Characterization of a Terahertz Isolator using a 1.5 Port Vector Spectrometer

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Abstract— **The 1.5 port vector spectrometer combines both transmission and reflection geometry of terahertz time domain spectroscopy (THz TDS) in a single setup which is beneficial for various characterization applications. Such an application is demonstrated here where we characterized a non-time invariant device - a terahertz isolator, in terms of isolation level and insertion loss using the 1.5 port vector spectrometer.**

I. INTRODUCTION

RECENT advancements in the field of Terahertz (THz, 100 GHz-10 THz) science and technology has resulted in its high impact on fundamental science and numerous applications in cross disciplinary fields. As a consequence, there is a high demand for THz components having analogous functionality to those used in optics. However, the development of such kind of components is highly impeded due to lack of characterization tools in the THz range.

The 1.5 port vector spectrometer contains both transmission and reflection configuration of THz time domain spectroscopy (TDS) in one system. So it is possible to acquire THz signals transmitted through and reflected from the device under test simultaneously. This versatile spectrometer has shown great potential for extracting the complex dielectric function and the physical sample thickness of a material by overcoming the insufficiencies of individual transmission or reflection TDS [1]. In this paper, we demonstrate the capability of our system in terms of characterizing a non-reciprocal device, namely a THz isolator. THz isolators are expected to play a very important role in communication and other applications [2], [3]. We show that the system can accurately determine its properties namely isolation frequency, isolation level and insertion loss. The isolation frequency and isolation level at that frequency are measured from the back-reflected THz wave, whereas, the insertion loss is calculated from the transmitted THz wave.

II. TERAHERTZ ISOLATOR

Isolators are absolutely vital for reliable and stable operation of high power, complex laser systems. The primary purpose of an isolator in optics is to reduce or eliminate back-reflections that perturb the laser or cause measurement errors and at the same time to transmit sufficient power in the forward direction. Although isolators are commercially available in the optical frequencies, THz isolators are still in the development phase. THz isolators may become relevant for THz quantum cascade lasers in a similar manner as optical isolators are for lasers in the optical range.

The THz isolator under investigation consists of a wire grid polarizer (WGP) and a birefringent plate that serves as a quarter wave plate (QWP) at the design frequency - a configuration similar to the one employed by Mendis *et. al.*[4], as illustrated in Fig. 1.

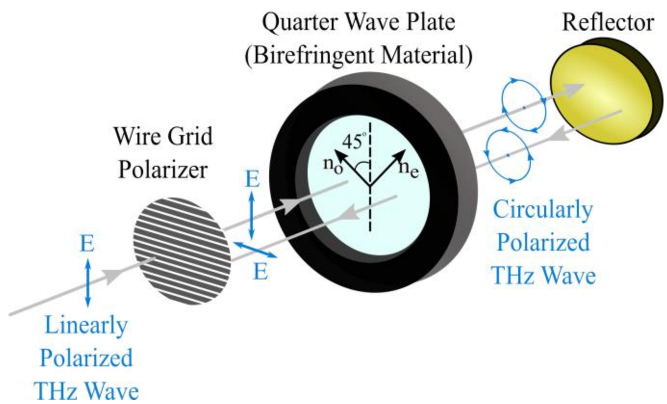

Fig. 1. Operating principle of a THz Isolator.

The optical axis of the birefringent plate is aligned to an angle of 45° with respect to the input polarization set by the WGP. As a result, the incoming signal is divided into two equal components that experience different indices of refraction, n_o and n_e, within the birefringent material. After propagating through the birefringent material with a thickness, d, these two orthogonal polarization components have acquired a phase difference of $\Delta\varphi = k_0 d|n_o - n_e|$, where $k_0 = 2\pi f/c_0$ is the THz wave vector and c_0 is the speed of light in vacuum. At the design frequency, the phase difference becomes $\Delta\varphi = (2m+1)\pi/2$, resulting in a circularly polarized wave. Back-reflected signals pass through the QWP again, resulting in a total acquired phase difference of $\Delta\varphi = (2m+1)\pi$. This effectively makes the polarization linear again but the polarization axis is rotated by 90°, i.e. orthogonal to the input polarization. Therefore, it is diverted in the off-axis direction by the WGP, essentially isolating it from the input beam path.

The frequencies at which the setup features maximum isolation are given by, $f_m = \frac{(2m+1)c_0}{4|n_o - n_e|d}$. As birefringent material we used Sapphire with 10-10 crystal orientation, having a $\Delta n = n_e - n_o = -0.32$ at 1 THz [5]. For a thickness of $d = 0.44$ mm, the first operation point with optimum isolation is calculated at 0.532 THz.

III. CHARACTERIZATION

For the 1.5 port vector spectrometer setup, a mode-locked fiber laser from Menlo Systems is used to produce optical pulses with a pulse duration of 90 fs and a repetition rate of 100 MHz. Laser pulses from the two fiber ports of the system drive the receiver of the transmission and reflection TDS. A free space port, phase locked with the fiber ports, drives the transmitter. An ErAs:In(Al)GaAs based photoconductive slotline antenna generates the THz pulses. For detection, ErAs:InGaAs based photoconductive H-dipole antennas are implemented, similar to those in [6]. A delay stage is included in the transmitter arm and a wire grid polarizer is used to split the reflected THz pulse coming from the isolator under test towards the receiver of the reflection TDS. As WGP we used polyethylene polarizers from Tydex (Model: POL-HDPE-CA40-OD50.8-T8) which are designed to work within the range of 7 µm to mm waves and feature 1200 grooves per mm.

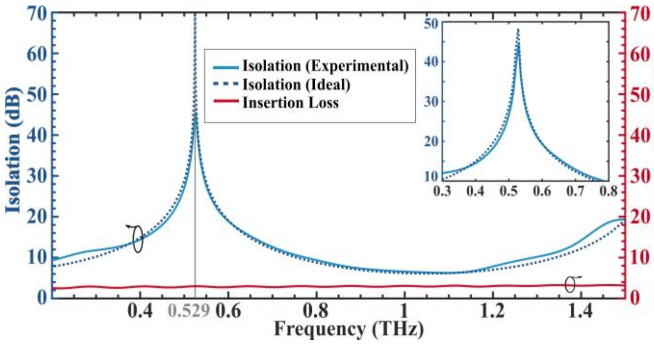

Fig. 2. Measured isolation and insertion loss for the THz isolator. The first isolation peak is observed at 0.529 THz and the insertion loss at that frequency is 2.98 dB. Inset: The dotted line signifies the theoretically calculated isolation averaged over the frequency resolution of 18 GHz and the solid line represents the experimental data.

The isolation level for our case is given by the ratio of the measured back reflected signal with and without the birefringent material. In order to prompt back reflection, a metal plate was inserted after the isolator, more precisely after the QWP. The reflected THz spectrum is recorded first with the QWP present in the setup and then the measurement is repeated after removing it from the setup. The results from these measurements are plotted in Fig. 2, where the maximum isolation is observed at 0.529 THz having an isolation level of around 44 dB. This isolation frequency is very close to the design frequency and well within the frequency resolution of 18 GHz. In the inset of Fig. 2, we compared the theoretical and experimental isolation level of the isolator. We note that the resolution of the TDS system is 18 GHz. The theoretical data are therefore averaged over 18 GHz with a sliding average. The experimental data shows excellent agreement to the theoretically calculated isolation level. This is due to high quality polarizers which exhibits less than 0.1% transmission of unwanted radiation within the whole operation range of 30 – 1000 µm (300 GHz – 10 THz) [7]. In fact, the measured isolation level of 44 dB shows that the polarizer transmits less than 0.01% at 0.529 THz, though this is still an upper limit as the TDS system averages over a bandwidth of 18 GHz.

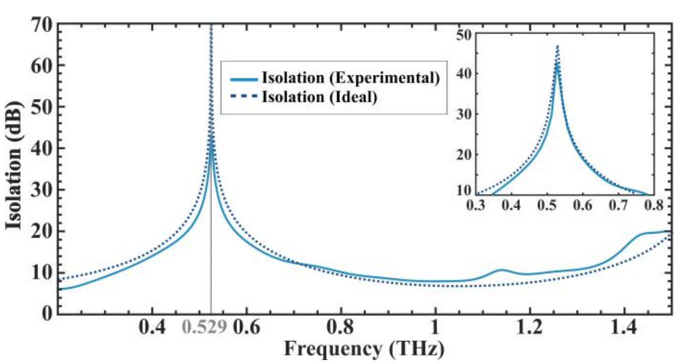

Fig. 3. Measured isolation for the THz Isolator with Si wafer replacing the metal plate. First isolation peak is observed at 0.529 THz is around 43 dB. Inset: The dotted line signifies the theoretically calculated isolation averaged over frequency resolution of 18 GHz and the solid line represents the experimental data.

The insertion loss of the isolator is given by the ratio of the spectra measured without and with the QWP in transmission configuration. For this case, the mirror plate is removed and measurements are carried out to record the transmitted THz spectra with and without the QWP present in the setup. From the measurements, the insertion loss is determined to be 2.8 ± 0.3 dB within 0.2 – 1.5 THz.

Afterward, the metal plate is replaced by a silicon wafer and similar procedures are repeated. This time, data have been extracted from both reflection and transmission TDS simultaneously. With this arrangement, it is possible to measure the isolation frequency, isolation level as well as insertion loss of the isolator at the same time without the hassle of changing between transmission and reflection TDS geometries. For this case, maximum isolation is observed to be 43 dB at 0.529 THz (depicted in Fig. 3) with same insertion loss as before.

IV. Conclusion

In conclusion, we have shown that the 1.5 port vector spectrometer can accurately determine the properties of a THz isolator and can be used as an effective characterization tool for non-reciprocal devices.

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