**From Crystal Symmetry to Heat Flow: Resolving Anisotropic Transport in Gallium Oxide Phases**

Markus R. Wagner1,2, Kai Xu3, Shuo Zhao4,5, Luca Sung-Min Choi2, Moritz Meißner1,2, Riccardo Mincigrucci6, Laura Foglia6, Danny Fainozzi6, Filippo Bencivenga6, Riccardo Rurali3, Zbigniew Galazka7, George Fytas8, Matthias Scheffler4,5, Bartlomiej Graczykowski8,9, Christian Carbogno4,5, Juan Sebastian Reparaz3

1Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V.,   
Hausvogteiplatz 5–7, 10117 Berlin, Germany

2Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstrase 36, 10623 Berlin, Germany

3Institut de Ciencia de Materials de Barcelona, ICMAB-CSIC, Campus UAB, 08193 Bellaterra, Spain

4The NOMAD Laboratory at the FHI of the Max-Planck-Gesellschaft

5IRIS-Adlershof of the Humboldt-Universität zu Berlin

6Elettra Sincrotrone Trieste S.C.p.A., Strada Statale 14, km 163.5, 34149 Basovizza (TS), Italy

7Leibniz Institute for Crystal Growth, Max-Born-Str. 2, 12489 Berlin, Germany

8Max Planck Institute for Polymer Research, Ackermannweg 10, 55128 Mainz, Germany

9Faculty of Physics, Adam Mickiewicz University, Uniwersytetu Poznanskiego 2, 61-614 Poznan, Poland

wagner@pdi-berlin.de

In low-symmetry monoclinic crystals with non-orthogonal axes the anisotropic nature of properties such as elasticity and dielectric response gives rise to unconventional phenomena, including hyperbolic sheer polaritons1, charge density waves or topological phase transitions not observed in higher symmetry materials2. In this work, we present a comprehensive, contactless investigation into the anisotropic phonon-governed properties of the ultra-wide bandgap semiconductor Ga₂O₃, with a focus on both nanoscale phonon dynamics and nanoscale thermal transport phenomena3. We employ a suite of complementary, all-optical spectroscopic techniques to map phonon behavior over multiple frequency and length scales. Anisotropic thermoreflectance thermometry provides sub-degree angular resolution of in-plane responses4, while polarized, angle-resolved Brillouin light scattering (BLS) probes acoustic phonons to extract the anisotropy of phonon phase velocities5.

Most notably, extreme UV transient grating spectroscopy experiments performed at the FERMI free-electron laser facility enable access to grating spacings as short as 26 nm6. This capability is crucial for isolating phonon contributions with varying mean free paths, including those relevant to nanoscale thermal transport that are elusive in conventional setups. Variation of the nanoscale grating spacing and temperature enables high and low frequency band-pass filtering in the THz regime. Furthermore, the transient responses reveal multiple oscillatory modes - attributable to GHz surface acoustic waves which reveal characteristic anisotropy. To complement our experimental findings, we perform ab-initio Green-Kubo calculations7 and Boltzmann Transport Equation (BTE) simulations to capture non-equilibrium phonon interactions and the interplay between phononic properties and thermal conductivity anisotropy. Our results deepen the understanding of anisotropic thermal transport in transparent conductive metal-oxides and provide guidelines for optimized heat dissipation.

**References**

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