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Terahertz Second harmonic generation and Interference Effects

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Abstract

Investigate terahertz wave generation and Second Harmonic Generation (SHG). Optical instruments were used to set up a Fabry-Perot interferometer to observe the interference effects of terahertz waves, with analyses conducted in both time and frequency domains. Successful generation of terahertz waves was achieved. The formation and intensity of interference fringes were found to be closely related to the optical path difference and interference conditions. The setup's effectiveness was validated, and the influence of constructive and destructive interference on the characteristics of terahertz waves was observed. A terahertz time-domain spectroscopy(TDS) system was integrated for further examination, utilizing a silicon wafer as the interferometer medium.

Introduction

Second Harmonic generation

SHG is used to produce laser light with twice the frequency of the original laser. From the following relation, as the electric field increases, the frequency-doubling efficiency also improves:

$$\eta_{2\omega} \equiv \frac{I_{2\omega}(z)}{I_{\omega}(0)} = \kappa^2 z^2 |\bar{E}_{\omega}|^2 sinc^2\left(\frac{\Delta kz}{2}\right)$$

The lattice oscillations produce Stokes radiation, which is then amplified to generate THz waves.

Momentum Conservation

$$\Delta \vec{k} = \vec{k}_{\omega 3} - \vec{k}_{\omega 2} - \vec{k}_{\omega 1} = 0; \vec{k}_{\omega 3} = \frac{2\pi n\omega_1 n\omega_2}{\lambda_{\omega 3}} 、\vec{k}_{\omega 1} = \frac{2\pi n_{\omega 1}}{\lambda_{\omega 1}} 、\vec{k}_{\omega 2} = \frac{2\pi n_{\omega 2}}{\lambda_{\omega 2}}$$

(k: wave vector, λ: wavelength, n: corresponding refractive index.
When the crystal satisfies phase matching, this condition is fulfilled.

Energy Conservation

$$\hbar\omega_3 = \hbar\omega_1 + \hbar\omega_2$$

$\hbar$ is the constrant, so $\omega_3 = \omega_1 + \omega_2$ during the interaction.

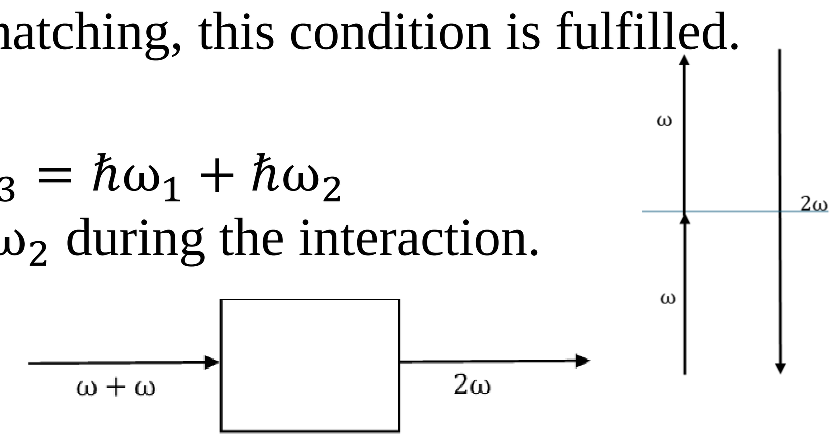
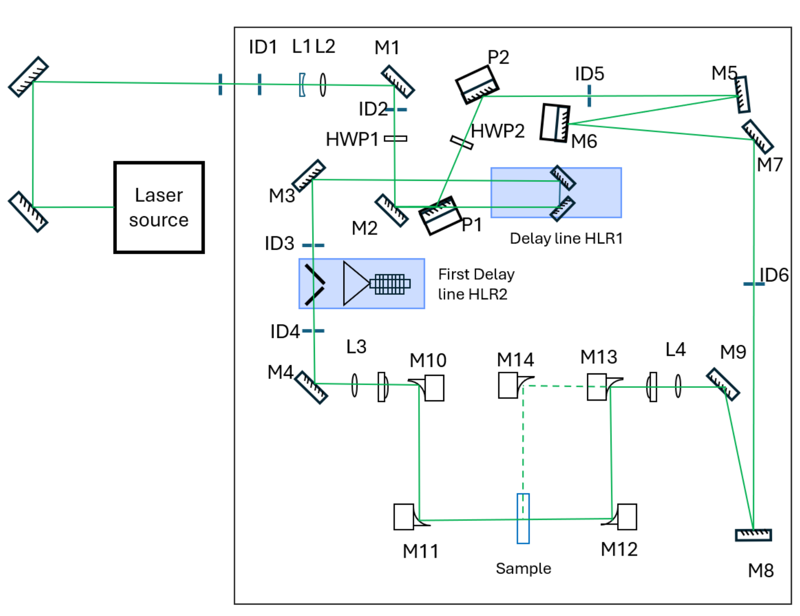


Fig. 1 Nonlinear system and double frequency diagram of the system

Terahertz time-domain spectroscopy system (TDS)



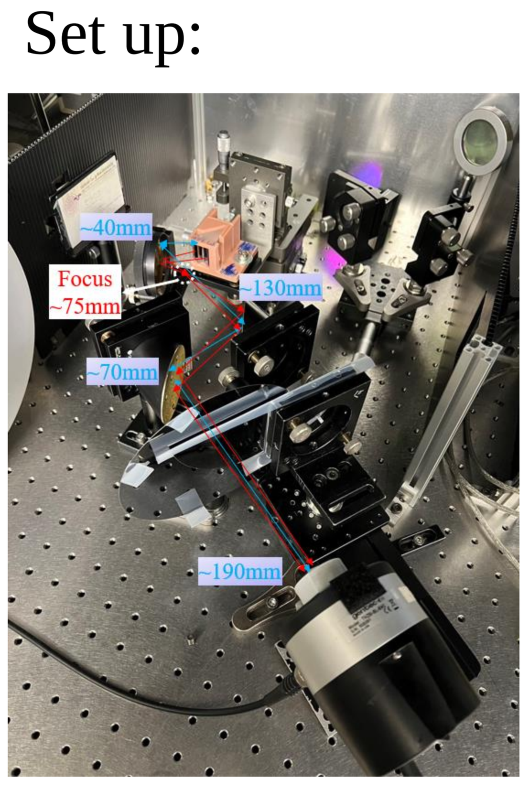
It derives the frequency-domain response of materials by analyzing the transmission or reflection behavior of terahertz waves in the time domain, enabling the characterization of material properties.

Fig. 2 Schematic of TDS system

Methods and Results

THz SHG

Set up:



Add 2 parabolic mirrors:

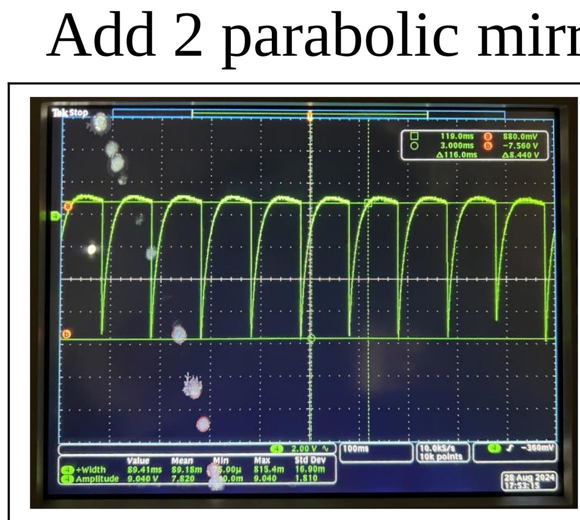
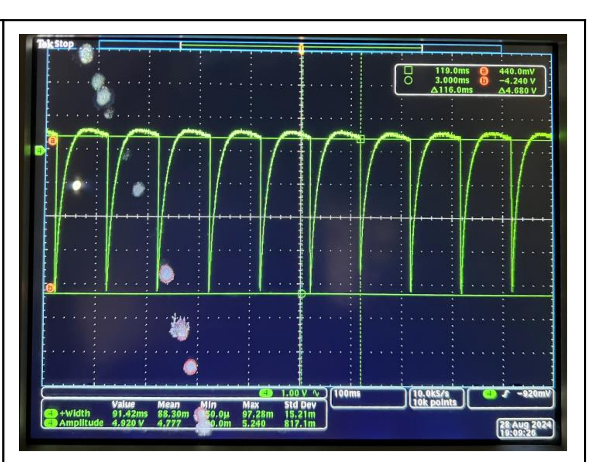
	
(a) Without silicon plate, amplitude = 8.44V.	(b) Two parabolic mirrors added, amplitude = 4.68V.

Fig. 3 Amplitude before and after adding silicon plate

Add silicon wafer:

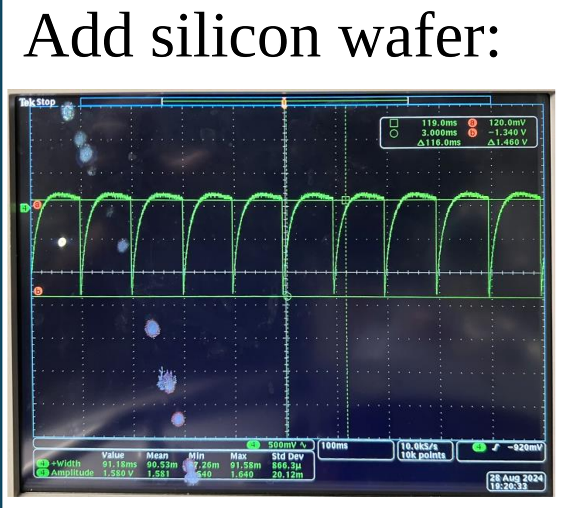


Fig. 4 Amplitude after adding silicon wafer Amplitude drops to 1.64V.

Destructive constructive interference:

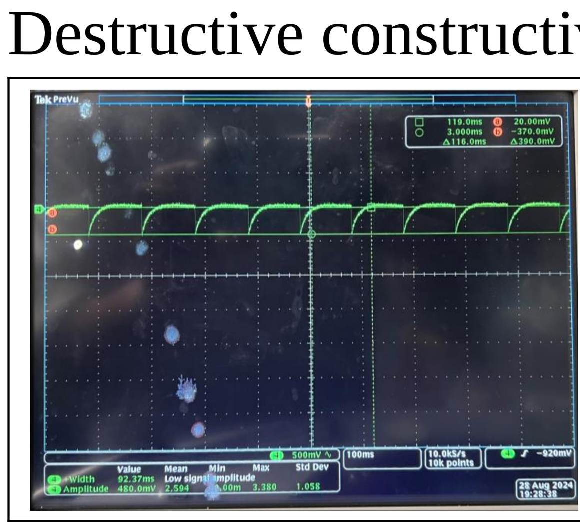
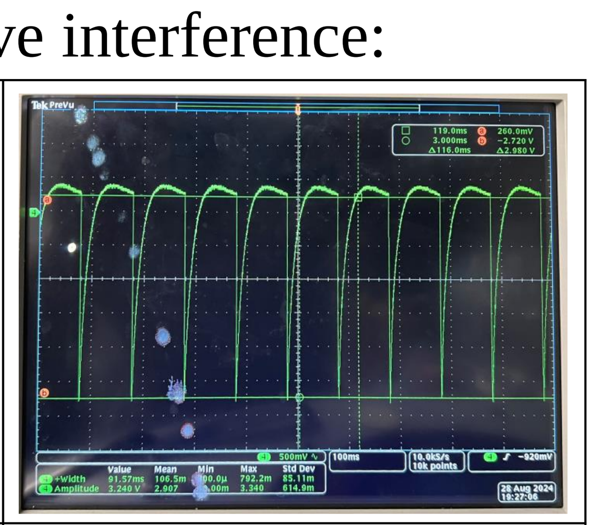
	
(a) Deconstructive, amplitude = 0.46V	(b) Constructive, amplitude = 3.24V

Fig. 5 Amplitude of destructive and constructive interference

Result analysis:

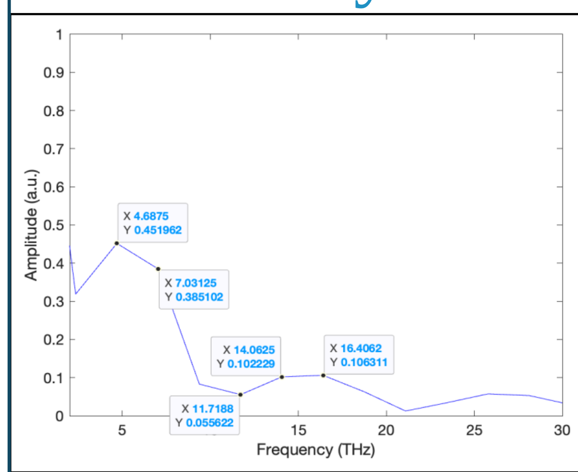
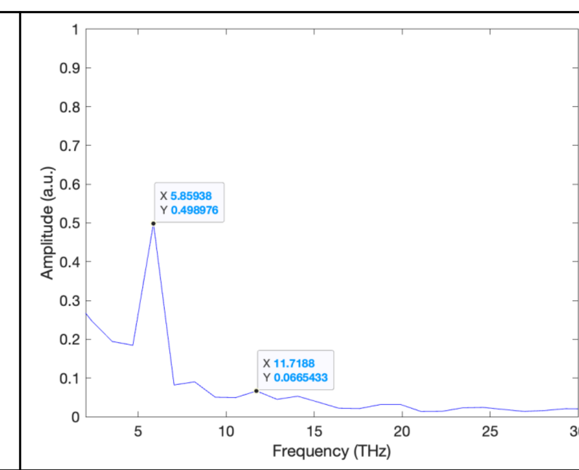
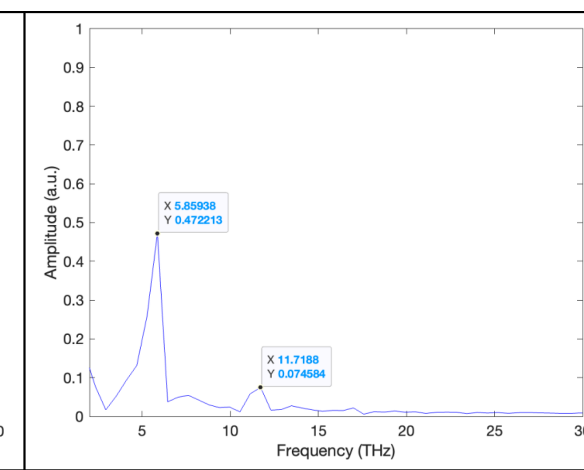
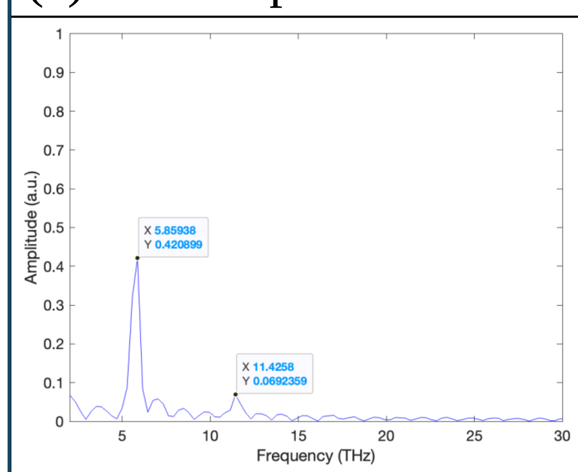
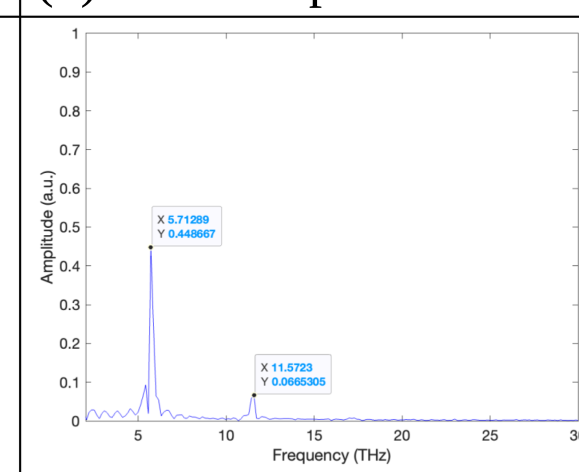
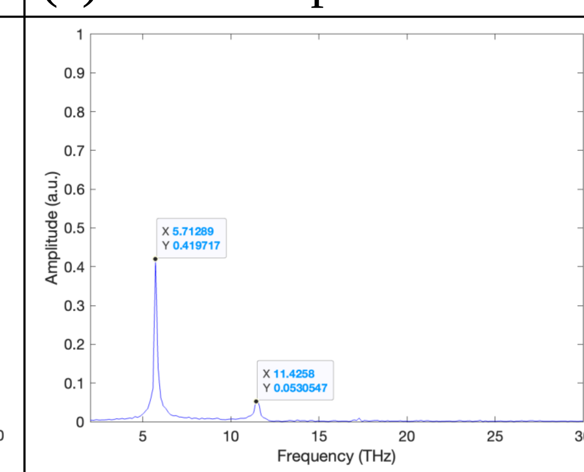
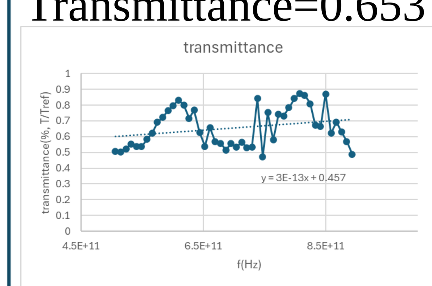
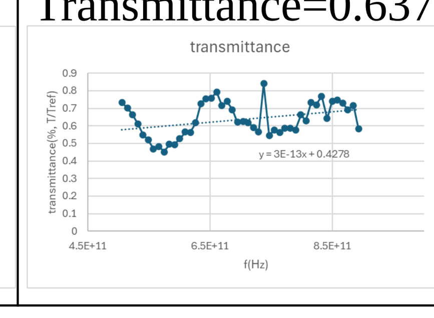
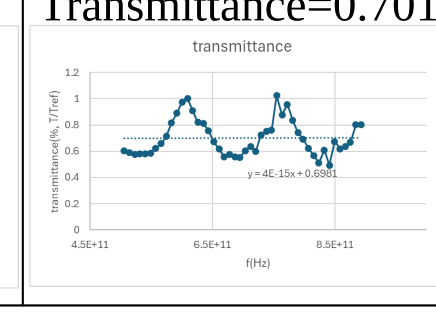
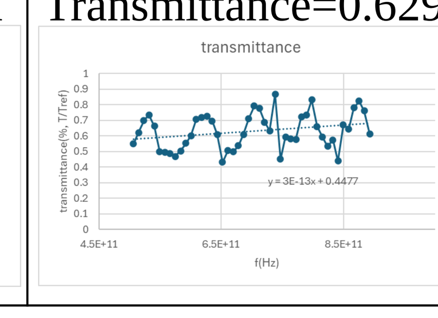
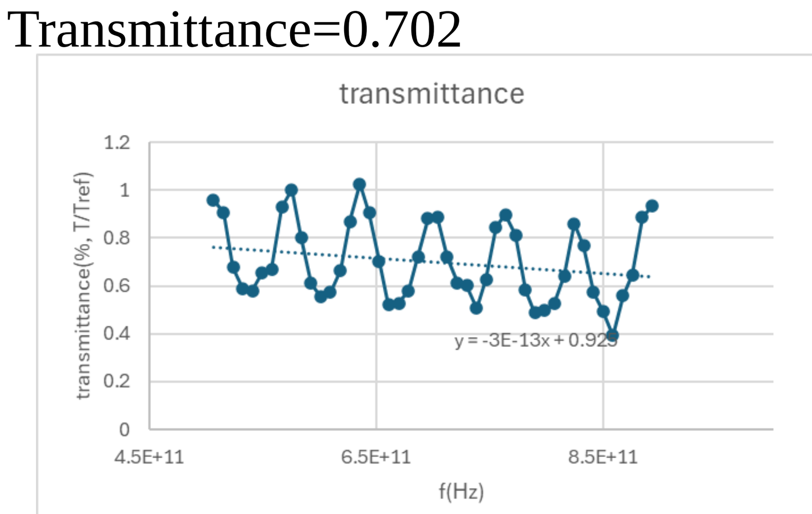
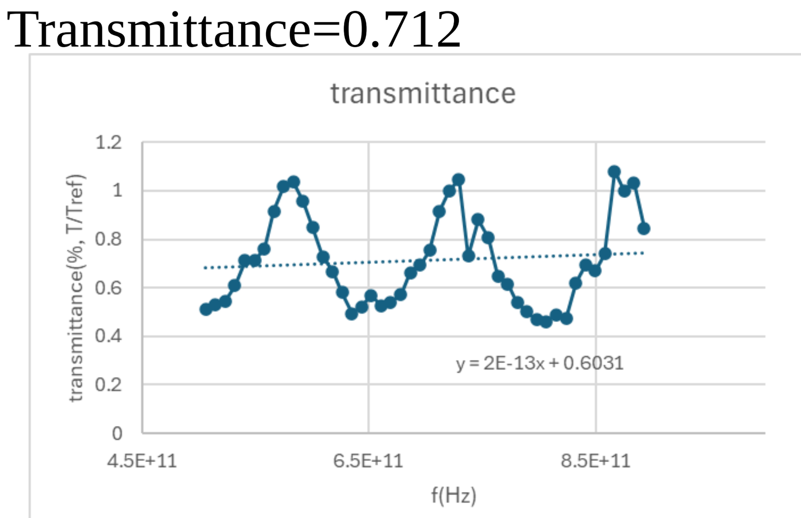
		
(a) 50 data points	(b) 100 data points	(c) 200 data points
		
(d) 400 data points	(e) 800 data points	(f) 1000 data points

Fig. 6 FFT resolution

TDS measuring transmittance

Silicon Sample Specifiation:

(a) P type	(b) N/P type	(c) undoped	(d) N/Ph type
R=1~50Ω	R=3~30Ω	R>30000Ω	R=3~30Ω
DSP	SSP	DSP	SSP
Thick=200um	Thick=275um	Thick=280um	Thick=500um
Transmittance=0.653	Transmittance=0.637	Transmittance=0.701	Transmittance=0.629
			

(d) N type	(e) N type
R>10000Ω	R=5000~12000Ω
DSP	SSP
Thick=675um	thick=300um
Transmittance=0.702	Transmittance=0.712
	

Conclusion

(1) Successfully generated THz waves and conducted analysis of the results.
(2) Significant variations in terahertz wave output power were observed when silicon plates were used for interference, highlighting the influence of interference on terahertz wave properties.
(3) Investigated the effects of sampling points and varying Fast Fourier Transform (FFT) resolutions on terahertz wave characteristics.
(4) Confirmed the effectiveness of the Fabry-Perot interferometer setup and its application in experimental results.
(5) Deduced that doping does not directly correlate with refractive index; measured refract.
(6) Silicon wafers with varying impedance exhibited different transmittance and reflectance, influencing interferometer imaging.

Reference

(1) Christina Chaccour, et.al (2022), Seven Defining Features of Terahertz (THz) Wireless Systems: A Fellowship of Communication and Sensing, IEEE Communications Surveys & Tutorials Volume 24
(2) Ran-Jin Lin, (2000) Gap-tunable Fabry-Perot Interferometers Fabricated by MEMS Technologies, 《光學工程》Issue 72 (2000/12) Pp. 21-29
(3) Matthias Hoffmann (2006), Novel Techniques in THz-Time-Domain-Spectroscopy, Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences ,chapter 1