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Frequency Selection Techniques in Terahertz Spectroscopy and Focus Diameter Estimation

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I. Introduction

Recent technological advancements have enabled the development of efficient methods for generating and detecting electromagnetic radiation in the terahertz (THz) range [1]. Due to the photons'energy falling within the range of a few milli-electronvolts (meV), such radiation possesses attractive properties for investigating condensed matter systems [2]. Among the recent applications, terahertz time-domain spectroscopy (THz-TDS) [3] has allowed the study of phonons in quantum materials.

II. Justifications/Objectives

Terahertz radiation lies in the invisible spectrum of electromagnetic radiation, posing certain instrumental and experimental challenges. Parameters such as the focal spot size and bandwidth present non-trivial acquisition aspects. During experiments, many samples exhibit distinct spatial configurations; therefore, characterizing the transmission occurring within the setup is crucial for understanding the results. Thus, investigating its behavior sheds light on experimental limitations and criteria.

III. Materials and Methods

The experimental setup features an optical arrangement consisting of a pumping laser, beam splitter, delay line, chopper, two antennas for emitting and detecting terahertz pulses, four concave mirrors for focusing radiation, and the sample holder. The study conducted time-domain spectroscopy of 15 sample apertures (10 apertures with distinct diameters and 2 mm thickness, along with 5 apertures of 3 mm diameter with varying thickness).

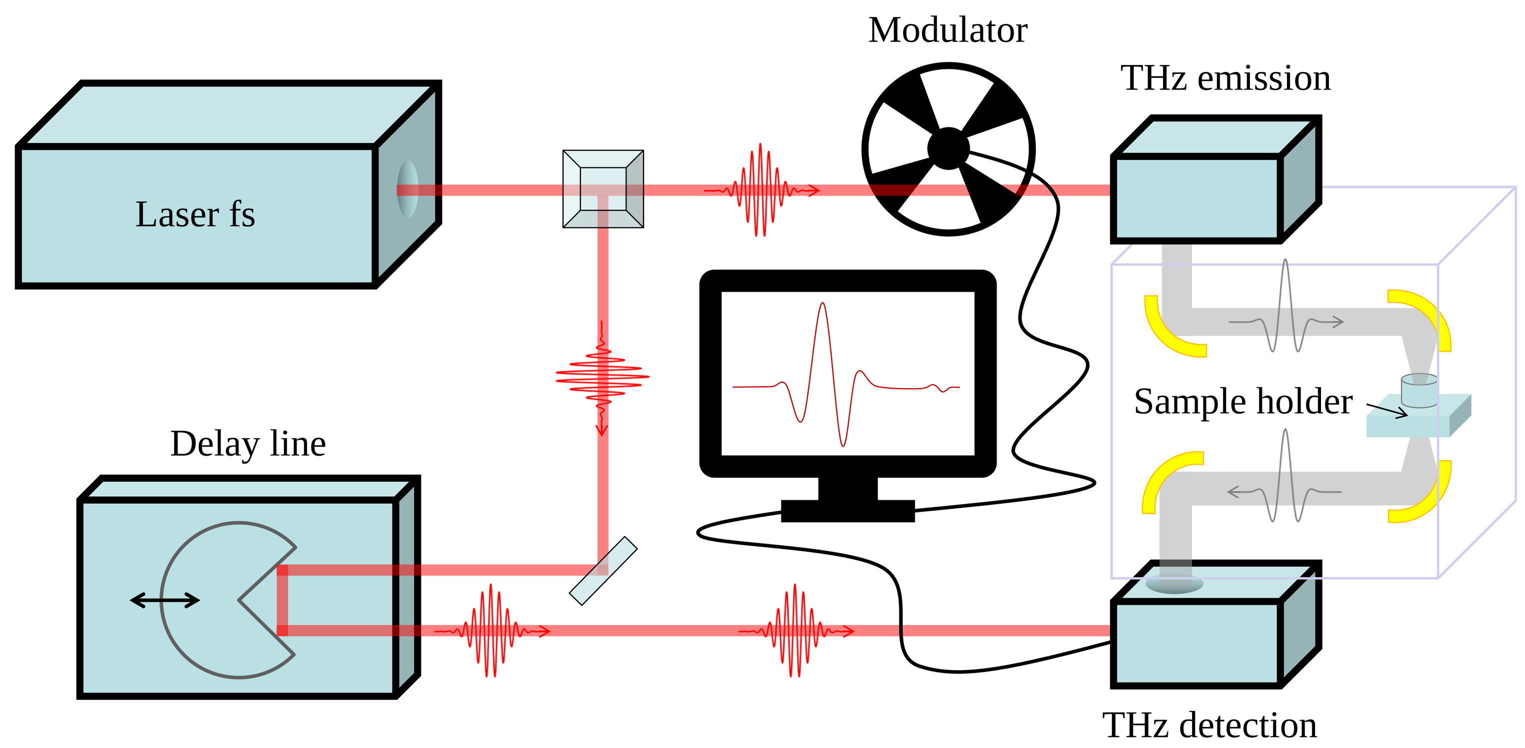

Figure 1. Diagram of the experimental setup for time domain spectroscopy. The sample holder containing the openings is located in a low humidity region to avoid absorptions of some terahertz frequencies.

The signal is amplified by a lock-in and undergoes Fast Fourier Transform (FFT) [4] to analyze the transmitted frequencies. By calculating the maximum amplitudes of the electric field, a Gaussian error function was fitted to estimate the focus diameter using the Gaussian's Full Width at Half Maximum (FWHM) [5].

$$f(x) = a * ERF\left[\frac{(x-x_0)}{\sigma}\right] + f_0 \quad | \quad FWHM = 2\sqrt{2\ln(2)}\,\sigma \approx 2.355\,\sigma$$

IV. Results

Figure 2 depicts the terahertz pulses and their corresponding FFT for various aperture diameters. It can be observed that the magnitude of frequencies decreases as the aperture size decreases. Furthermore, there is a loss of frequencies for apertures with 0.5 and 1.0 mm diameters. Therefore, it is recommended to use diameters larger than 1.5 mm.

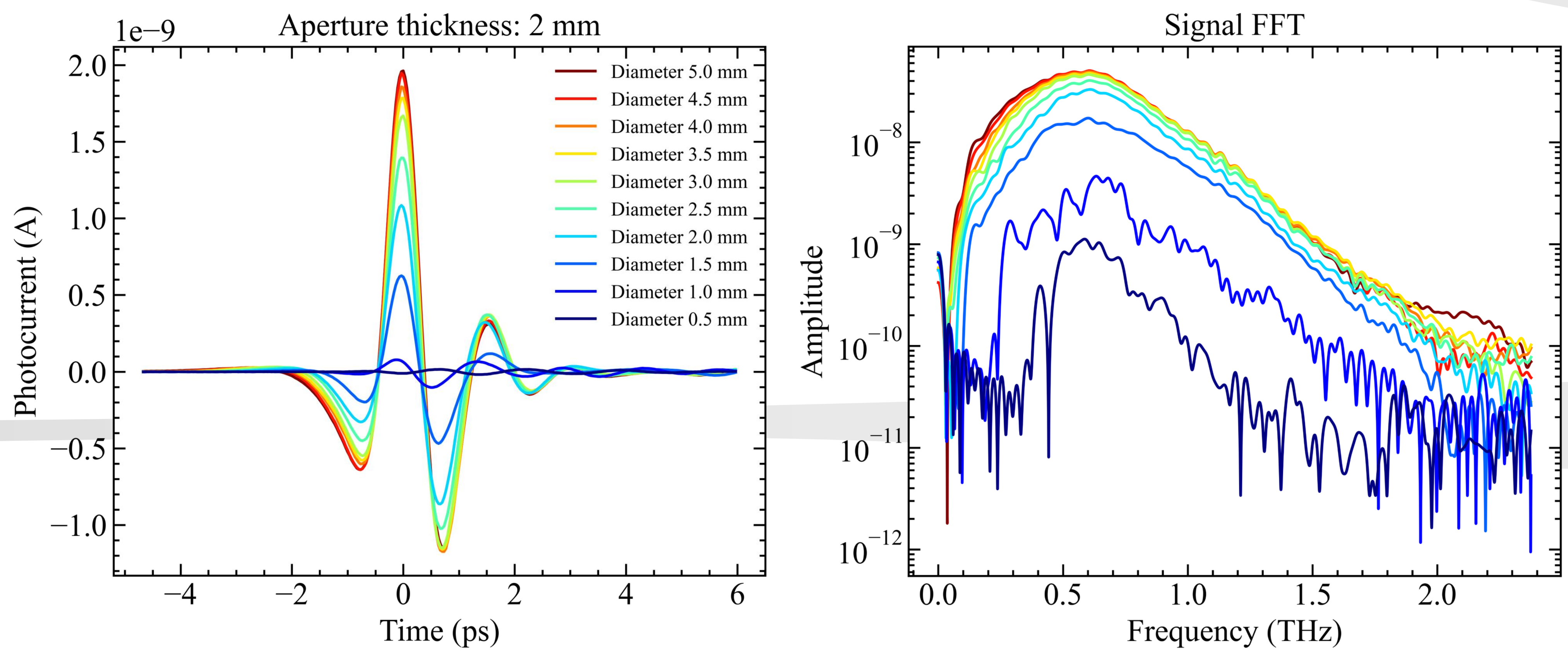

Figure 2. Terahertz pulse detection graph for each aperture diameter. Considering that the pulse is in the time domain, it is possible to analyze the frequencies transmitted by the FFT of the signal.

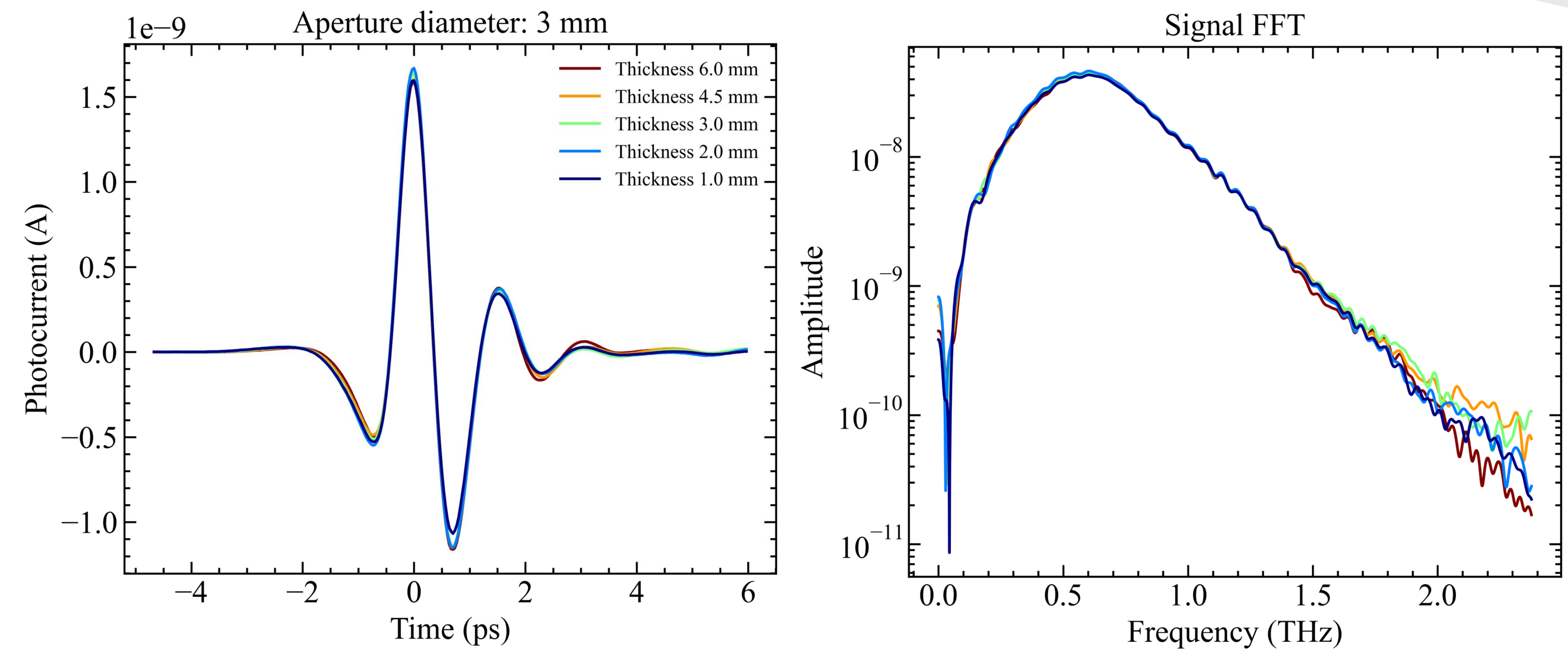

Figure 3. Terahertz pulse detection graph for each aperture thickness. Considering that the pulse is in the time domain, it is possible to analyze the frequencies transmitted by the FFT of the signal.

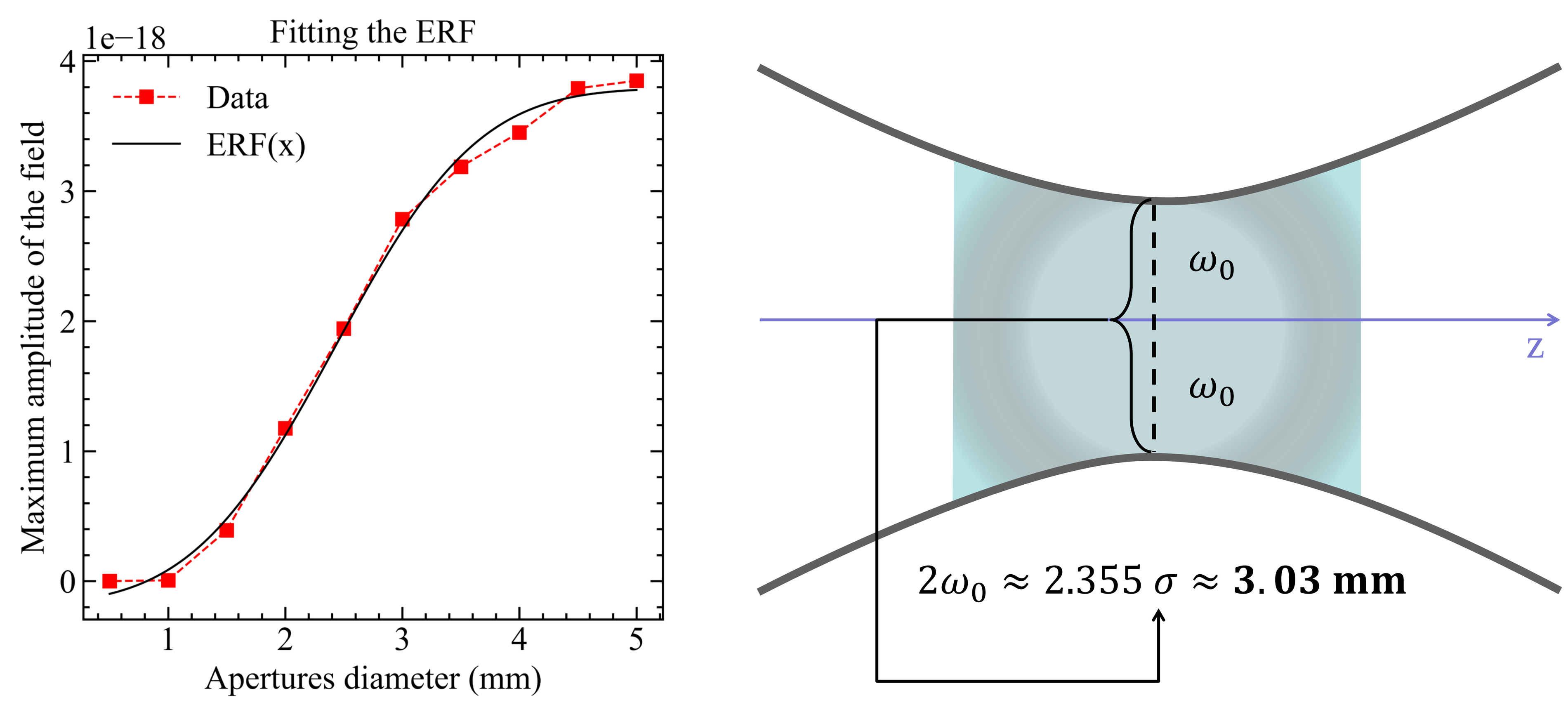

Figure 4. Graph of peak intensity of terahertz pulses as a function of sample holder opening diameter. An adjustment was made with the parameters of the Gauss error function. The standard deviation (σ) obtained was approximately 1.29 mm.

V. Conclusions

It was determined that the thickness of the sample holder apertures does not bring about changes in transmitted radiation, dismissing the hypothesis of resonances within the apertures. However, it was possible to describe the impact of aperture diameter on the transmitted frequency band, as well as to estimate the focus diameter.

References

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