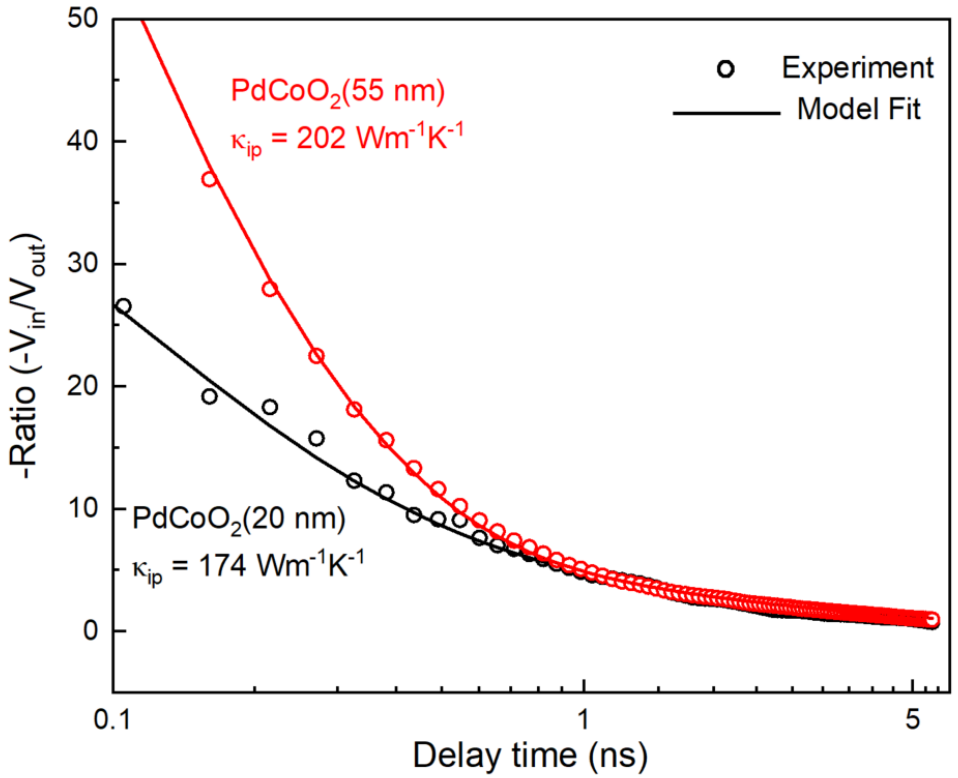


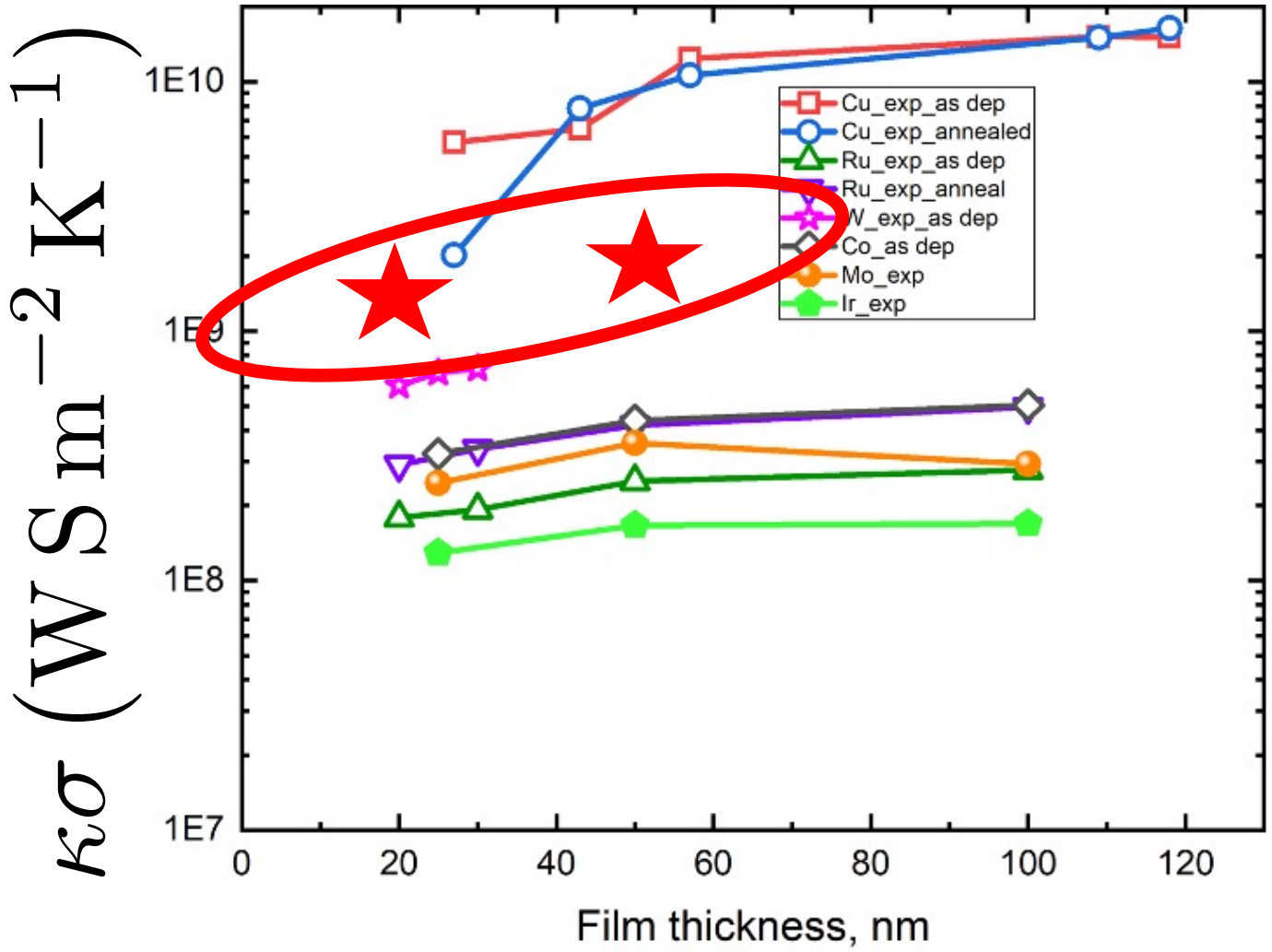


Collaborator
Nair (Cornell)

TR-MOKE to realize extremes of metallic heat conduction

Exceptionally high in-plane thermal conductivities of $PdCoO_2$ delafossite films, and non-normalized FOM on par Cu





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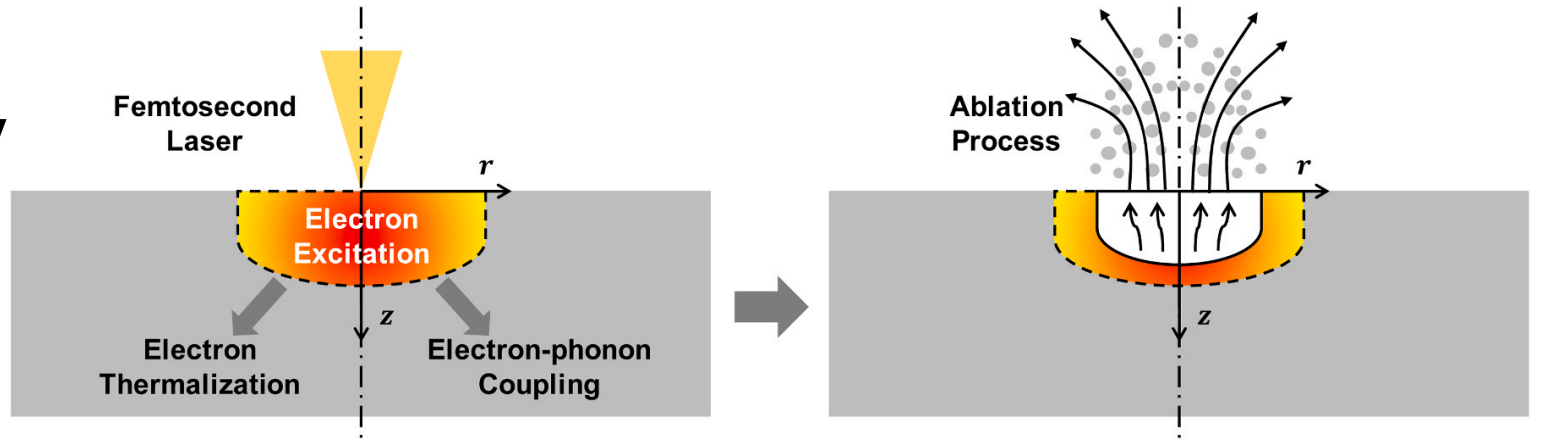
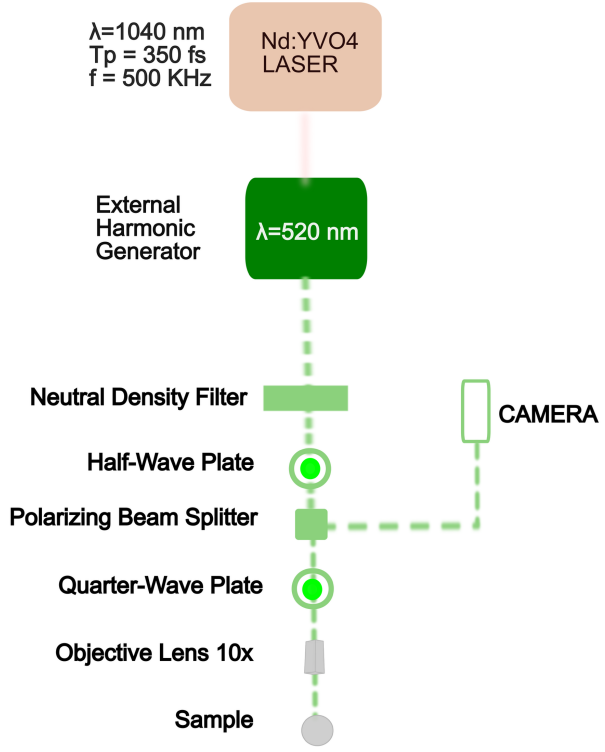
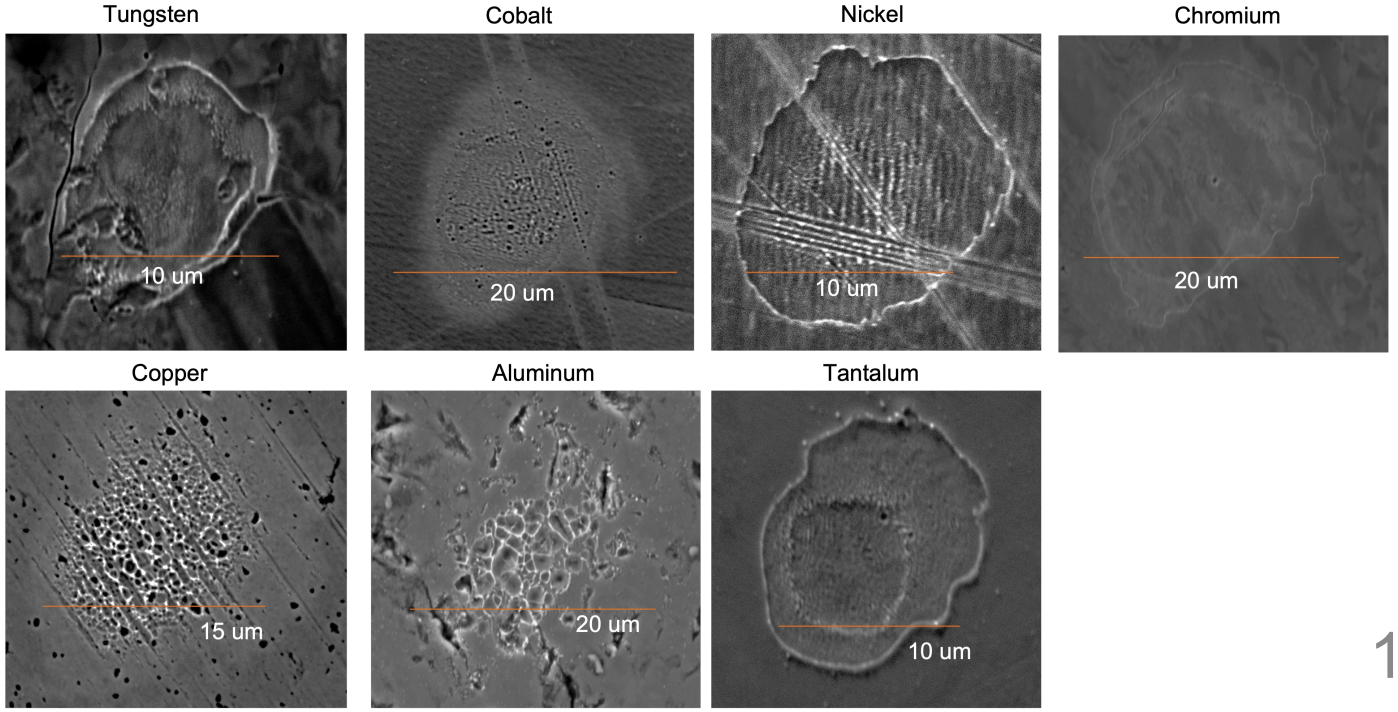
Insight into reliability with mechanical properties

- Electromigration (MTTF) ~modulus~Cohesive energy
- Femtosecond laser ablation drives ejected material from bond breaking

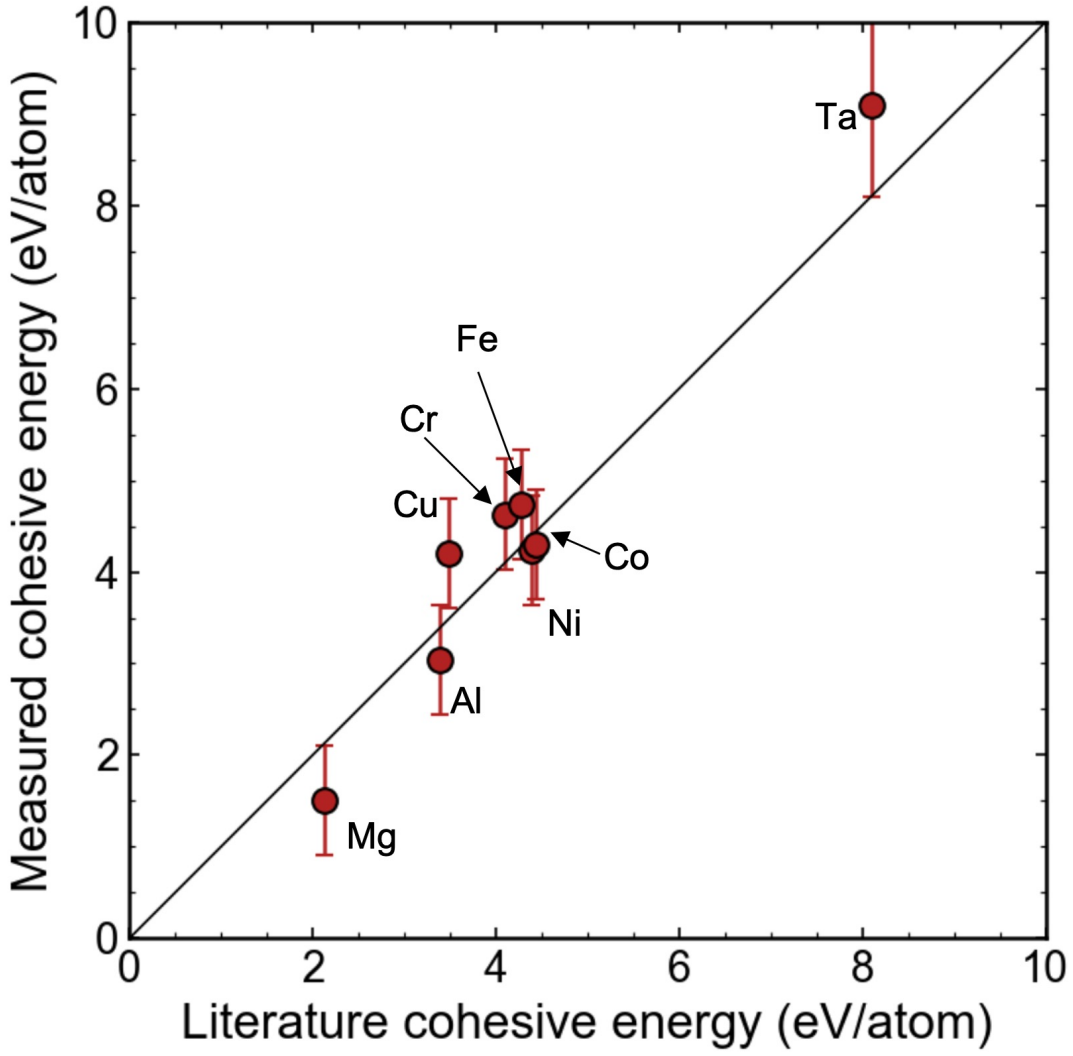


J. Alloy and Compounds **1002**, 175360

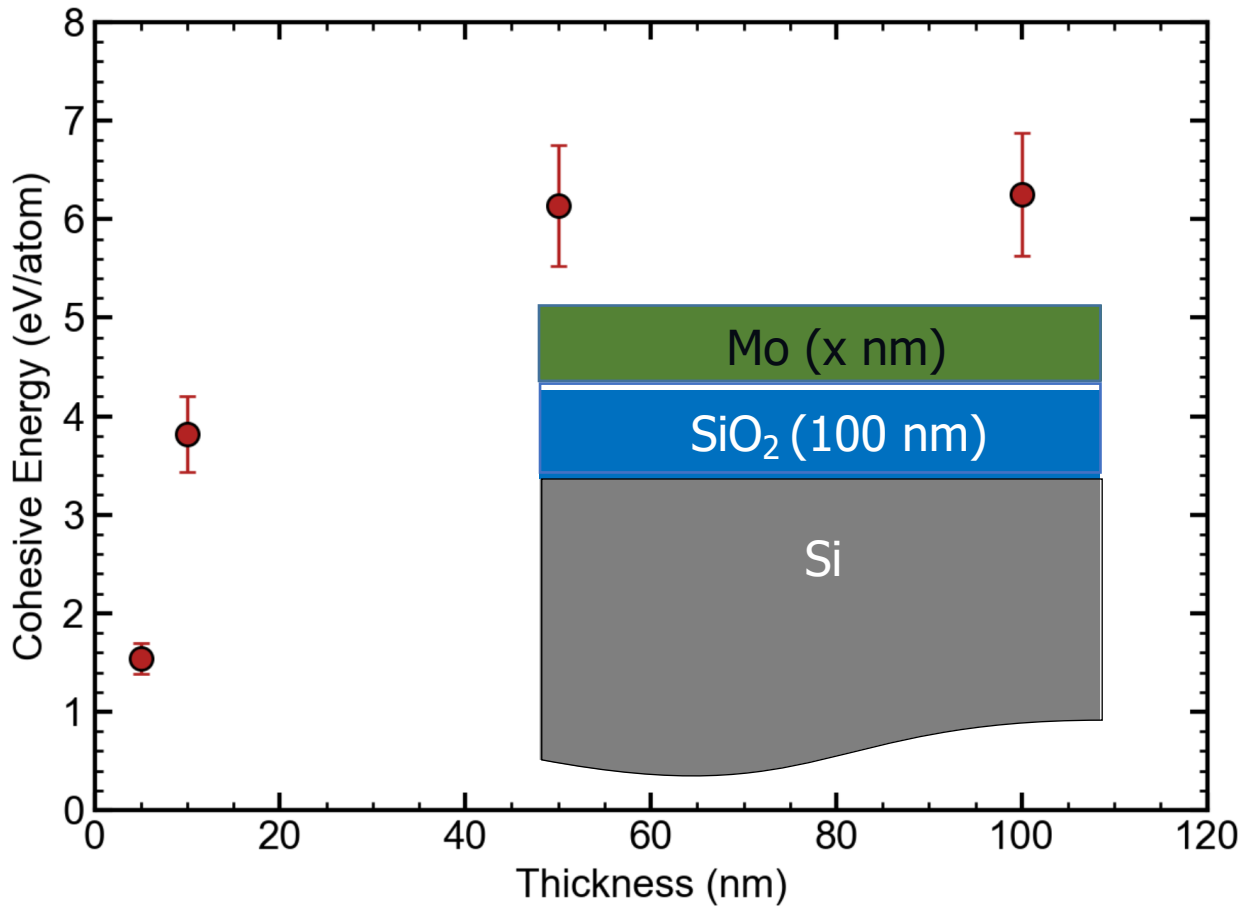




Calibrate on bulk metals, extend to thin films (Mo)



Collaboration w/ JC Zhao (UConn)



Thanks!

Dr. Rafiqul Islam (Intel)

Dr. Saman Zare

Jessica Reyes

Dr. Shafkat Bin Hoque (Intel)

Collaborators

- King, Landon, Jezewski (Intel)
- Lee, Tapily (TEL)
- Chandrasekaren, Tynell, Kachel (ASM)
- Founta, Adelmann (IMEC)
- Van Dyck, Detavernier (U. Ghent)
- Gall (RPI)
- Nair (Cornell)
- Giri (URI)
- Banerjee (UCF)
- Gaskins (LT)
- Zhao (UConn)

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Article

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Evaluating size effects on the thermal conductivity and electron-phonon scattering rates of copper thin films for experimental validation of Matthiessen's rule

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Check for updates

Md. Rafiqul Islam[1], Pravin Karna[2], John A. Tomko[3], Eric R. Hoglund[3,4], Daniel M. Hirt[1], Md Shafkat Bin Hoque[1], Saman Zare[1], Kiumars Aryana[1], Thomas W. Pfeifer[1], Christopher Jezewski[5], Ashutosh Giri[2], Colin D. Landon[6], Sean W. King[7] & Patrick E. Hopkins[1,3,8]

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