Quantifying Nanoscale Heat Transport in 2D Materials using Pre-Time-Zero Spatiotemporal Pump-Probe Microscopy

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2D materials, particularly transition metal dichalcogenides (TMDs), have attracted significant research interest over the last decade, due to their many intriguing electrical, mechanical, optical and thermal properties. In-depth knowledge and control of the heat transport properties in these materials will help heat management in optoelectronic devices and in designing novel materials for energy conversion and storage [1]. Consequently, scientists have developed several techniques [2] to determine the heat transport in 2D materials, nevertheless, these techniques usually require accurate knowledge of material parameters, such as thickness, optical absorption and heat capacity, and require relatively strong heating (ΔT ~ 100 K).

Here, we address these limitations and present a pre-time-zero spatiotemporal pump-probe microscopy technique [3] to obtain the in-plane thermal diffusivity (*D*) by examining the spatial profile at a small negative pump-probe delay time, i.e., when the probe pulses arrive before the pump pulses. Thus, the probe is sensitive to remnant heat created by previous pump pulses from the pulse train. We demonstrate the working principle of our method by quantifying the *D* of four TMD materials: $MoSe_2$ (0.18 ± 0.01 cm^2/s), WSe_2 (0.20 ± 0.03 cm^2/s), MoS_2 (0.35 ± 0.03 cm^2/s), and WS_2 (0.59 ± 0.07 cm^2/s), in excellent agreement with reported thermal properties [4, 5]. We also predict that our proposed technique will facilitate an advance in the understanding of unconventional nanoscale thermal transport phenomena, for example non-diffusive phonon transport, in low-dimensional materials.

References

[1] Zhao, Bei, et al., Adv. Funct. Mater. 31(48), 2105132 (2021).
[2] Sandell, Susanne et al., J. Appl. Phys. 128, 131101 (2020).
[3] Varghese, Sebin et al., *In preparation*.
[4] Jiang, Puqing, et al., Adv. Mater. 29 (36), 1701068 (2017).
[5] Reig, David Saleta et al., Adv. Mater. 2108352 (2022).

Figures

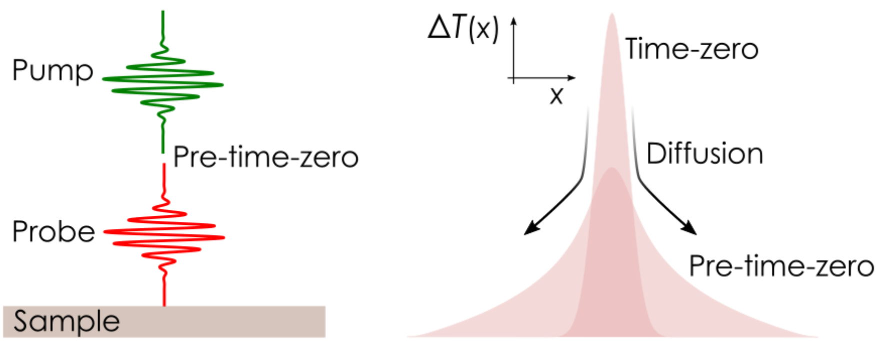

Figure 1: Schematic of the concept behind the pre-time-zero spatiotemporal microscopy technique.