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Material Parameter Estimation of Thin Wafers with Terahertz Time-Domain Spectroscopy

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Introduction

Terahertz Time-Domain Spectroscopy(THz-TDS) is a spectroscopic technique that can be implemented to perform non-destructive material parameter extraction on a variety of materials. Accuracy of these material parameters is often limited by statistical variation between measurements and insufficient knowledge of the thickness of the slabs being measured.

The goal of this project was to develop an in-house procedure that would allow us to perform THz-TDS on thin wafers using an up-to-date signal processing algorithm that would provide:

- Accurate predictions for the thickness of the wafers
- Reliable estimations of the wafer's material parameters
- Demonstration of a moving average filter that considers boundaries established by the inherent noise of the measurement system

Experimental Setup

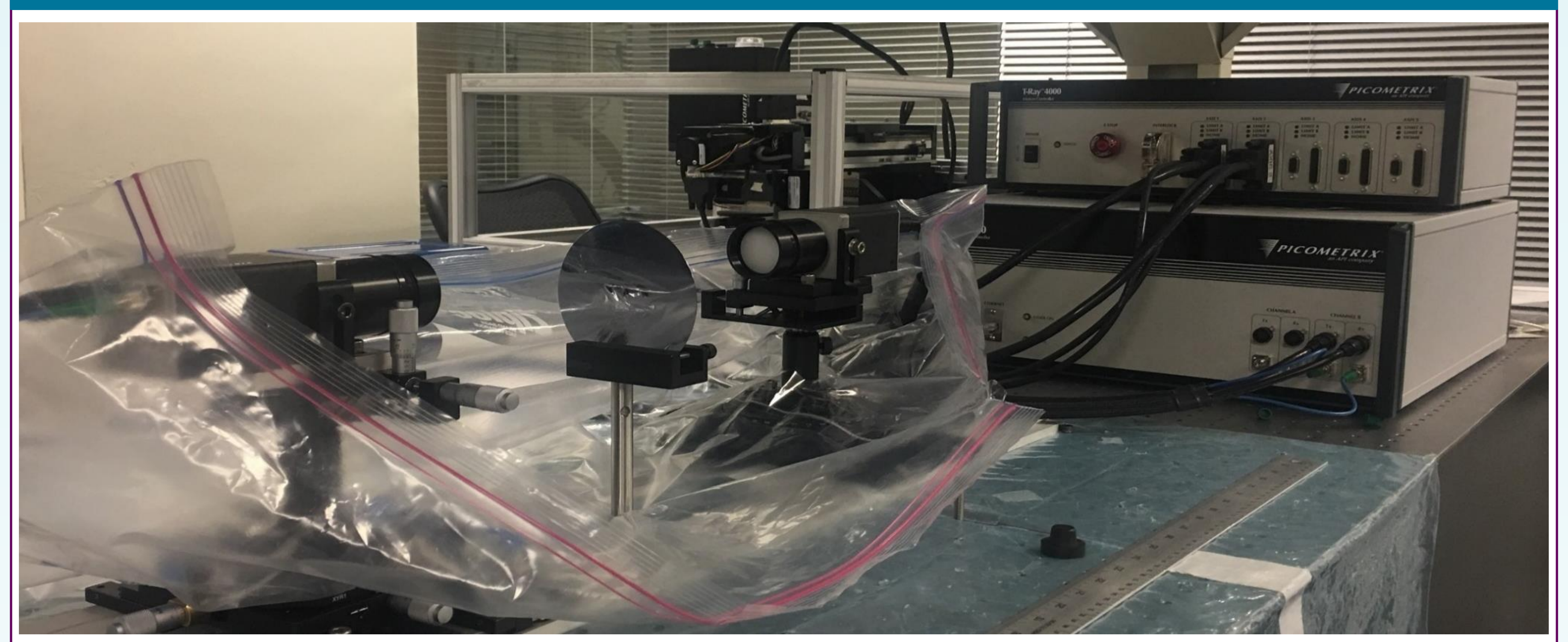

Fig. 1. Picometrix THz-TDS system with dry-air apparatus.

The procedure begins with time-domain measurements performed in a dry-air environment. The transmitter emits a picosecond pulse of radiation in a collimated beam that is transmitted through the wafer and detected by the system's receiving antenna, which we then define as our sample signal. The same measurement is also performed in absence of the wafer, which we define as our reference signal.

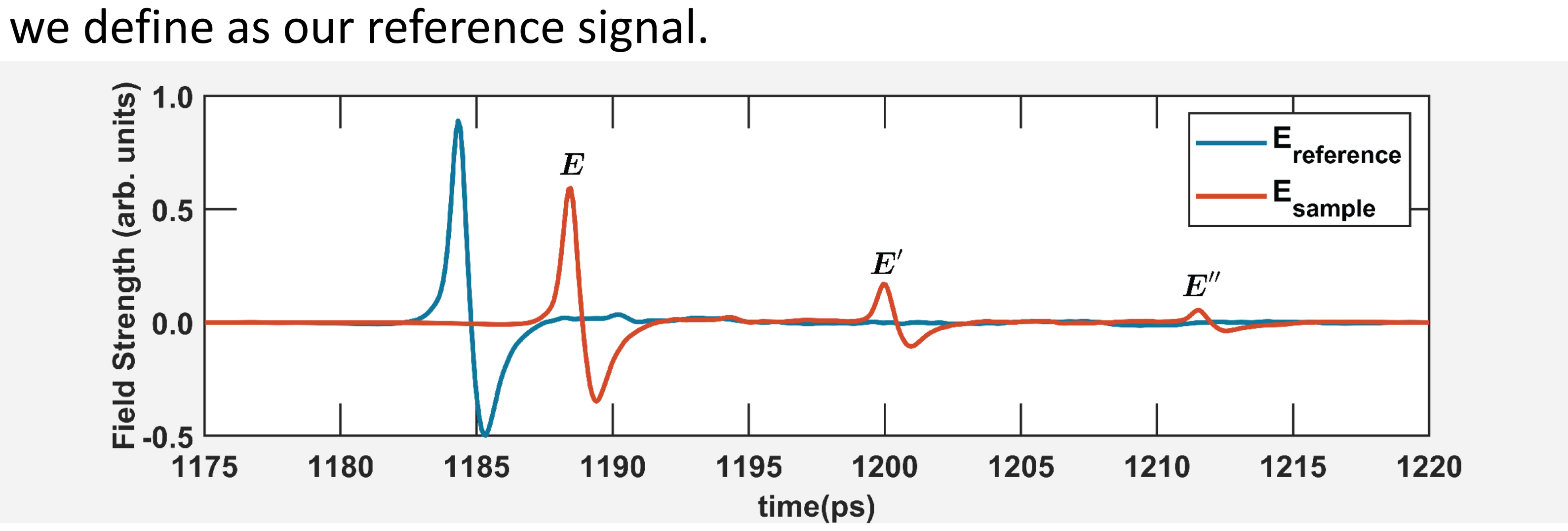

Fig. 2. Measured time-domain signals.

Model for Beam-Wafer Interaction

We then examine the predicted optical behavior of our experimental setup in the frequency domain to establish a mathematical model that we can then use to determine the complex index of refraction of our wafer, $\tilde{n}_{sample}(\omega)$.

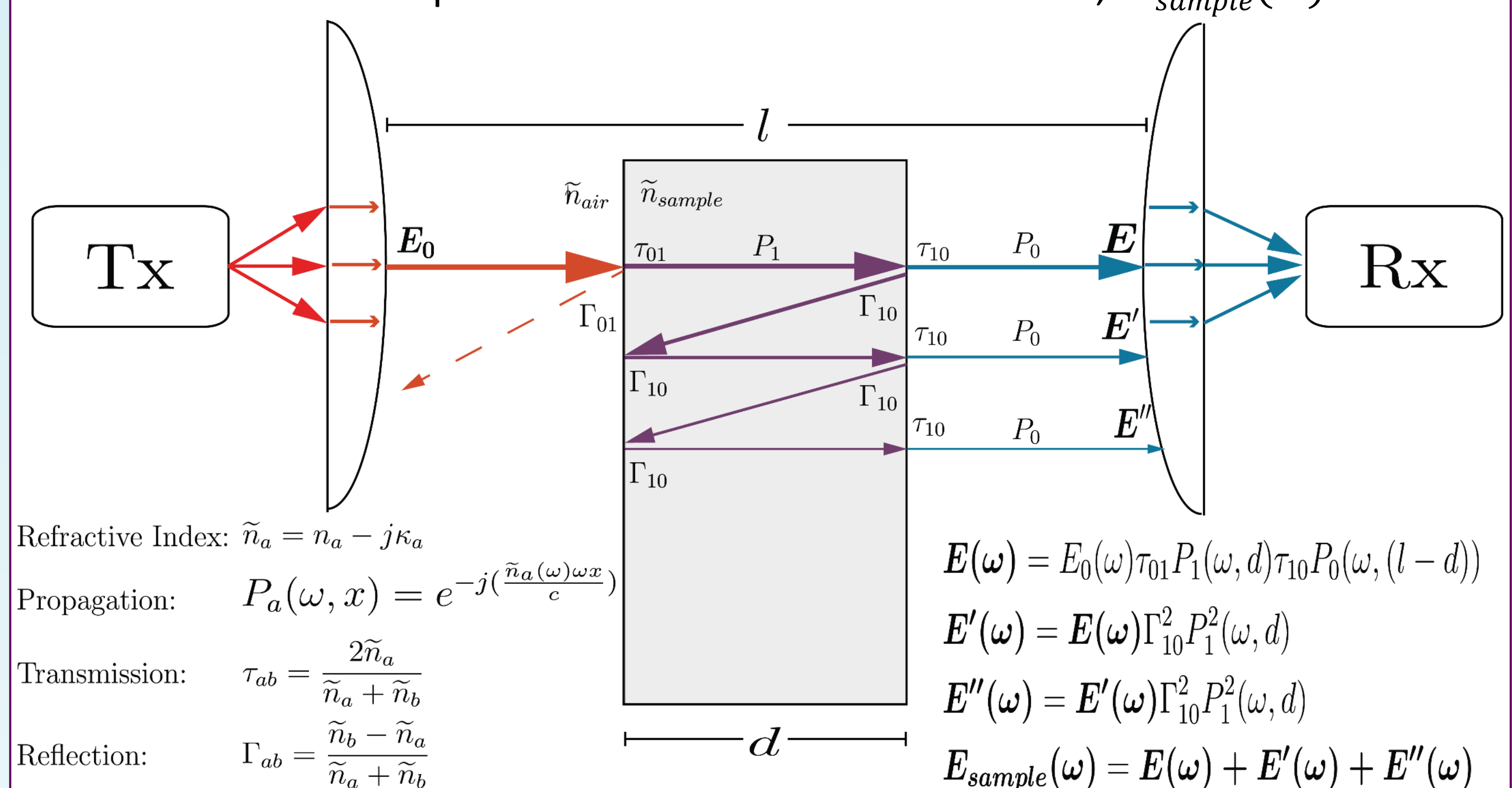

Fig. 3. Model for beam-wafer interaction.

Regarding $E_{sample}(\omega)$ as the sum of received pulses, we then define our model transfer function $H_{model}(\omega) = \frac{E_{sample}(\omega)}{E_{reference}(\omega)}$.

Extracting Material Parameters

We use a numerical solver to find the values of $\tilde{n}_{sample}(\omega)$ that satisfy $H_{model}(\omega) = H_{measured}(\omega)$ for an array of possible slab thicknesses d.

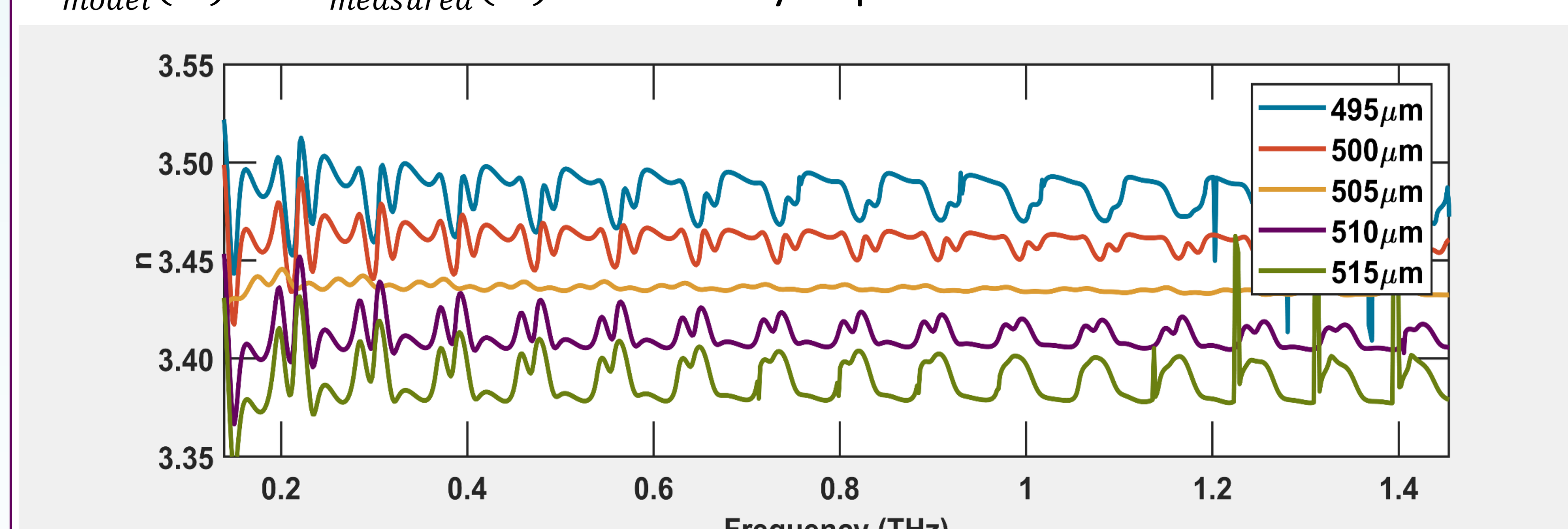

Fig. 4. $n_{sample}(\omega)$ for slab thickness range.

The value of d resulting in the least variation of $n_{sample}(\omega)$ indicates where $H_{model}(\omega)$ best matches $H_{measured}(\omega)$. We proceed by assuming this value to be the correct thickness [1]. We then apply a Spatially Variable Moving Average Filter to smooth the plots of $n_{sample}(\omega)$ and $\kappa_{sample}(\omega)$ within the parameters allowed by the statistical variation between a given set of measurements [2].

Results

After applying the extraction algorithm, we were able to obtain frequency dependent values for $n_{sample}(\omega)$ and $\kappa_{sample}(\omega)$ that agreed well with the expected values for the silicon wafers we measured.

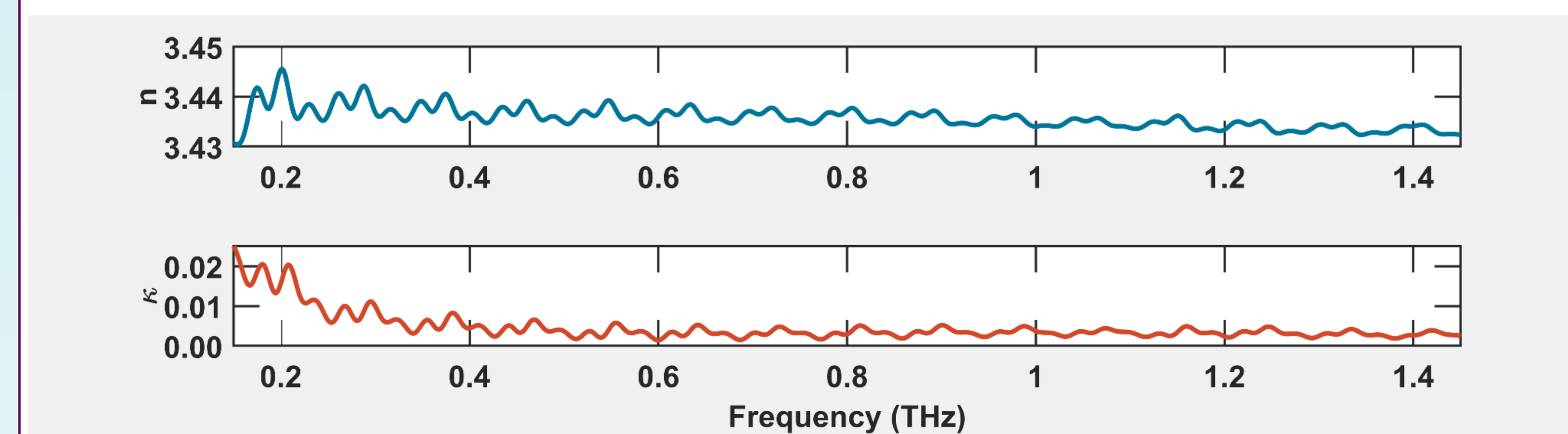

Fig. 5. Extracted values $n_{sample}(\omega)$ and $\kappa_{sample}(\omega)$ for 505 μm thick wafer.

With our values for $n(\omega)$and $\kappa(\omega)$, we are able to compute additional material parameters such as complex permittivity $\tilde{\varepsilon}(\omega)$, conductivity $\sigma(\omega)$, and absorption coefficient $\alpha(\omega)$.

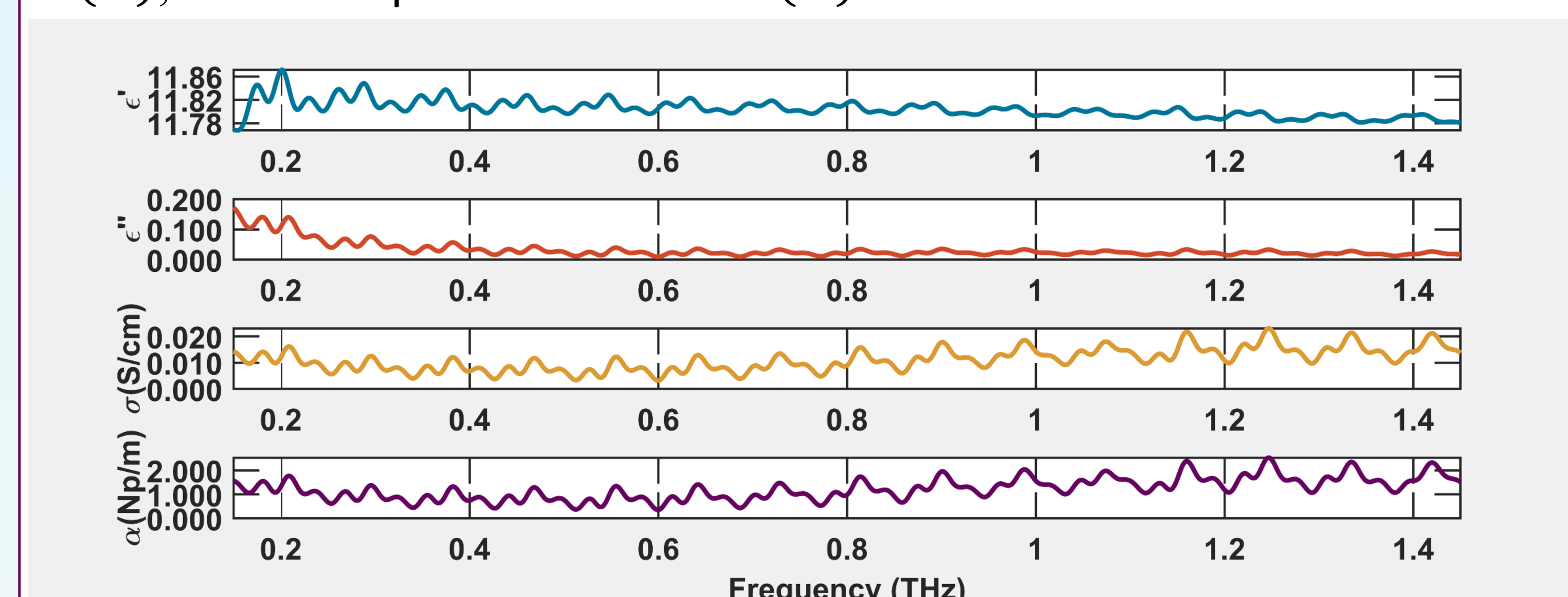

Fig. 6. Material parameters computed from n and κ.

Conclusion

Using a single, powerful THz-TDS algorithm, we are able to extract values for the optical material parameters of thin silicon wafers. Testing wafers of differing material composition will be required to verify the algorithm's versatility. Notable errors in computed values of conductivity were observed, which is likely a consequence of the small disturbances in κ that are greatly magnified in the THz regime.

References

[1] T. D. Dorney, R. G. Baraniuk, and D. M. Mittleman, "Material parameter estimation with terahertz time-domain spectroscopy.," *Journal of the Optical Society of America. A, Optics, image science, and vision*, vol. 18, no. 7, pp. 1562–71, Jul. 2001.

[2] I. Pupeza, R. Wilk, and M. Koch, "Highly accurate optical material parameter determination with THz time-domain spectroscopy," *Opt. Express, OE*, vol. 15, no. 7, pp. 4335–4350, Apr. 2007.

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