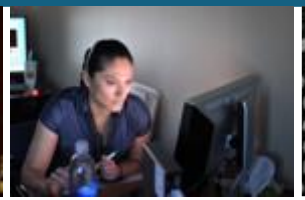
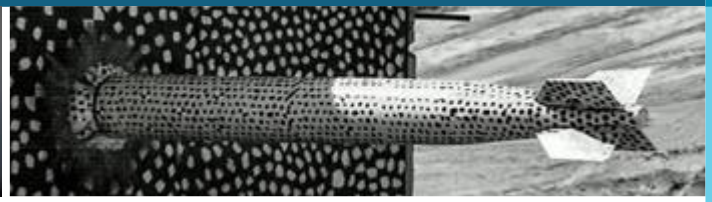
SAND2020-6517C

Sandia National Laboratories

Sensing Depths in Periodic Thermal Measurements





PRESENTED BY

Wyatt Hodges, Jacob Mahaffey, Elbara Ziade

Quality & Performance Assurance
Center 9200

07/13/2020

LDRD
Laboratory Directed Research and Development

U.S. DEPARTMENT OF ENERGY

NNSA
National Nuclear Security Administration

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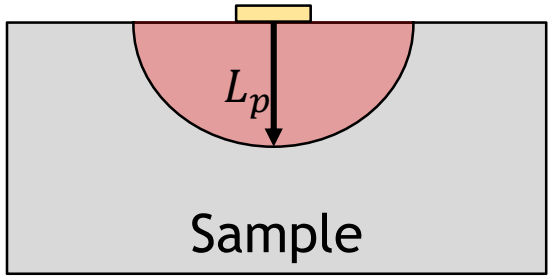
Outline

- Motivation
- Thermal Length Scales
  - Sensing Length
- Simulation of Sensing Lengths in Silicon and SiO_2
- Experimental Results
- Conclusions

Motivation

3ω



Dames, Chris. (2005) *Measuring the Thermal Conductivity of Thin Films: 3 Omega and Related Methods.*

Motivation

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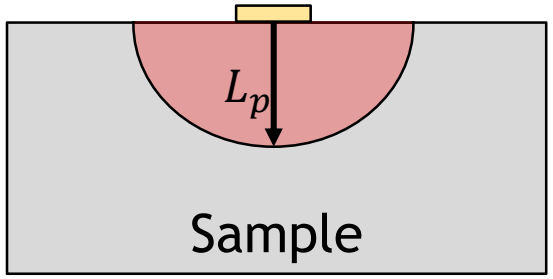

2-5 “thermal penetration depths” to appear semi-infinite

$$L_p = \sqrt{\frac{2\alpha}{\omega}}$$

α → Thermal diffusivity $[{}^{W}/_{mK}]$; ${}^{k}/_{\rho C_p}$

ω → Heating frequency $[{}^{rad}/_{s}]$

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Motivation

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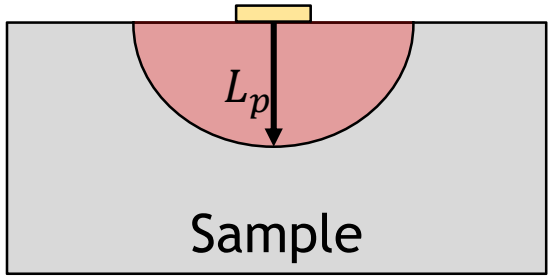

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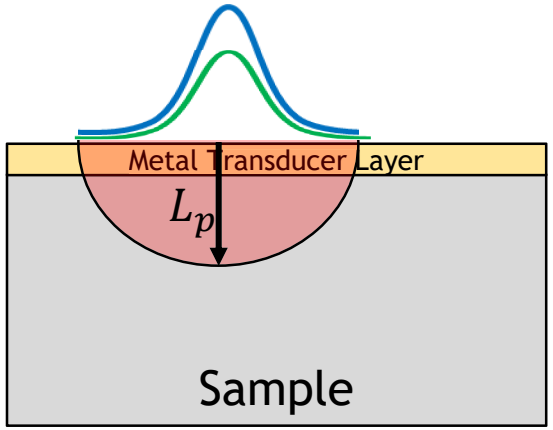
TDTR/FDTR

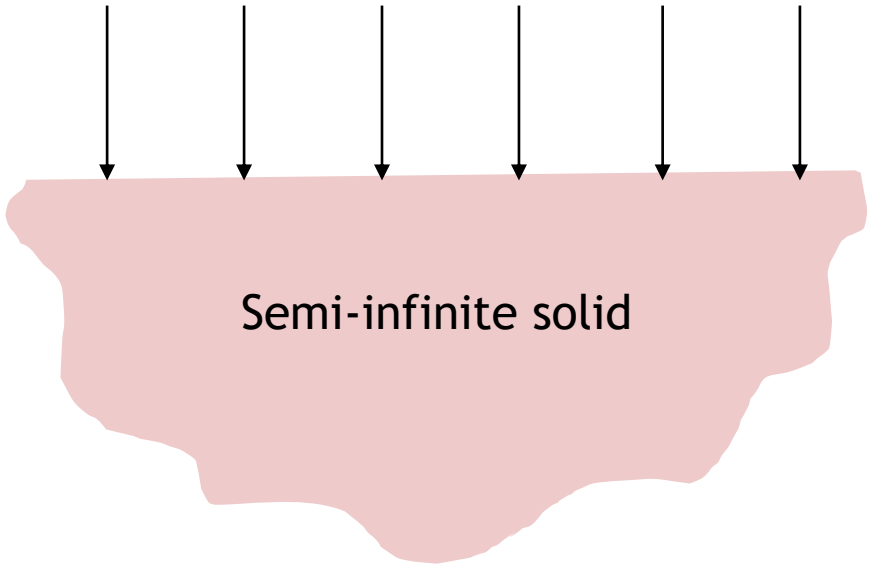


How deep does a measurement “see” into the sample?

Schmidt, Aaron. (2009) *A frequency-domain thermoreflectance method for the characterization of thermal properties.*

Thermal Length Scales

$$\frac{T(x,t) - T_i}{\Delta T} = \exp\left(-x\sqrt{2\alpha/\omega}\right) sin\left(\omega t - x\sqrt{2\alpha/\omega}\right)$$



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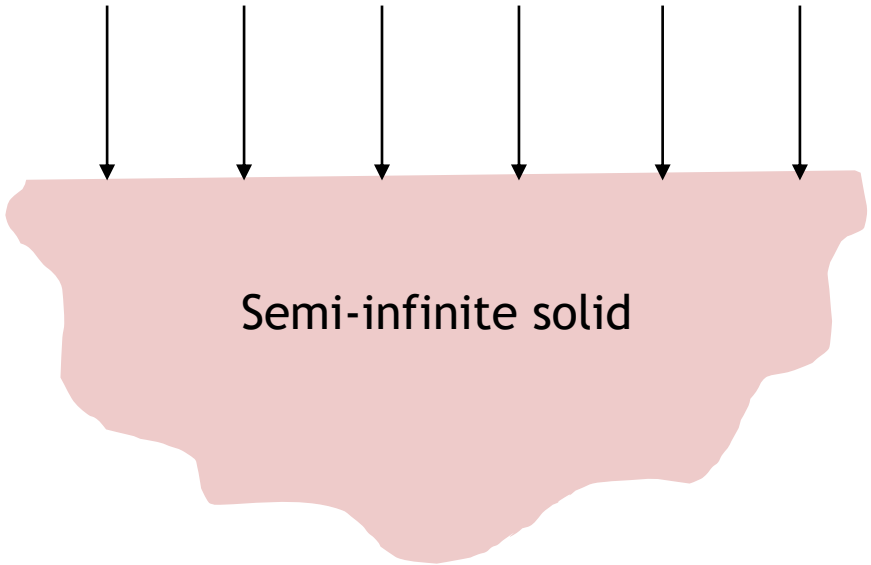

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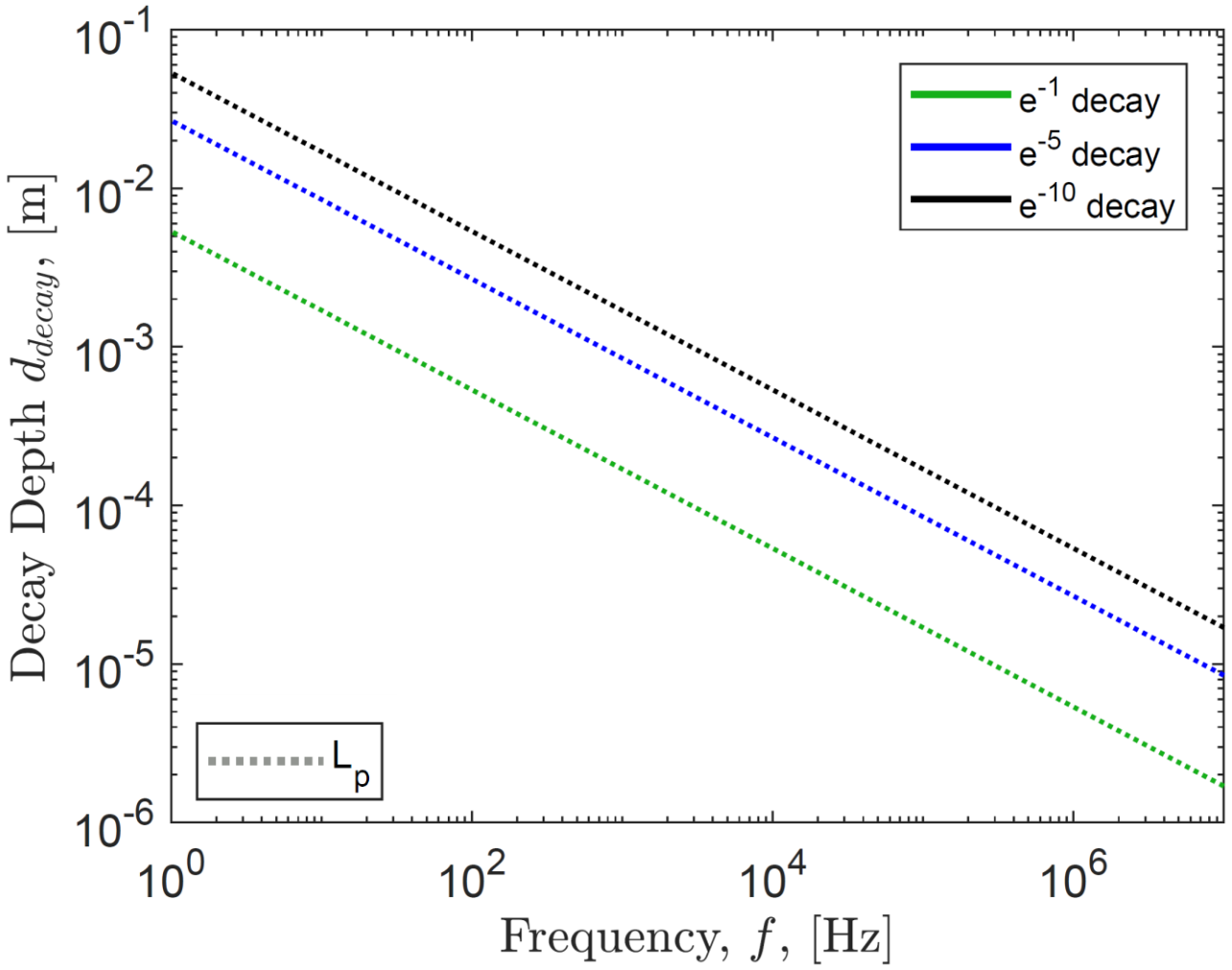

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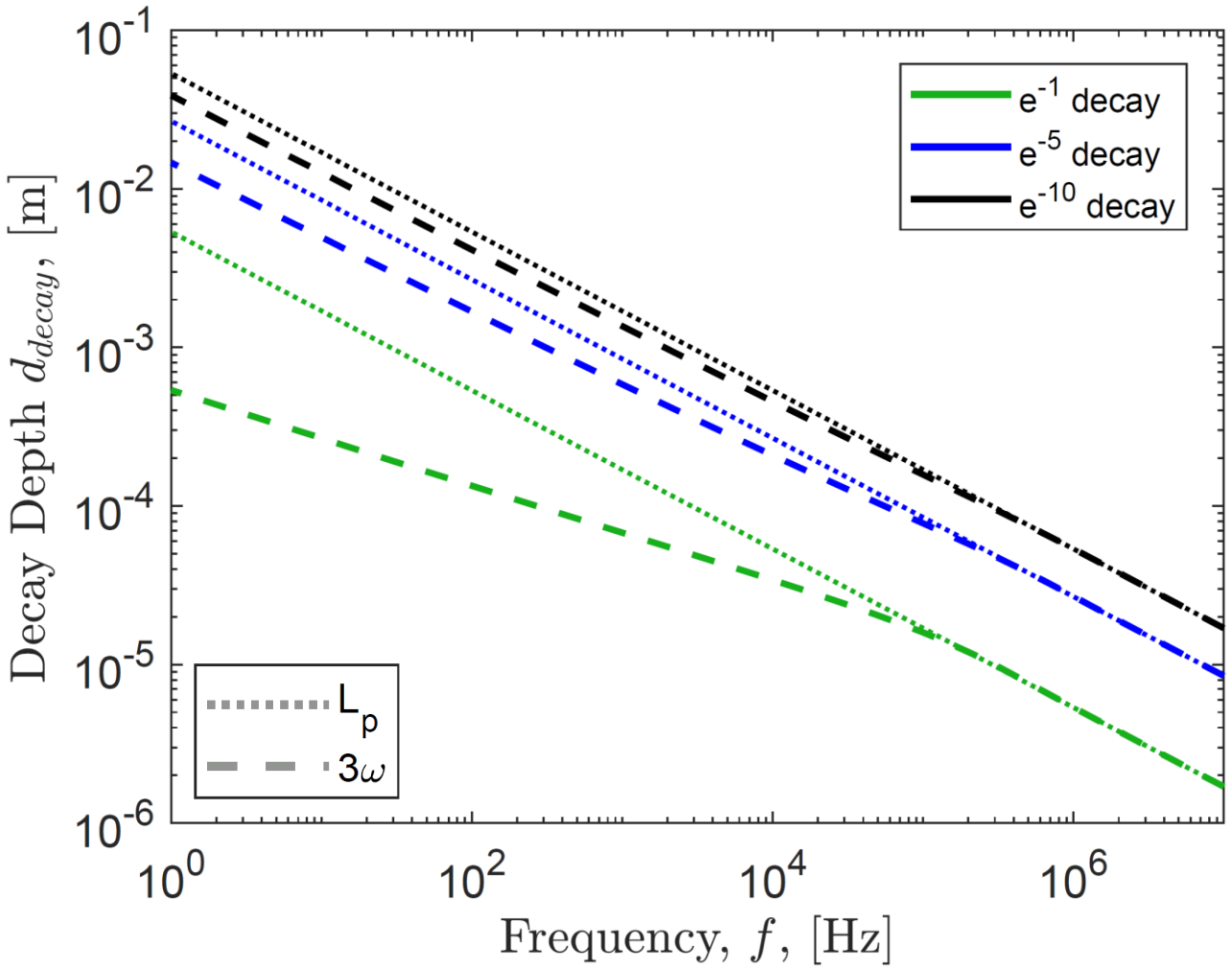

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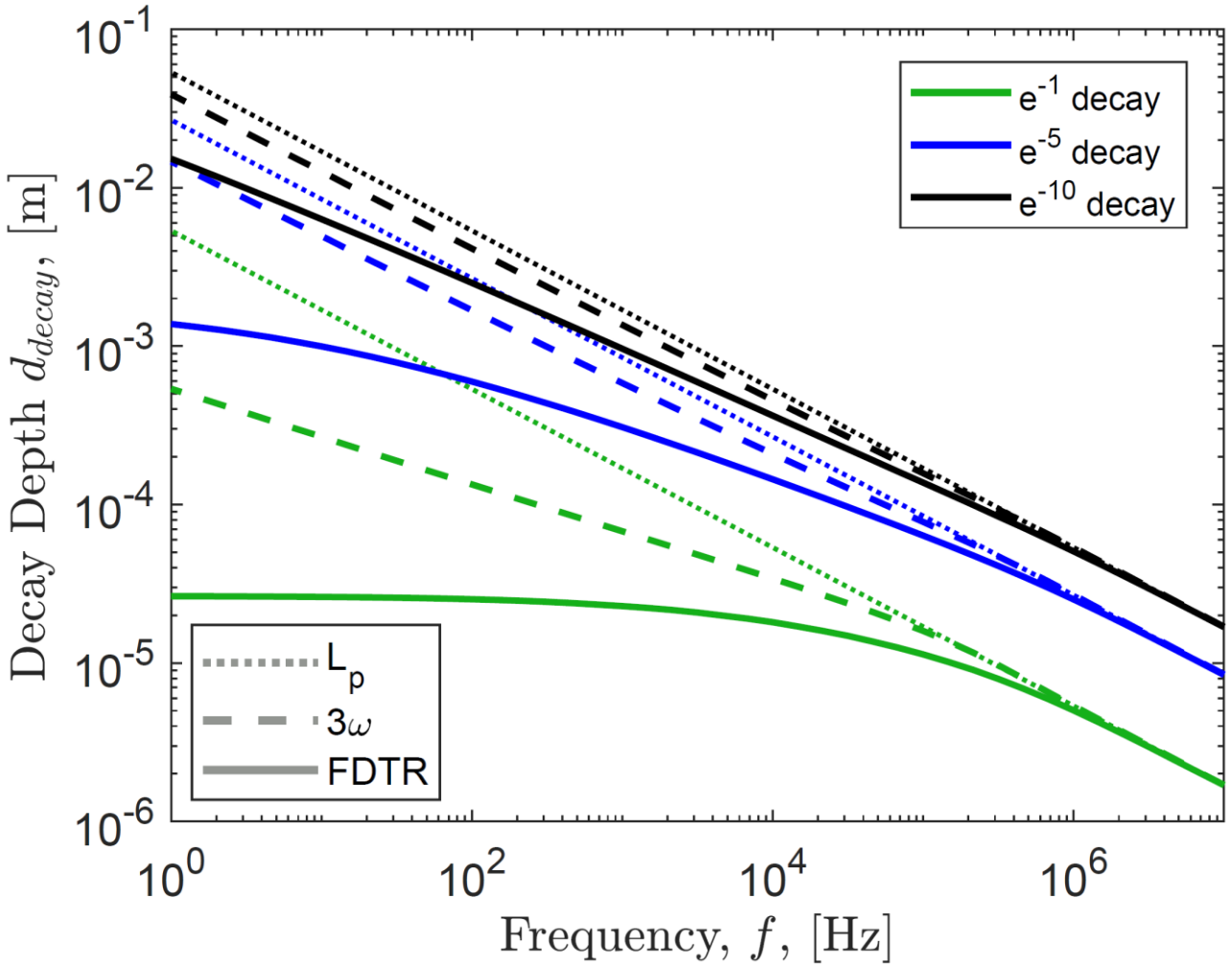
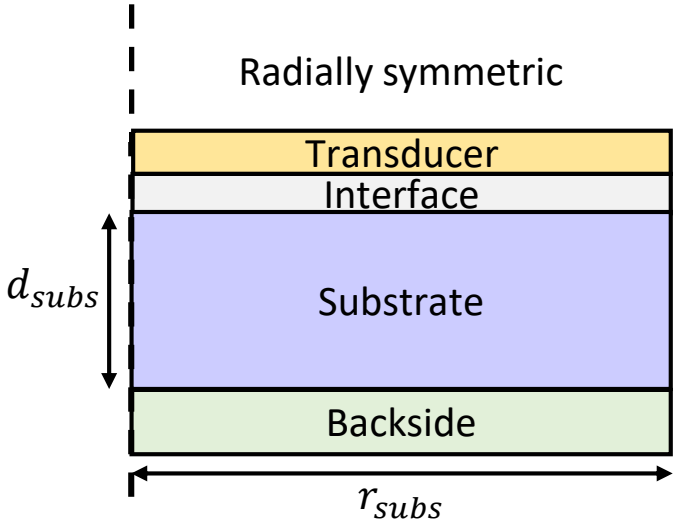


Sensing Lengths $[L_s]$



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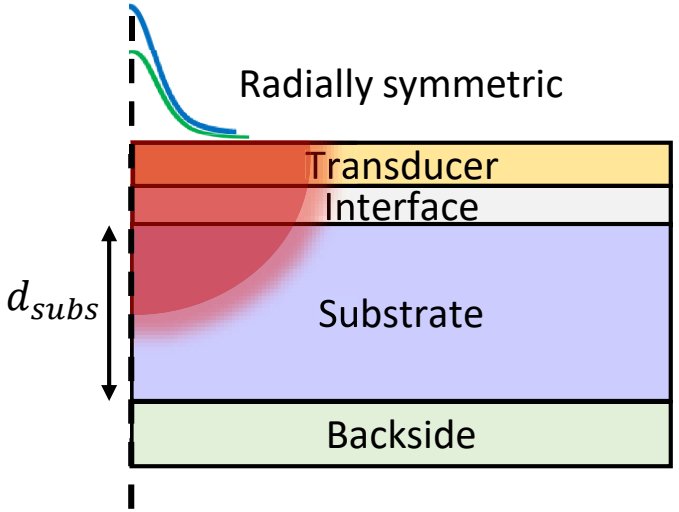
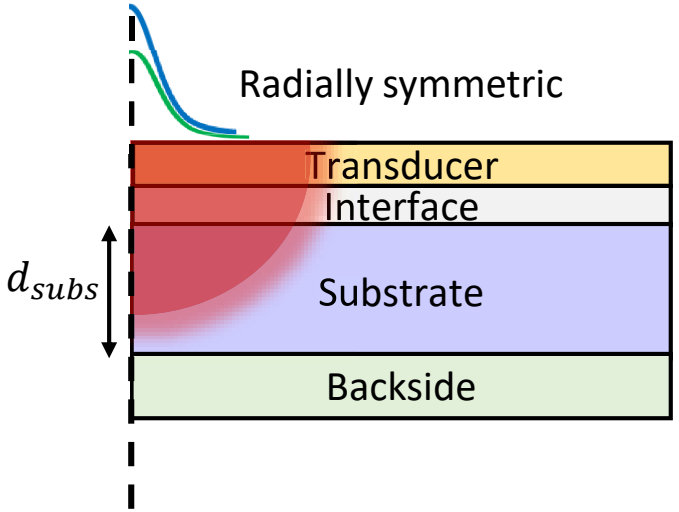


Sensing Lengths $[L_s]$



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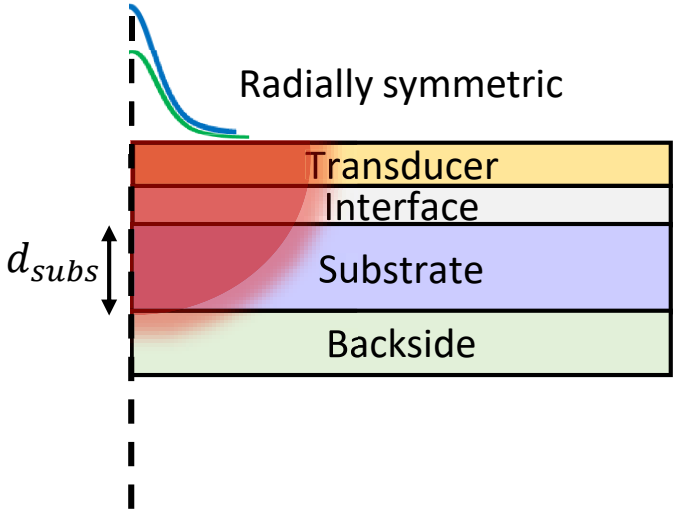
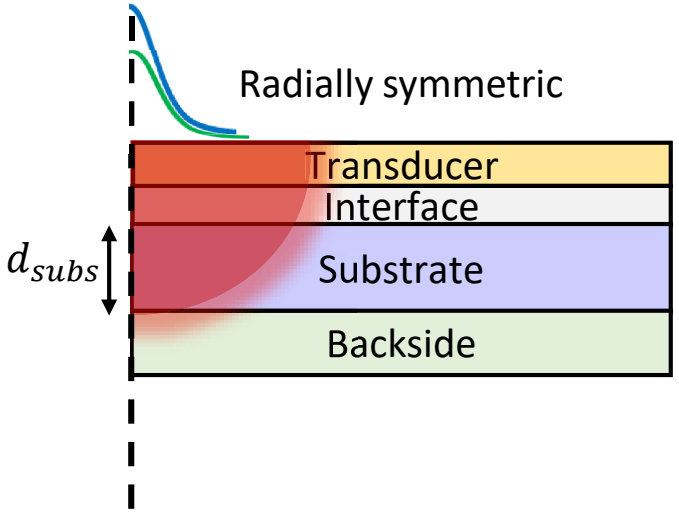
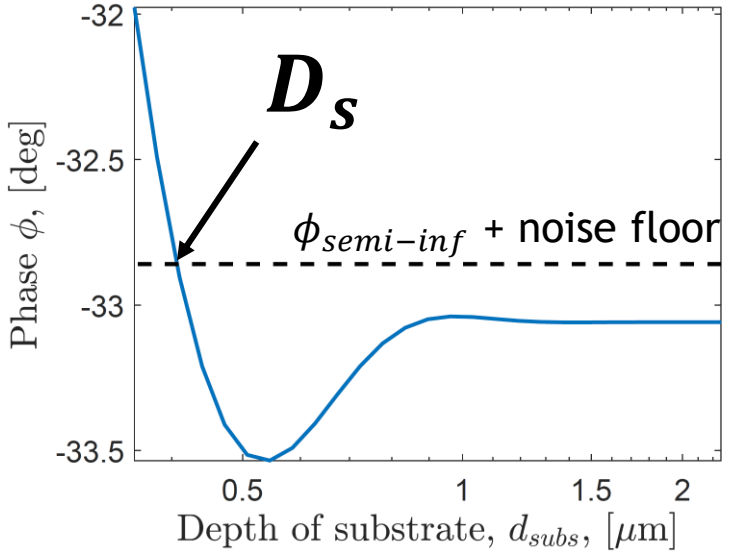


Sensing Lengths $[L_s]$



Vary d_{subs}



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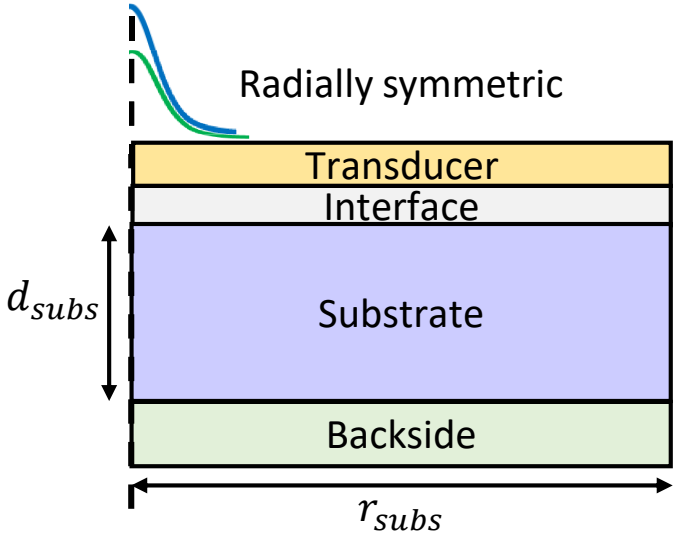
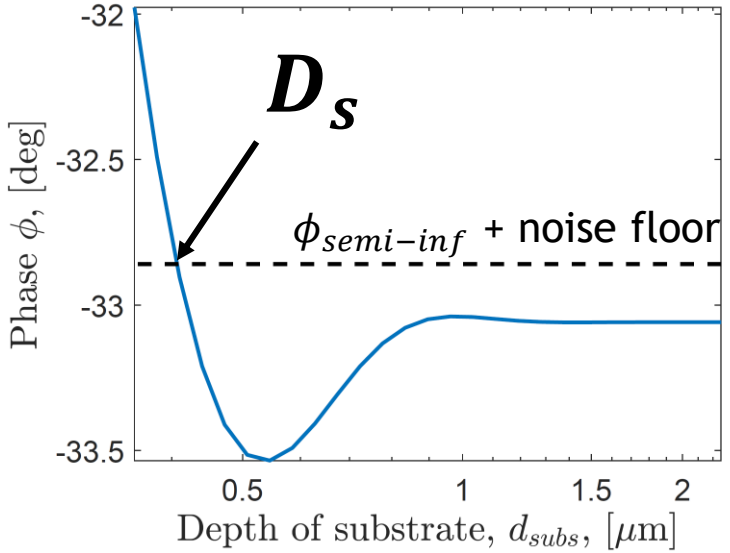
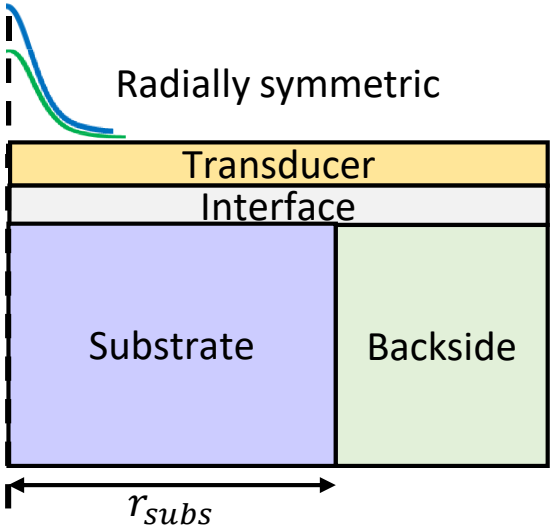
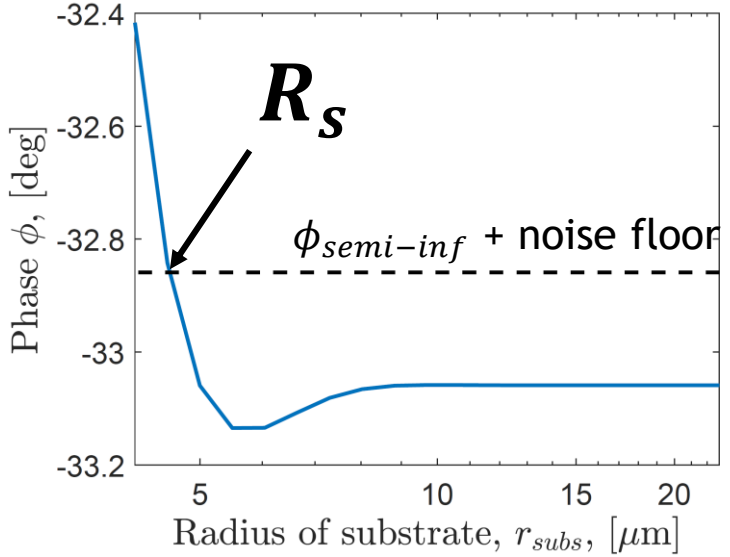


Vary d_{subs}

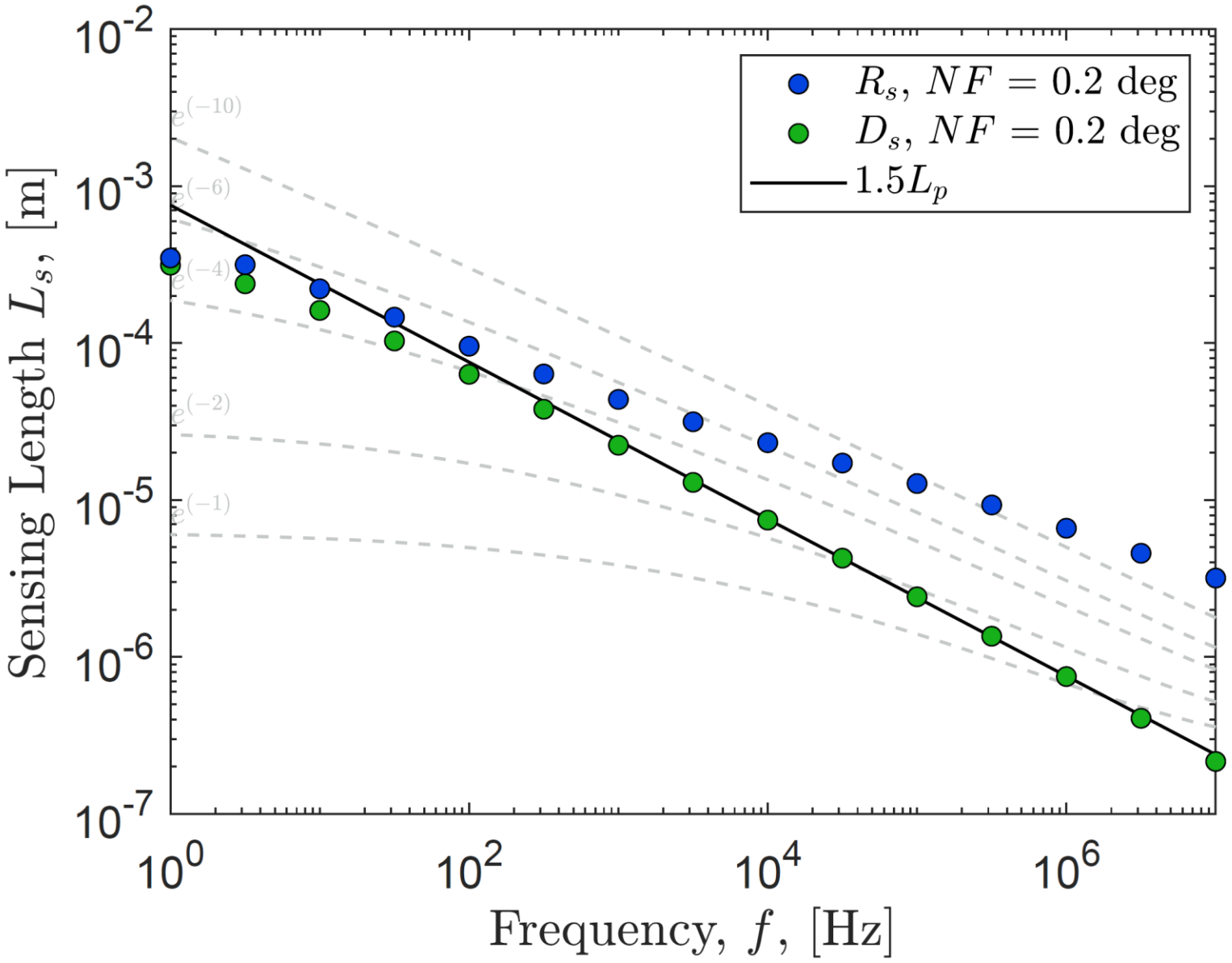




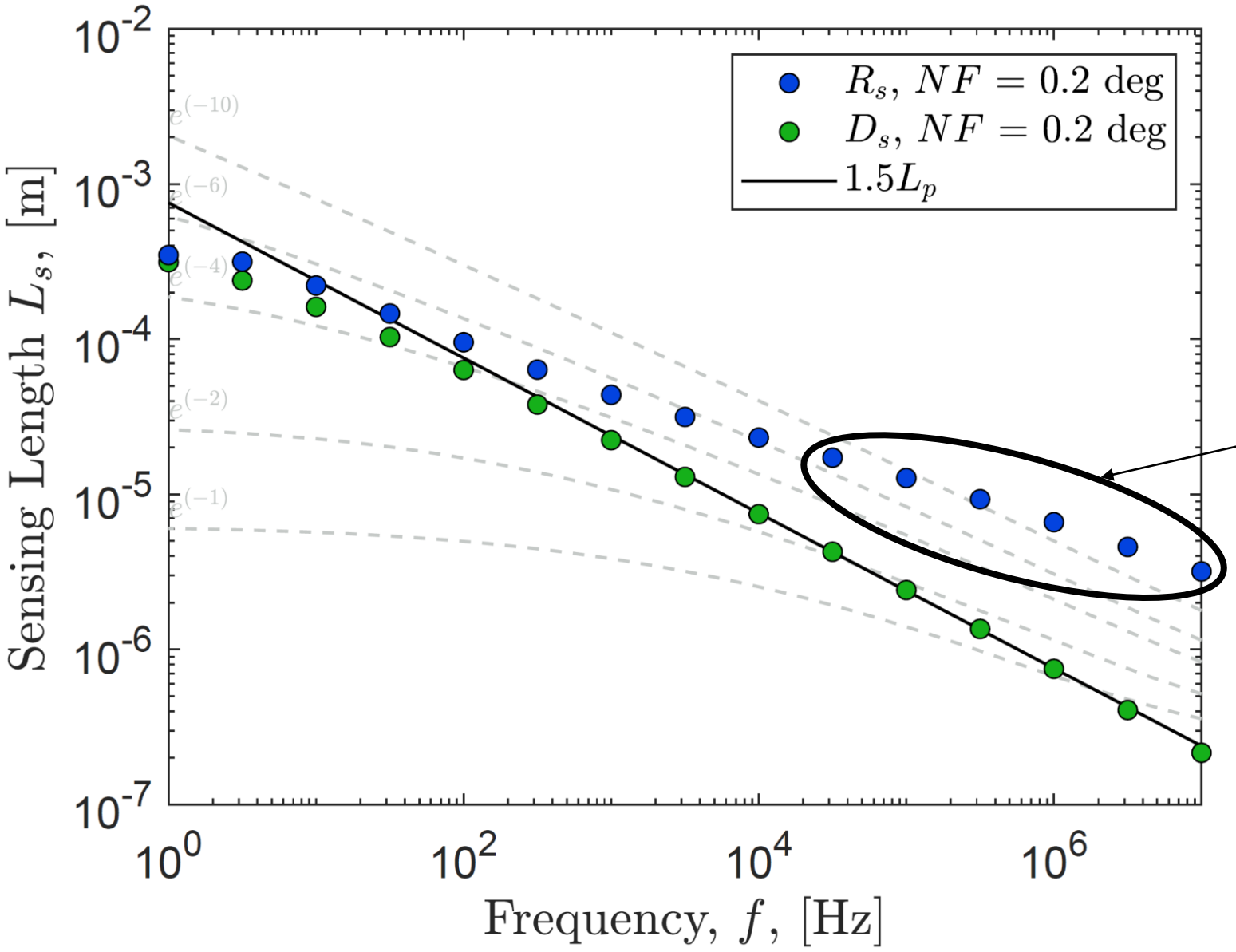
Vary r_{subs}



Sensing Lengths - SiO_2



Sensing Lengths - SiO_2



Transducer layer causes increased radial heat spreading

$$\alpha_{Transducer} \gg \alpha_{SiO_2}$$

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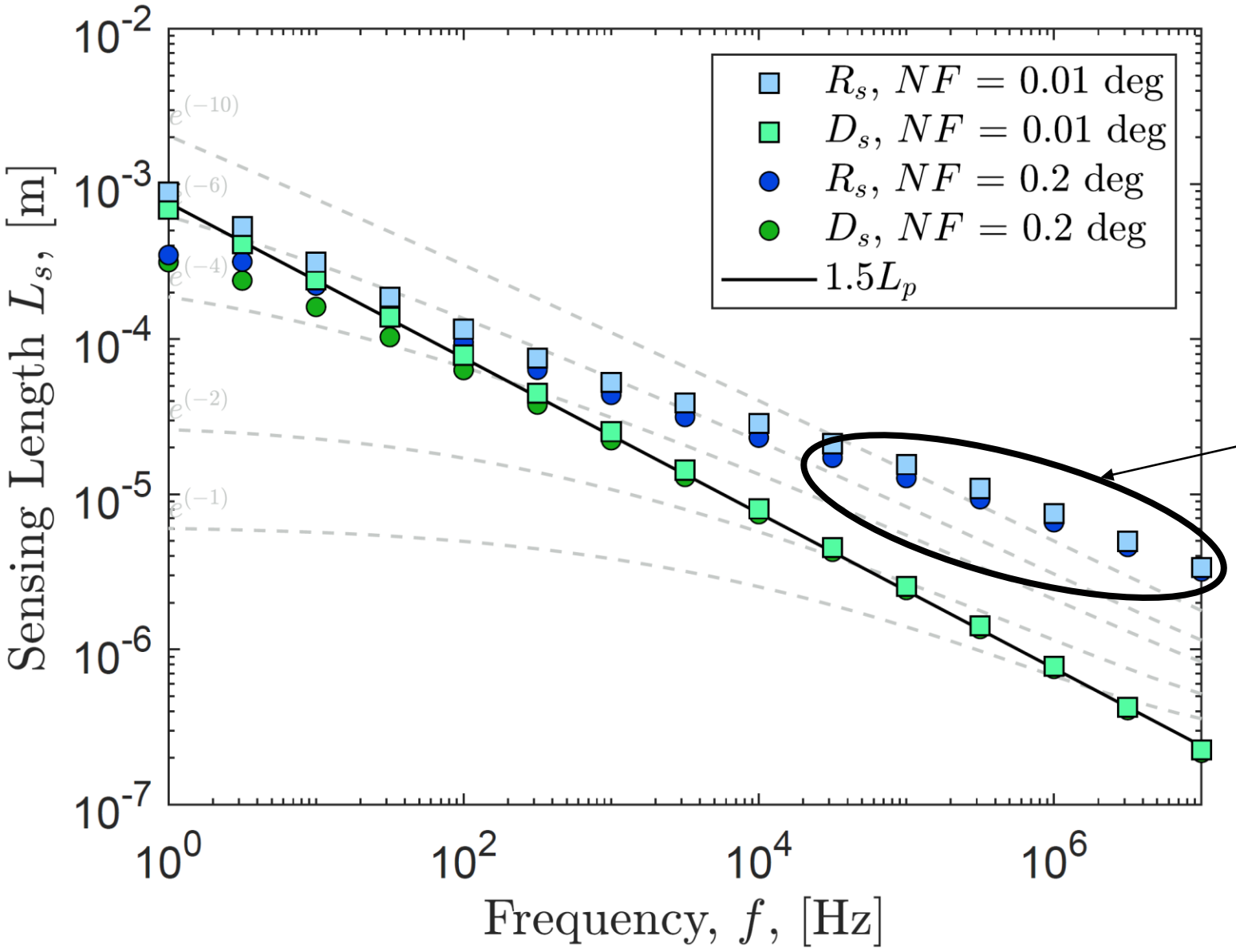

Transducer layer causes increased radial heat spreading

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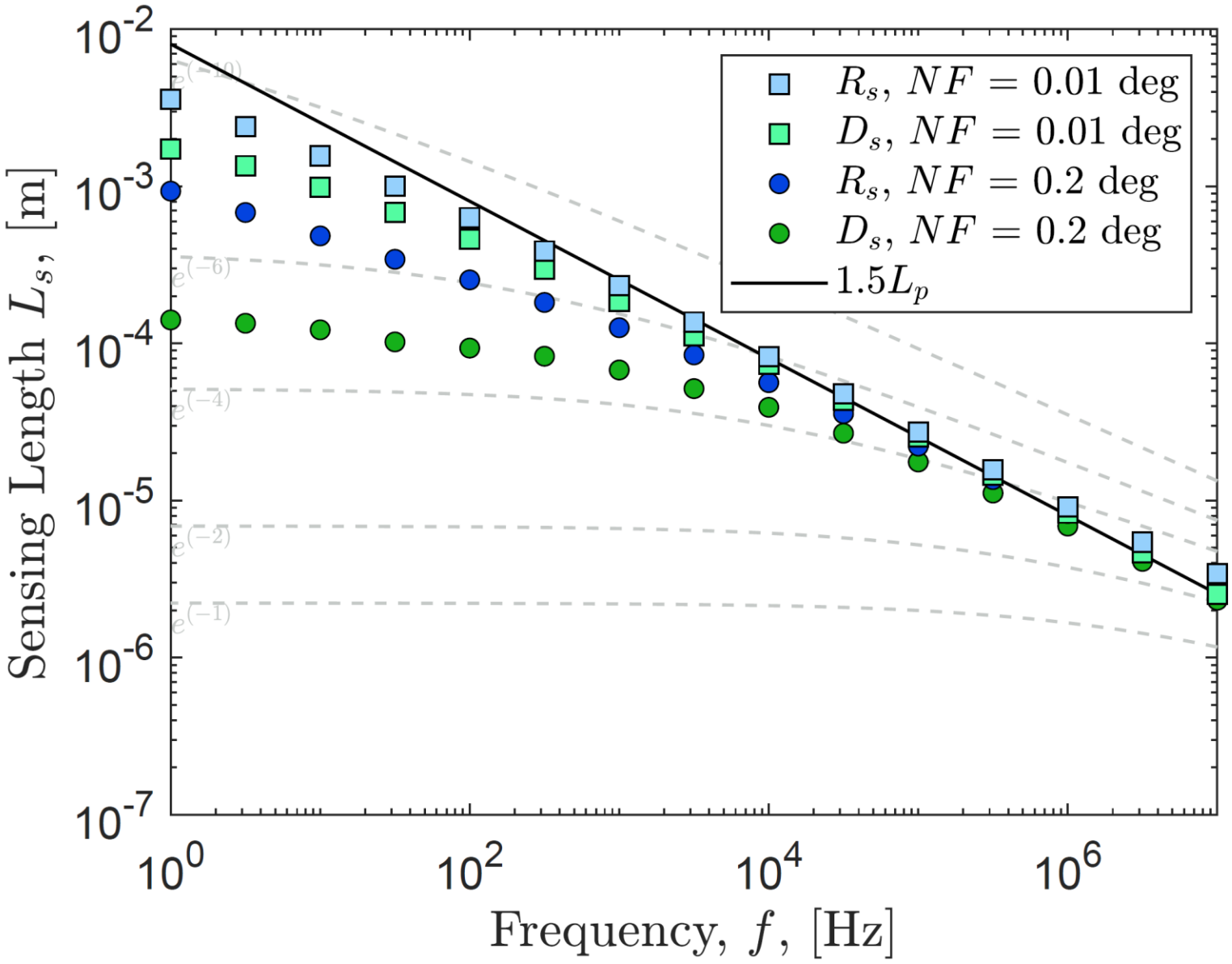
Sensing Lengths - Silicon



$$\alpha_{Transducer} \sim \alpha_{Si}$$

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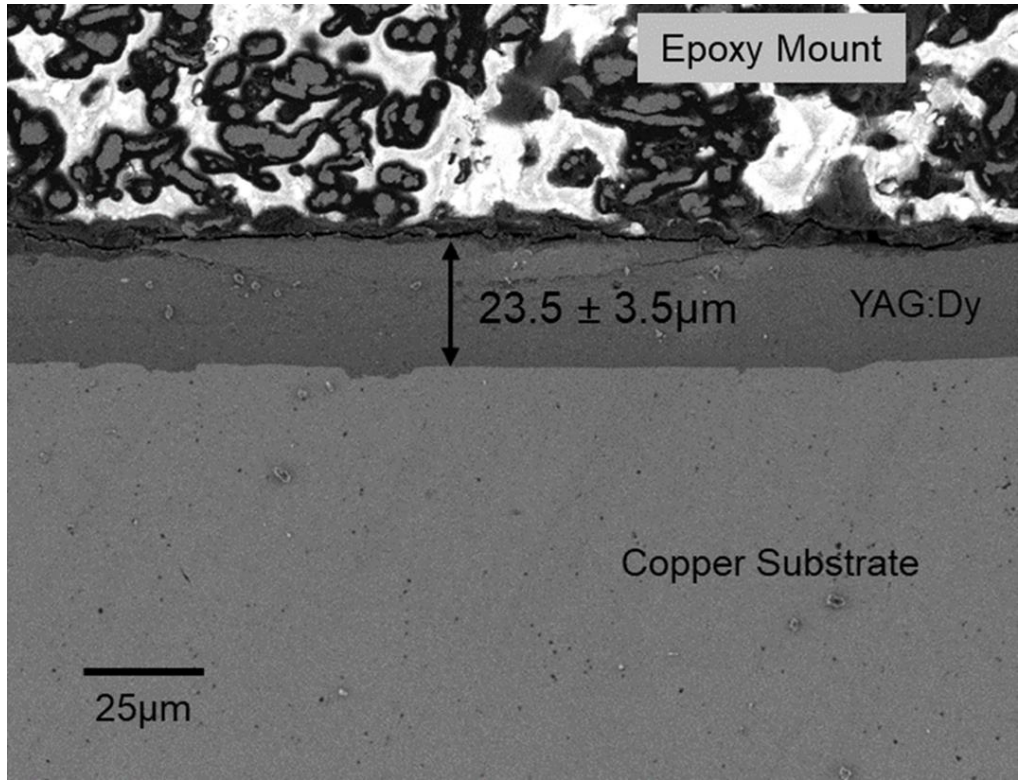
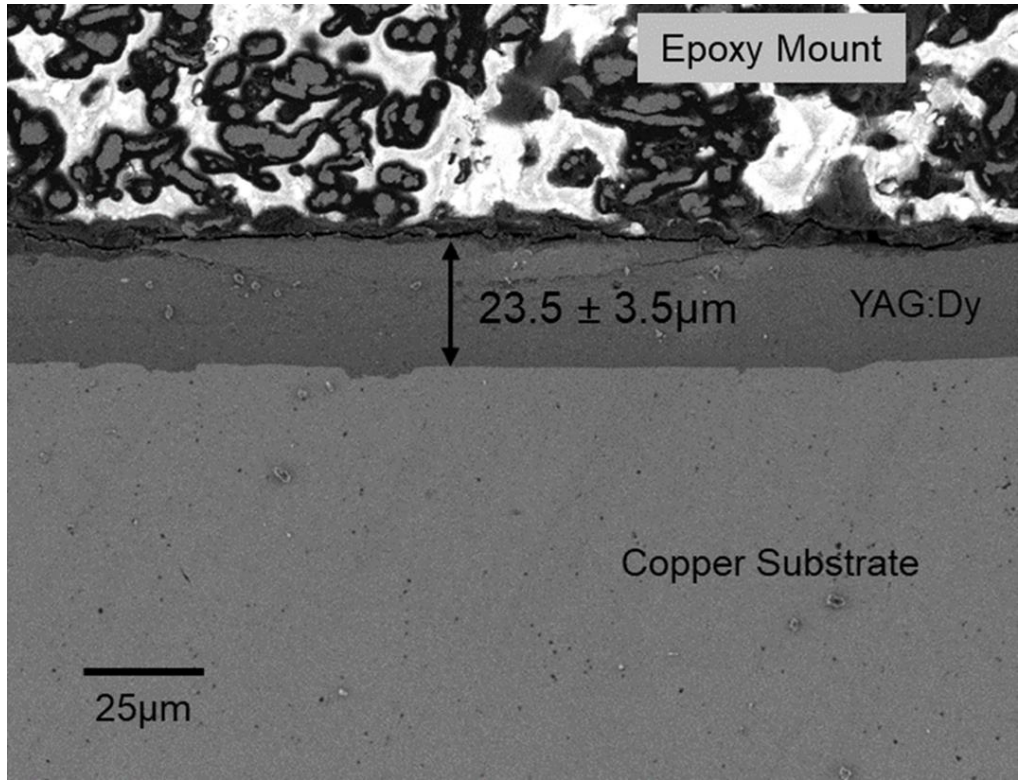
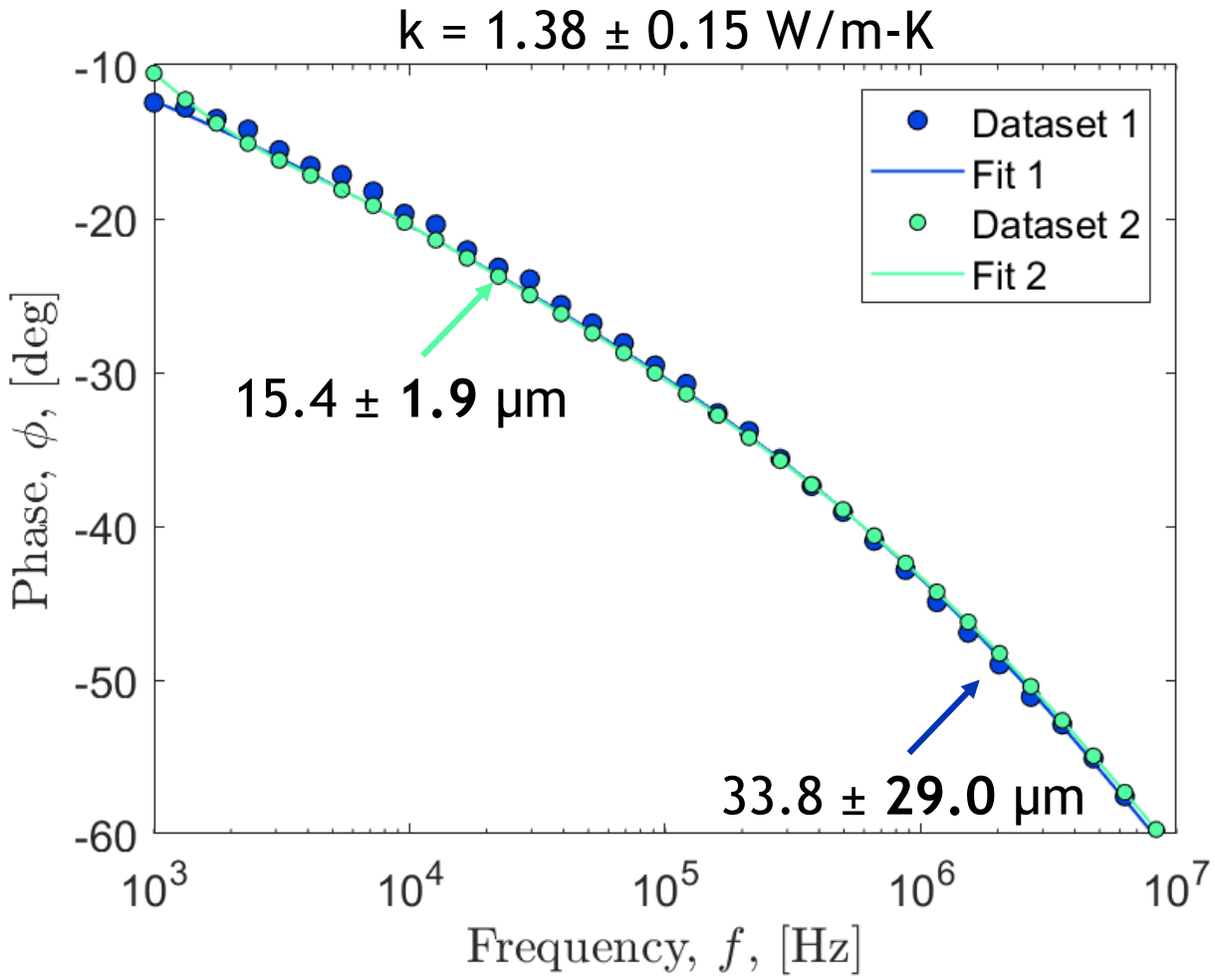
Experimental Results – YAG film



YAG → Yttrium Aluminum Garnet, $Y_3Al_5O_{12}$

Experimental Results – YAG film thickness fitting





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Conclusions

- Thermal penetration depth, temperature decay depth and sensing length are distinct concepts
- Sensing lengths in FDTR scales with thermal penetration depth at high frequency
- Lowering noise floor increases sensing length at low frequency
- Measurement of films thicker than sensing depth results in higher uncertainty, matching predictions