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Windowing of THz time-domain spectroscopy signals: A study based on lactose

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ABSTRACT

Time-domain spectroscopy has established itself as a reference method for determining material parameters in the terahertz spectral range. This procedure requires the processing of the measured time-domain signals in order to estimate the spectral data. In this work, we present a thorough study of the properties of the signal windowing, a step previous to the parameter extraction algorithm, that permits to improve the accuracy of the results. Lactose has been used as sample material in the study.

1. Introduction

A critical aspect of the terahertz time domain spectrometry (THz-TDS) is the accurate estimation, from the raw data provided by the spectrometer, of the actual far-infrared parameters of a material. Such parameters, namely the frequency-dependent (real) refractive index and the absorption coefficient, cannot be obtained in closed form from the temporal trace of the pulses transmitted through (or reflected from) the sample to be characterized. Hence some kind of numerical, typically iterative, method must be employed for their calculation. Different parameter extraction algorithms have been developed over the last decades to process the THz-TDS-acquired data [6–8,17–19,1]. Naturally, these algorithms always involve time–frequency transformations which are carried out with signal processing tools such as the Fast Fourier Transform (FFT). Although the use of such rather standard, well-established technique should apparently be straightforward, in practice there can be great differences in the final performance of the algorithm depending on the characteristics of the time-window which mandatorily accompanies any real-world spectral estimation. Windowing is, in fact, unavoidable due to the finite duration of the captured signals, and the lack of an explicit windowing operation is fully equivalent to the application of a rectangular window. In this work, we analyze how the overall procedure for the calculation of the optical parameters of the materials is affected by the specific time-window chosen.

Despite the importance of windowing in the THz-TDS algorithms, it is not possible to find in the existing literature any in-depth, systematic analysis on the effects and suitability of the different time-domain windows for this type of signal processing. Some examples where some limited focus has been put on the time-window problem can be cited, such as [20], where a Nuttall window was used to neglect undesired pulses (focusing on the main pulse) and a broad Hamming window was used to eliminate the effect of spectral leakage. A more comprehensive reference is perhaps the study presented in [11]; in this work, however, the focus is put on Short Time Fourier Transform (STFT), Discrete Wavelet Transform (DWT) and Wide-Band Cross Ambiguity Functions (WBCAF) based analysis.

The aim of this paper is to cover the gap in the literature and make a first detailed study of the effects of different windows applied in the time domain to THz-TDS. This comprehensive study has been carried out using empirical data obtained as described next in Section 2. Section 3 presents the results detailing how windowing affects them and conclusions are discussed in Section 4.

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Table 1
Pellets used in this study, indicating name, dilution ratio and measured thickness.

Sample	Lactose fraction (approx) (wt%)	Thickness (μm)
Lactose 100%	100	1260
Lactose 60%	60	2080
Lactose 50%	50	4260
Lactose 25%	25	4820

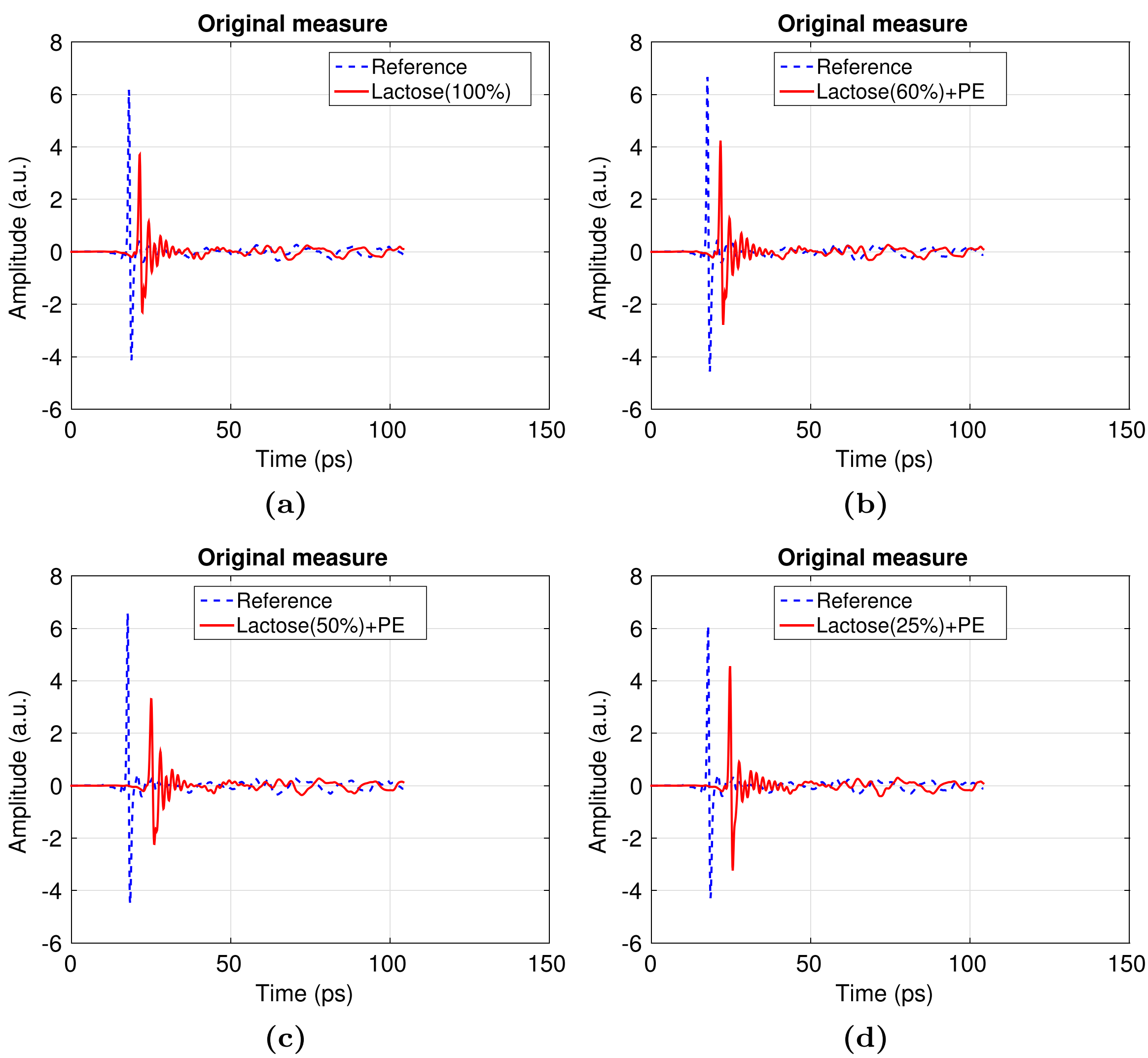

Fig. 1. Measured time domain pulse for: lactose 100% (a), lactose 60% (b), lactose 50% (c), lactose 25% (d).

2. Materials and methods

2.1. Sample preparation

For this work, α-lactose monohydrate[1] has been chosen as the test material in the study, whose optical properties had already been characterized in the terahertz region [2].

Lactose powder was mixed with different ratios of polyethylene[2] and then pressed with 7 t for 5 min to form pellets with a diameter of 1.3 mm. The resulting thicknesses of the pellets (measured using a vernier caliper) are summarized in Table 1.

2.2. Measurement procedure

A Menlo Tera K15 Spectrometer was used for the THz-TDS analysis. The system is based on a 1560 nm fiber laser that generates 90 fs pulses at a repetition rate of 100 MHz. This provides a compact fiber-coupled setup. The system was operated in a nitrogen rich atmosphere in order to avoid the signature of water absorption in the recorded samples. The measurements were obtained using the system in transmission mode.

The pellets were placed at the focus of the THz optical system. Ten samples and ten reference measurements (empty sample holder) were performed for each pellet in order to reduce the measurement noise through averaging. Each acquisition generated a 104 ps-long temporal photocurrent trace. The time domain results are plotted in Fig. 1. The reference amplitude was considerably stable for all the samples and large enough to avoid critical dynamic range problems (which only appear at amplitudes smaller than about 1 a.u.). It must also be noted that if the sample thickness had been exactly the same, then the sample amplitude would have followed a monotonic decreasing value from lactose 25% to lactose 100%, but the results deviated from the expected behavior mainly due to the thickness differences.

[1] α-Lactose monohydrate (CAS No. 5989-81-1, ≥99% total lactose basis (GC)) was purchased from Sigma-Aldrich.

[2] Polyethylene (CAS No. 9002-88-4, powder, spectrophotometric grade) was purchased from Sigma-Aldrich.