Thickness Determination for Homogeneous Dielectric Materials through THz-TDS

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***Abstract*— Through the use of terahertz time-domain spectroscopy (THz-TDS), the sample thickness can be determined by exploiting the Fabry-Pérot effect. Given the reference pulse and the full-scanned sample pulse traversing a homogeneous dielectric material with a known index of refraction, the method calculates the thickness from the fringe pattern, i.e. the maxima and minima, appearing in the transmission amplitude spectrum. High accuracy is attainable when a material has a constant index of refraction and low loss across the T-ray frequency region. This paper demonstrates results using silicon and cycloolefines as test material.**

I. Introduction

Several methods to extract the sample thickness from THz-TDS signals have been reported. Duvillaret *et al.* [1] and Dorney *et al.* [2] proposed methods to simultaneously determine the sample thickness and complex index of refraction. Yet, the methods suffer from iteration. Huang *et al.* [3] determined the sample thickness from a phase difference between the ratio of primary/reference pulses and the ratio of echo/primary pulses. This method requires separation between echo and primary pulses, which occurs only in an optically-thick sample.

This paper reports a novel approach for the calculation of the sample thickness via Fabry-Pérot fringes. If the index of refraction is known, the sample thickness can be extracted from the fringes' maxima and minima.

II. Theory

Given a T-ray signal transmitted through a dielectric sample at normal incidence, $E_{\mathrm{sam}}(t)$, and a reference signal travelling an identical path without the presence of the sample, $E_{\mathrm{ref}}(t)$, a transfer function, obtained by deconvolving the sample pulse with respect to the reference pulse, is described by [2]:

$$H(\omega) = \frac{E_{\mathrm{sam}}(\omega)}{E_{\mathrm{ref}}(\omega)} = \tau\tau' \exp\left[-i(n_s - 1)\frac{\omega l}{c}\right] \cdot \mathrm{FP}(\omega)\,, \quad (1)$$

where τ and τ' are the transmission coefficients at the entry and exit faces of the sample, l is the sample thickness, and n_s is the sample index of refraction. In Equation (1), $\mathrm{FP}(\omega)$ represents the Fabry-Pérot effect or the interference in the received signal from reflections within the sample,

$$\mathrm{FP}(\omega) = \left\{1 - \rho^2 \exp\left[-2in_s\frac{\omega l}{c}\right]\right\}^{-1}\,, \quad (2)$$

where ρ is the reflection coefficient.

Provided that the index of refraction is constant, the modulus of the transfer function has local maxima following $|\mathrm{FP}(\omega)|$. The local maxima occur at $n_s\omega l/c = 0, \pi, 2\pi, \ldots$ Therefore, the thickness l equals $c/(2n_s\Delta f)$, where Δf is frequency separation between any two adjacent local maxima. This calculation is also applicable to the local minima.

III. Results

A FZ silicon wafer and a cycloolefines piece are investigated by THz-TDS. Their T-ray spectra are shown in Figure 1.

The silicon thickness determined from the fringes is 1.9985 mm, comparable to the thickness of 1.9931 mm determined from the time-domain peaks. The cycloolefines thicknesses determined from the fringes and the peaks are 1.0836 mm and 1.0951 mm, respectively. Since the laser fluctuation disturbing the peak of a time-domain signal is diluted in the frequency domain, the thickness obtained from the spectrum could be more reliable.

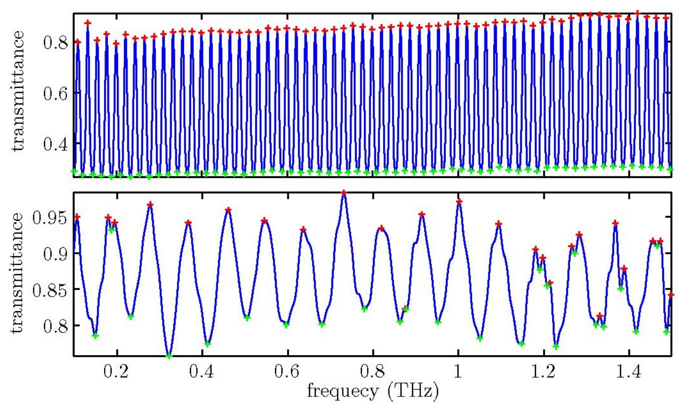

Fig. 1. Transmittance of 2-mm-thick silicon (top) and 1.1-mm-thick cycloolefines (bottom). The cross signs indicate the maxima and minima.

IV. Conclusion

The proposed thickness calculation method, exploiting fringes in a transmission spectrum, showed promising results. However, its accuracy, in particular under the presence of noise, is a subject of further study.

References

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