Terahertz Spectroscopy on Graphene-Polymer Nanocomposites

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Introduction

Terahertz time domain spectroscopy (THz - TDS) is a non-destructive form of spectroscopy, which utilizes THz waves to measure the electrical and optical properties of objects with sub-picosecond resolution. The advantage of this method compared to conventional spectroscopy, is that it measures the amplitude and phase of the THz electromagnetic field. This allows for the calculation of such parameters as index of refraction and absorption coefficient, electric permittivity and conductivity. This method is being in the lab, to characterize the properties of graphene - polymer samples.

Setup

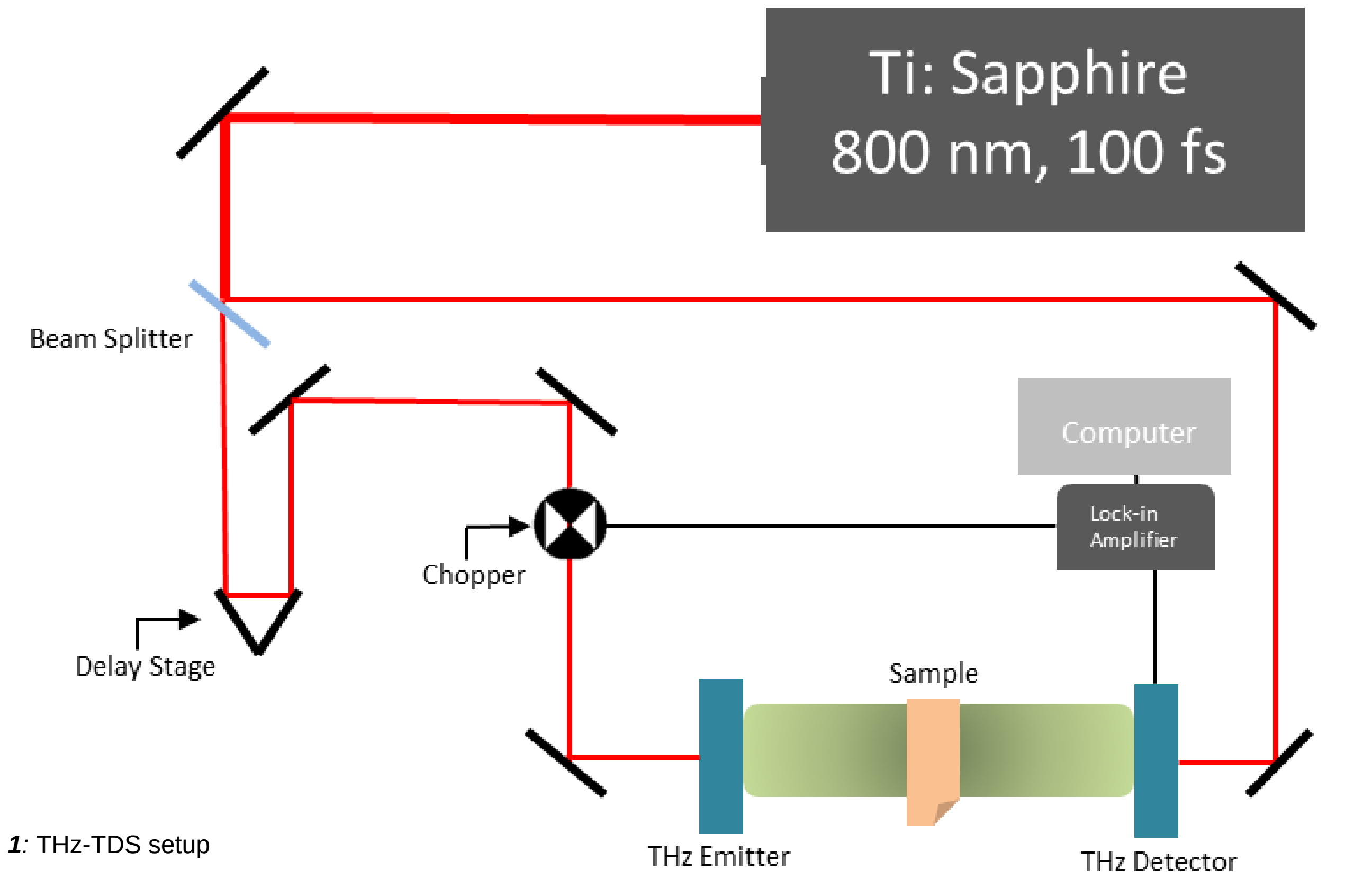


Figure 1: THz-TDS setup

The THz TDS setup that was used is shown in Figure 1. A tunable Ti: Sapphire laser, with a wavelength of 800 nm, was used to excite the photoconductive GaAs emitter which generates THz radiation. A similarly developed photoconductive GaAs detector was utilized to detect the THz radiation (Figure 2). A delay stage was used to measure cross-sections of the THz pulse, to capture a time domain signal (Figure 3A). The measurements were conducted in a nitrogen environment to eliminate the water vapor absorption.

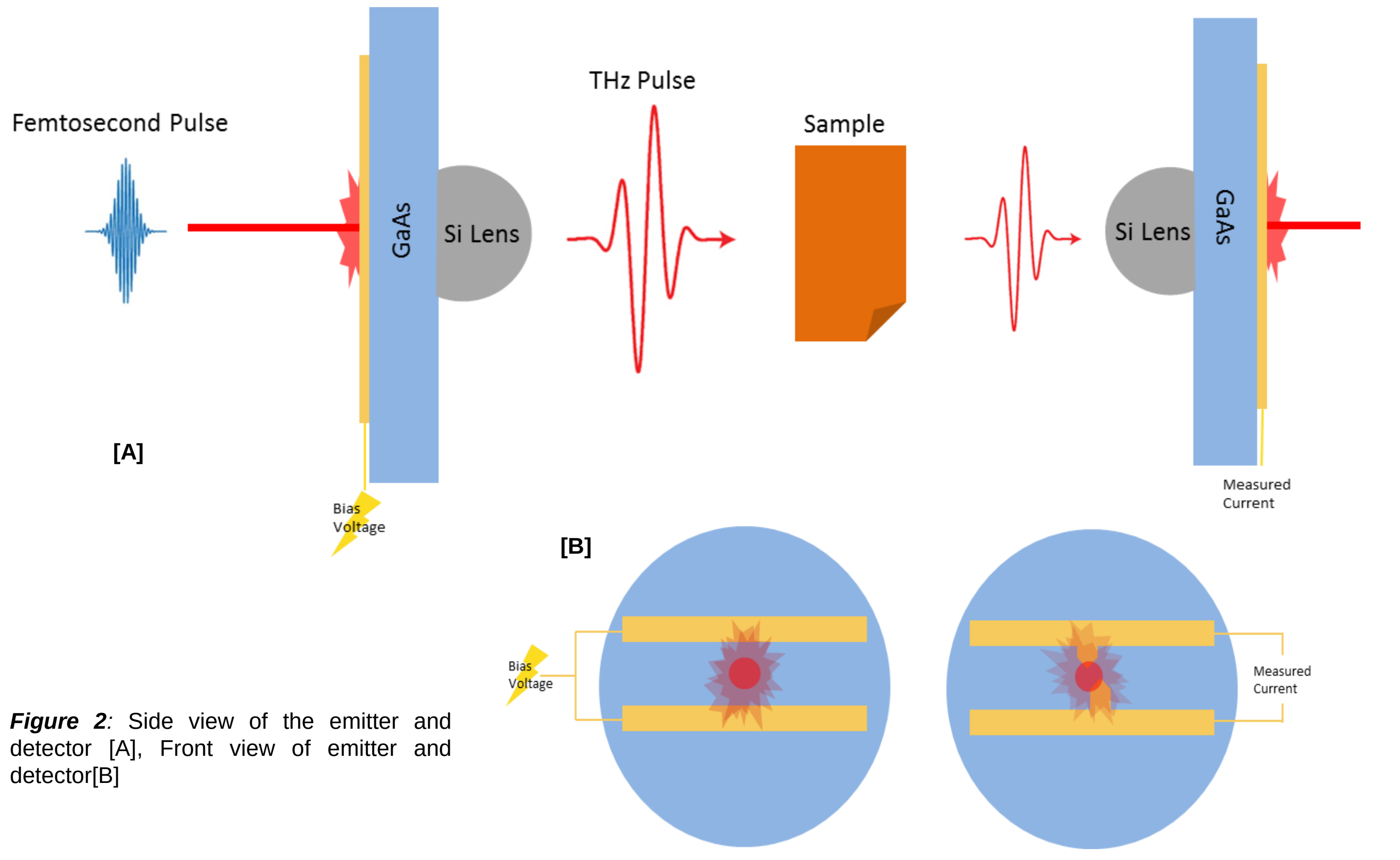


Figure 2: Side view of the emitter and detector [A], Front view of emitter and detector[B]

Measurement Results

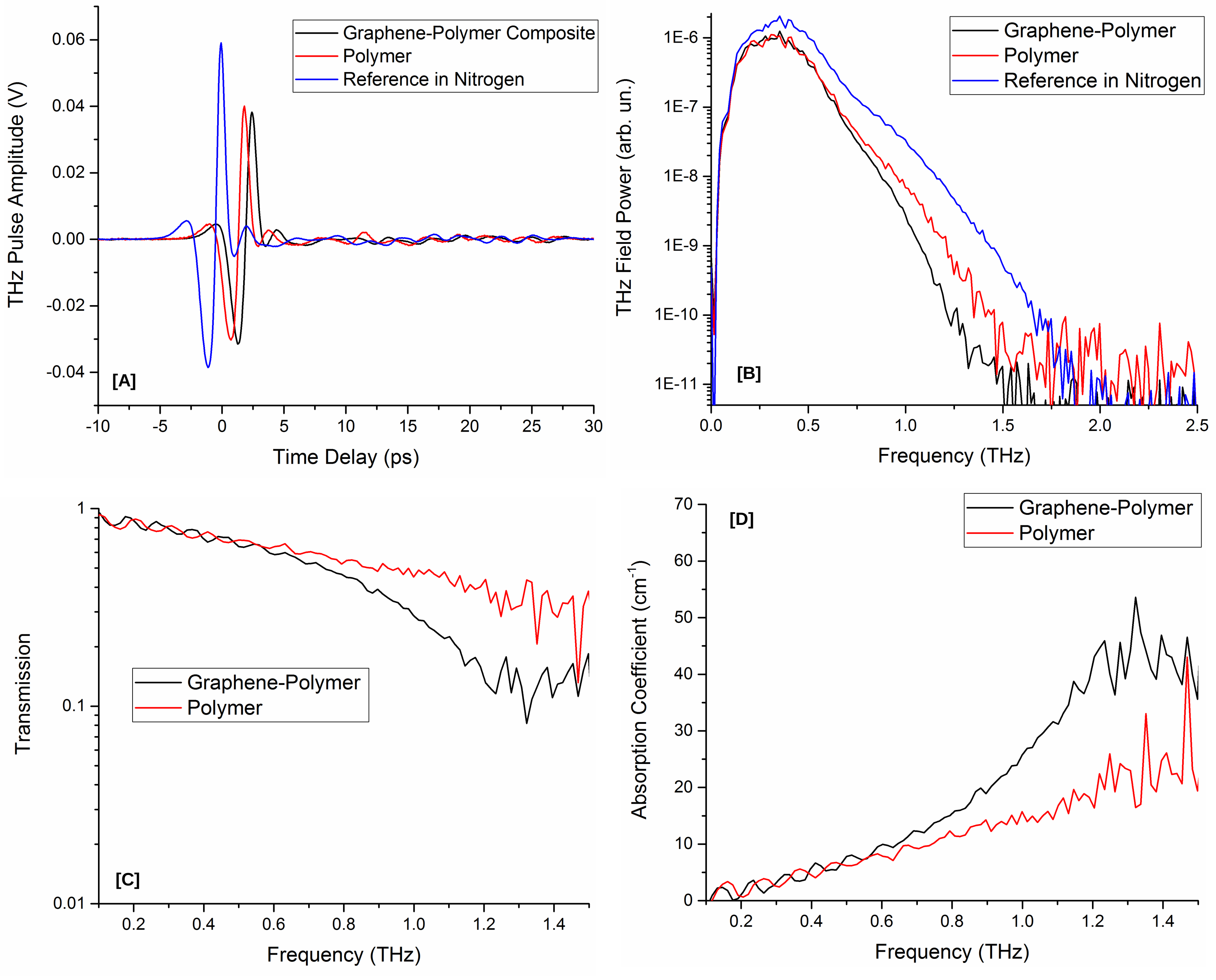


Figure 3: THz pulses [A], Spectrum of the THz pulses [B] , Absorption Coefficient [C], Transmission through sample [D]

$$n(\omega) = 1 + \frac{(\varphi_{ref} - \varphi_{sam})^2}{\omega d} \quad (1)$$

$$k(\omega) = \frac{c\alpha}{2\omega} \quad (2)$$

$$\alpha(\omega) = -\frac{2}{d}\ln\left(\frac{E_{sam}(\omega)}{E_{ref}(\omega)}\frac{(n(\omega)+1)^2}{4n(\omega)}\right) \quad (3)$$

$$\begin{aligned} \varepsilon_1 &= n(\omega)^2 + k(\omega)^2 \\ \varepsilon_2 &= 2n(\omega)k(\omega) \end{aligned} \quad (4)$$

$$\begin{aligned} \sigma_1 &= 2\varepsilon_0 \omega n(\omega)k(\omega) \\ \sigma_2 &= (\varepsilon_{bg} - n(\omega)^2 + k(\omega)^2)\varepsilon_0\omega \end{aligned} \quad (5)$$

Figure 4: Equations used to calculate refractive index (1), extinction coefficient (2), absorption coefficient (3) permittivity (4) and conductivity(5)

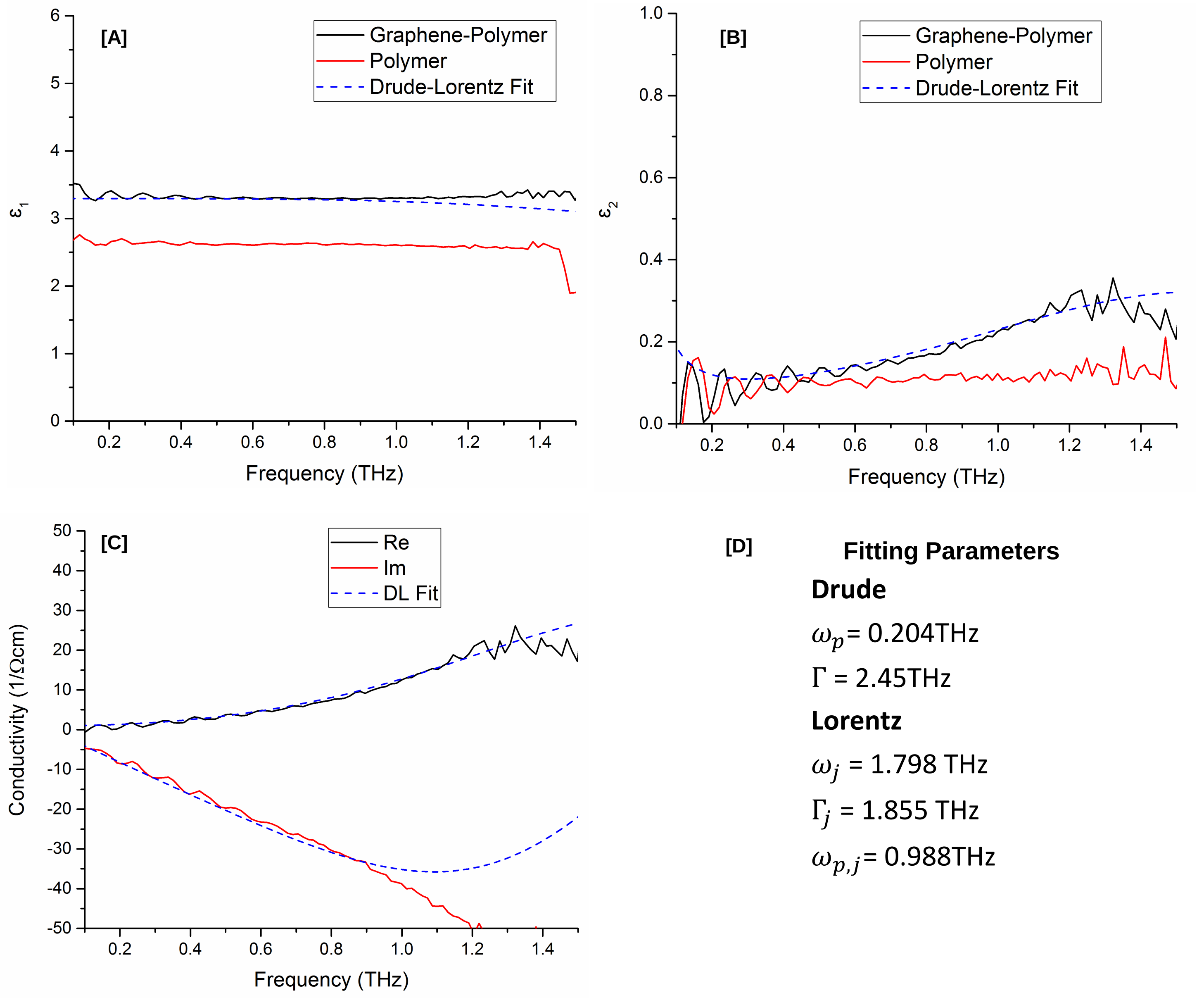
Conclusions

- A 0.9 mm thick graphene-polymer sample with graphene composition of 0.05% or 1% were tested.
- The data collected from these samples consistently showed an increase in absorption and decrease in transmission compared to the undoped polymer.
- The dielectric function and electric conductivity of graphene-polymer sample was calculated.
- Drude-Lorentz model (Figure 5) fits the permittivity and conductivity data the best (Figure 6C).
- The phonon frequencies, plasma frequencies, and scattering rates (as seen in figure 6D) were extracted from the fit data.

Calculated Results

$$\mathcal{E}_{particle} = \mathcal{E}_\infty + \frac{-\omega_p{}^2}{\omega^2 - i\Gamma\omega} + \Sigma_j \frac{\omega_{p,j}{}^2}{(\omega_j{}^2 - \omega^2) - i\Gamma_j\omega}$$

Figure 5: Drude-Lorentzian Model



Fitting Parameters

Drude

ω_p= 0.204THz

Γ = 2.45THz

Lorentz

ω_j = 1.798 THz

Γ_j = 1.855 THz

$\omega_{p,j}$= 0.988THz

Figure 6: Real Component of Permittivity [A], Imaginary component of Permittivity [B], Conductivity [C], Drude-Lorentz Parameters [D]

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