Review of Scientific Instruments

REPLY | APRIL 16 2024

Response to “Comment on ‘A spatially resolved optical method to measure thermal diffusivity’” [Rev. Sci. Instrum. 95, 047101 (2024)] FREE

F. Sun ; S. Mishra ; P. H. McGuinness ; Z. H. Filipiak ; I. Marković ; D. A. Sokolov; N. Kikugawa ; J. W. Orenstein ; S. A. Hartnoll ; A. P. Mackenzie ; V. Sunko

Rev. Sci. Instrum. 95, 047102 (2024)
https://doi.org/10.1063/5.0195810

AIP Publishing

Review of Scientific Instruments RESPONSE pubs.aip.org/aip/rsi

Response to "Comment on 'A spatially resolved optical method to measure thermal diffusivity'" [Rev. Sci. Instrum. 95, 047101 (2024)]

Cite as: Rev. Sci. Instrum. 95, 047102 (2024); doi: 10.1063/5.0195810
Submitted: 4 January 2024 • Accepted: 3 March 2024 •
Published Online: 16 April 2024

F. Sun,[1] S. Mishra,[1] P. H. McGuinness,[1] Z. H. Filipiak,[1] I. Marković,[1] D. A. Sokolov,[1] N. Kikugawa,[2] J. W. Orenstein,[3,4] S. A. Hartnoll,[5] A. P. Mackenzie,[1,6] and V. Sunko[1,3,a)]

AFFILIATIONS

[1] Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany
[2] National Institute for Materials Science, Ibaraki 305-0003, Japan
[3] Department of Physics, University of California, Berkeley, California 94720, USA
[4] Materials Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
[5] Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Cambridge CB3 0WA, United Kingdom
[6] School of Physics and Astronomy, University of St Andrews, St Andrews KY16 9SS, United Kingdom

[a)] Author to whom correspondence should be addressed: vsunko@berkeley.edu

https://doi.org/10.1063/5.0195810

We thank Salazar *et al.* for pointing out the error in Eq. (6) of our manuscript[1] and for offering the correct expression. While fully acknowledging the importance of their correction,[2] we emphasize that Eq. (6) was not used for any of our data interpretation or analysis, which therefore remains valid. We address those points in more detail below.

(1) In Eqs. (6) and (A23) of our paper, we repeat the claim of Ref. 13 of our original paper[3] that the diffusivity D along an arbitrary direction in an anisotropic material is given by

$$\frac{1}{D_\theta} = \frac{\cos^2\theta}{D_x} + \frac{\sin^2\theta}{D_y},$$

where D_x and D_y are the values of diffusivity along two principal axis directions and θ is the angle between the measured direction and the x axis. The difference between the claim of Ref. 3 and the older literature was brought to our attention in the review process, but we made an error while evaluating the two expressions, leading us to the incorrect conclusion that Eq. (6) is valid. As Salazar *et al.* convincingly argue in their comment,[2] the correct expression for D_θ, defined as the ratio of thermal conductivity and heat capacity, is

$$D_\theta = D_x\cos^2\theta + D_y\sin^2\theta.$$

(2) We emphasize that all the data analysis and ensuing conclusions of our work[1] remain valid since Eq. (6) was used only for illustrative purposes. The data are analyzed through the calculated relationships between the measured phase difference ϕ and the principal axis diffusivities D_x and D_y [Eqs. (A14) and (A20) for the overlapped and separated configuration, respectively]. Those relationships are not controversial: indeed, Eq. (A20) is reproduced in the comment by Salazar *et al.* [Eqs. (10) and (11) of Ref. 2 are equivalent to our Eq. (A20) in Ref. 1]. The quantities of interest in our measurements were the diffusivities along the two principal directions, and we never discussed diffusivity measured along an arbitrary direction. This approach is most prominent in Fig. 3(d): we plot the directly measured difference in phase lag between two domains as a function of orientation θ, without relying on any calculation for D_θ. We also note that, far from being a paper "devoted to the measurement of the in-plane thermal diffusivity of anisotropic materials," the large majority of our paper is about other topics since the case of anisotropic diffusivity appeared to be covered in the earlier literature. Indeed, as discussed in the introduction to our paper, the advances it reports are systematic methods to retain instrument focus over wide ranges of temperature and a technique involving overlapping pump and probe beams,

which enhances spatial resolution over techniques relying on separated pump and probe beams.

(3) Salazar *et al.* refer to "two mistakes" made in our work: Eq. (6) and the claim that the diffusivity along an arbitrary direction can be deduced from the measured phase lag. However, that is actually the same mistake. Our incorrect Eq. (6) implies that the phase difference ϕ measured at an angle θ is proportional to the diffusivity along the direction defined by θ, whereas the correct one pointed out by Salazar *et al.* shows that this is not the case away from the principal axes. However, we never utilize that relationship in our analysis (point 2 above).

To conclude, we regret that we propagated a misunderstanding in the field, and we are grateful to Salazar *et al.* for clarifying it. We hope that our work, and this exchange, helps bring this technique into new experimental regimes, studying small inhomogeneous samples, both isotropic and anisotropic, over a broad range of temperatures.

AUTHOR DECLARATIONS

Conflict of Interest

The authors have no conflicts to disclose.

REFERENCES

[1] F. Sun, S. Mishra, P. H. McGuinness, Z. H. Filipiak, I. Marković, D. A. Sokolov, N. Kikugawa, J. W. Orenstein, S. A. Hartnoll, A. P. Mackenzie, and V. Sunko, Rev. Sci. Instrum. **94**, 043003 (2023).
[2] A. Salazar, A. Mendioroz, A. Bedoya, and E. Marín, Rev. Sci. Instrum. **95**, 047101 (2024).
[3] J. Zhang, E. M. Levenson-Falk, B. J. Ramshaw, D. A. Bonn, R. Liang, W. N. Hardy, S. A. Hartnoll, and A. Kapitulnik, Proc. Natl. Acad. Sci. U. S. A. **114**, 5378 (2017).