Non contact measurements of anisotropic thermal conductivity in additively manufactured metals

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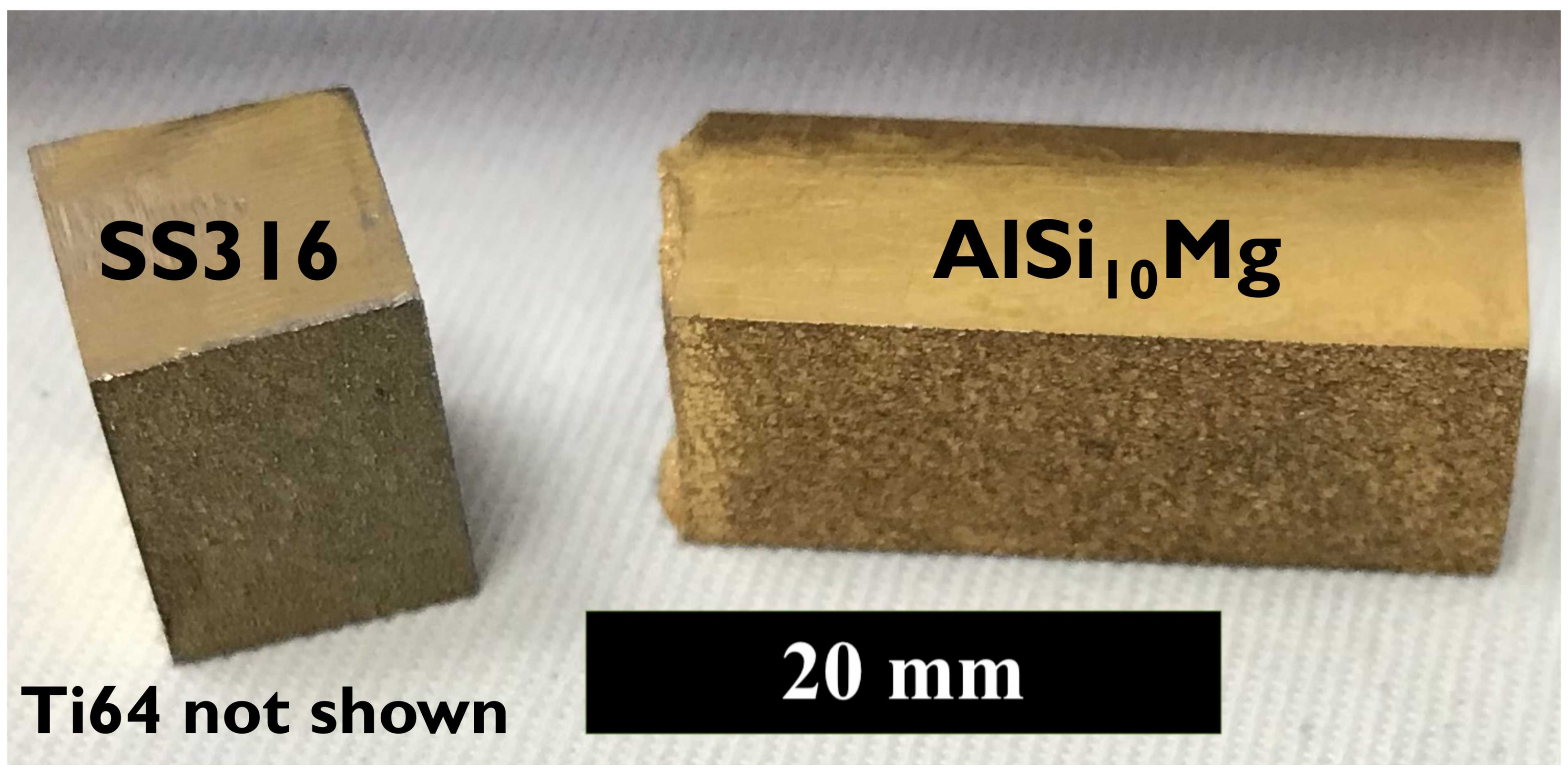
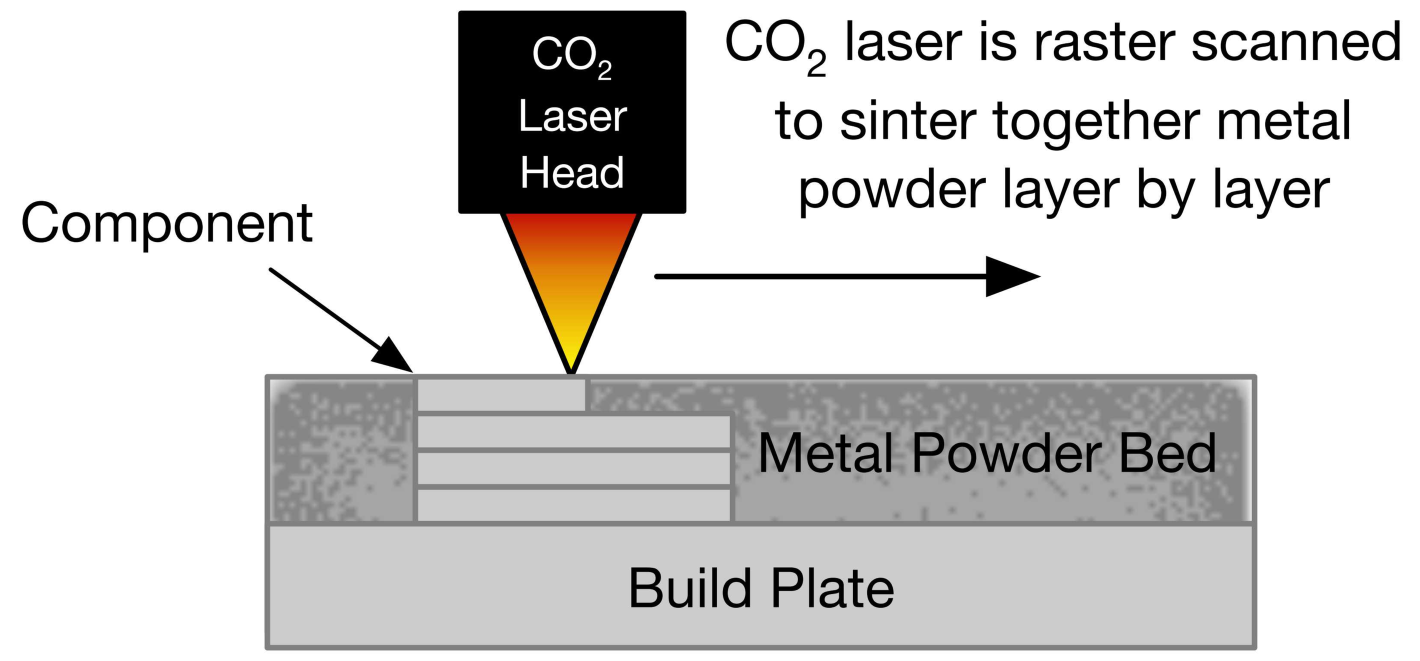
Introduction

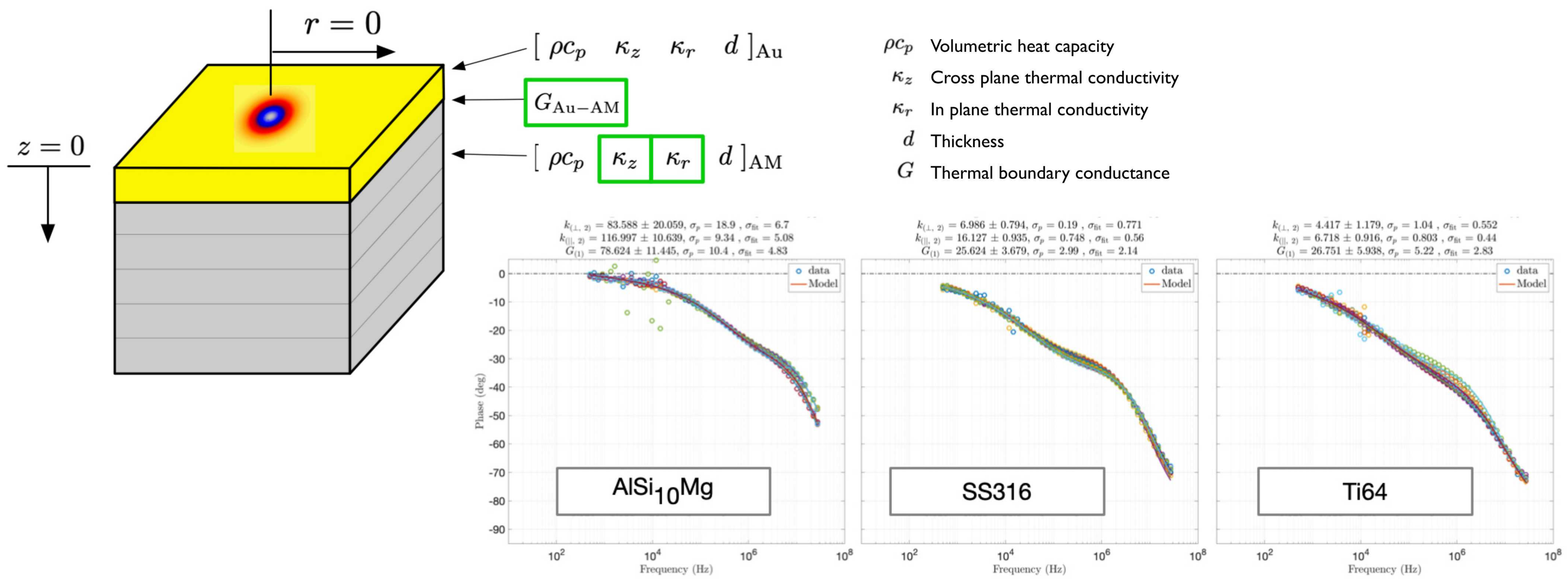
Frequency domain thermoreflectance (FDTR) is laser-based pump-probe measurement technique that can simultaneously extract parameters such as in-plane and cross-plane thermal conductivity, volumetric heat capacity, the thickness of embedded thin films, and thermal resistance across an interface of two dissimilar materials. Here, we present anisotropic thermal conductivity measurements with FDTR of additively manufactured metal components. The in-plane and cross-plane thermal conductivities obtained with FDTR were compared to those measured with laser flash. Our results demonstrate of the utility of FDTR for quality control in additively manufactured components.

Additively Manufactured Metal Samples





Anisotropic Thermal Conductivity



The pump-laser frequency is swept from 500 Hz to 50 MHz and the surface temperature phase lag with respect to the pump is recorded. Each material has a unique response as a function of frequency. The higher the thermal conductivity, typically, the lower the phase lag. The in-plane and cross-plane thermal conductivity of the AM sample as well as thermal boundary conductance between the metal transducer and the AM component are determined from a least square estimate of the non-linear thermal model to the measure phase lag as a function of frequency (shown above).
Uncertainty in the fitted parameters was estimated from the uncertainty in the fixed parameters, residual of fit, and standard deviation in fitted parameters from multiple measurements across the sample surface. The table below compares FDTR measurements and previous laser flash results and includes the respective standard uncertainties (k = 1).

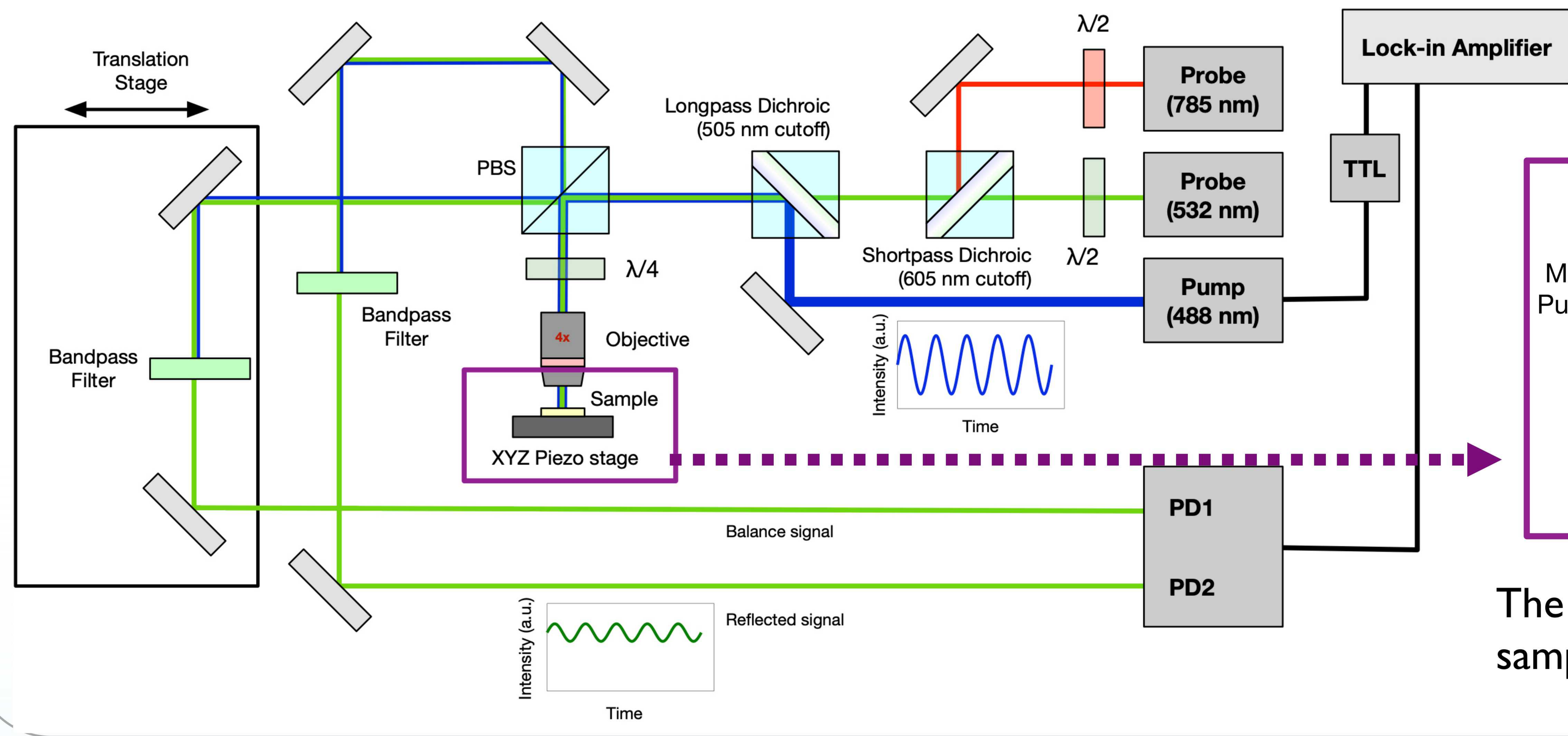
Thermal conductivity of AM parts [W m^{-1} K^{-1}]

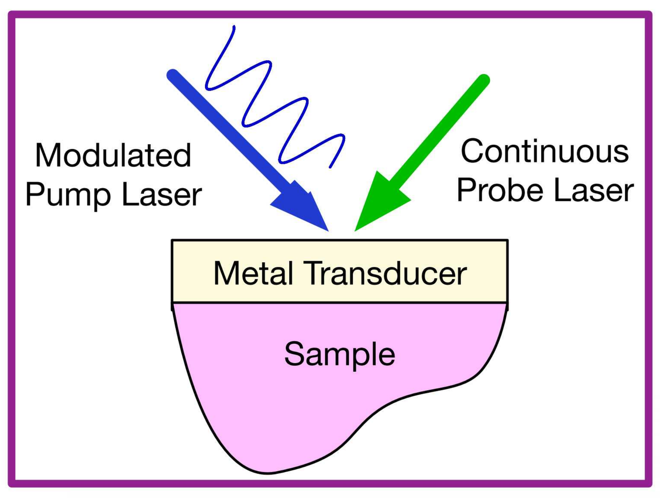
	Lit Value	FDTR		Laser Flash [1]		
	$k_{isotropic}$	k_z	k_r	k_z	k_r	$k_{isotropic}$
AlSi10Mg	146	**84 ± 20**	**117 ± 10**	97.7 ± 6.9	114 ± 8.0	
Ti64	6.7	**4.4 ± 1.2**	**6.72 ± 0.92**	-	-	3.86
SS316	21.4	**6.99 ± 0.79**	**16.13 ± 0.94**	-	-	8.34

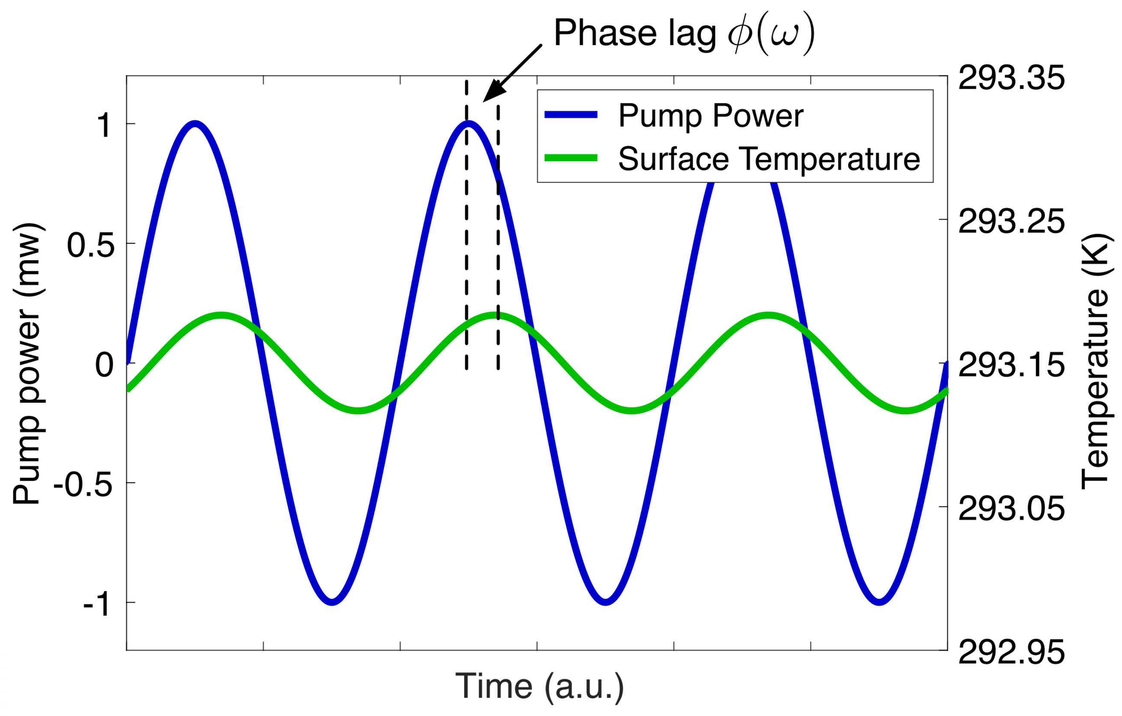
Note: a large portion of uncertainty in the FDTR results is due to variations from multiple measurements across the sample surface.

Non Contact Measurements: Frequency Domain Thermoreflectance (FDTR)

Simplified schematic of FDTR optical circuit [2]







The surface ***temperature phase lags*** behind the surface heat flux because the sample needs time to absorb the heat energy and physically heat up.

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References

[1] Yang, P., Deibler, L. A., Bradley, D. R., Stefan, D. K., & Carroll, J. D. (2018). Microstructure evolution and thermal properties of an additively manufactured, solution treatable AlSi10Mg part. *Journal of Materials Research, 33*(23), 4040-4052.
[2] Ziade, E. (in preparation) On the limits of thermal property measurements in bulk and thin-film materials with frequency-domain thermoreflectance. *Review of Scientific Instruments.*

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