Design and Simulation of a Compact Terahertz Cavity for Reflection Geometry TDS Using COMSOL

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Abstract: Optical cavities play a major role in any spectroscopic setup. THz being invisible to normal human eye, designing a proper cavity for TDS setup becomes essential. Unlike the standard TDS setups for transmission geometry, the setups for reflection geometry is tricky in terms of alignment. Also the Gaussian beam shape plays critical role in the setup design.
Keywords: Terahertz cavity, THz TDS, Reflection.

1. Introduction

The gap between the optical and microwave in the far infrared region of Electro Magnetic (EM) spectrum with frequencies in the range 0.1THz to 10THz is popularly known as Terahertz (THz). The research in THz started quite late among its other counterparts in the EM spectrum due to unavailability of suitable sources and detectors. THz Time Domain Spectroscopy (TDS) for transmission geometry has progressed to a well-established position over the last decade through extensive research [1]. But in case of the reflection geometry THz TDS there is still lot of scope for improvement, mainly because the alignment of THz beam, which is invisible to human eye, is extremely difficult for reflection geometry [2-4].

In this article we have designed and simulated a four mirror cavity for reflection geometry with practical conditions in RF module of COMSOL. This simulation gives a good insight about how a THz Gaussian beam propagates within a cavity. It may also help in understanding the interaction of an electromagnetic wave, especially invisible one like THz, with a substrate. We have designed a compact cavity with all the four parabolic mirrors aligned only along two axes and the incident angle on the substrate is 45. The compactness of the cavity is extreme importance due the fact that THz has to pass through an OH^- less ambiance (for practical purpose minimizing OH^- molecules from the THz path). Therefore, we purge the path with dry N_2 gas. So lower the cavity length smaller will be the time for purging.

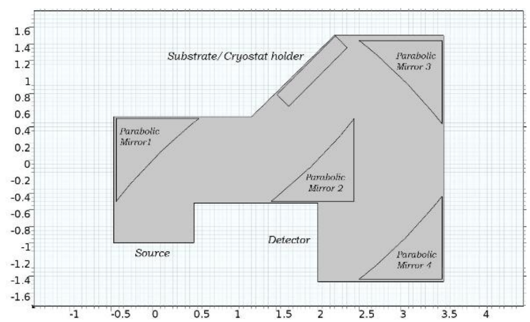

Figure 1. Four mirror cavity for reflection THz TDS

2. Use of COMSOL Multiphysics

The RF and Wave Optics modules of COMSOL provided a good platform to study the THz wave propagation within the cavity. With inserting exact parameters of the Gaussian THz wave from a point source we have tried to replicate the propagation of THz wave in the cavity. We have simulated the 2D set up in RF physics using frequency domain study.

A horizontally polarized Gaussian beam in THz is launched in the vertical direction (fig1) as a point source from an input port. The expression used for the beam is

$$E_x = e^{-\frac{N(x-X_i)^2}{w_0^2}} \cos k_0 y$$

Where, E_x is the electric field along horizontal axis, N=4log2, $k_0 = {2\pi}/{\lambda_0}$, λ_0=wavelength, X_i=position of the point source and w_0=beam waist.

The parabolic mirrors with exact dimensions are drawn in Matlab and then exported. The reflecting surfaces are assigned with perfect electric conductor boundary condition (BC). All other surfaces excluding the probes are assigned scattering boundary condition.

3. Results

The aim of the simulation was to design a compact (yet spacious enough to accommodate cryostat holder) cavity for THz TDS in reflection geometry. The present cavity design is extremely compact in size with dimensions of ~(3f+mirror)×(f+mirror). Where 'f' is the effective focal length of an off-axis parabolic mirror. The design also provides liberty to place cryostat for low temperature measurements. The simulation also helps to figure out beam propagation in each polarization

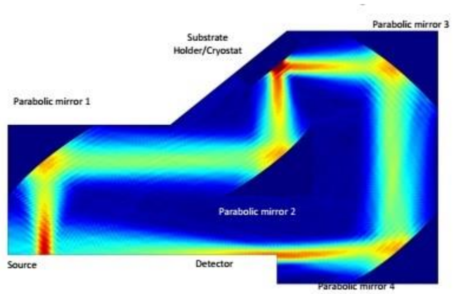

Figure 2. Normal component of Electric field in the cavity E_n.

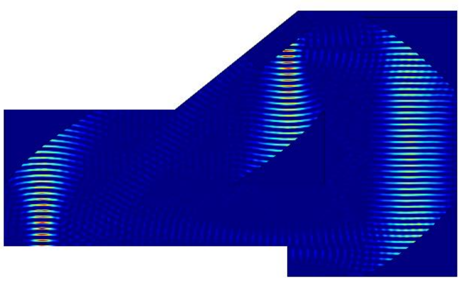

Figure 3. E_x at 0.3THz.

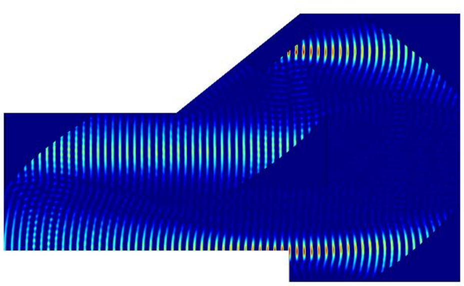

Figure 4. E_y at 0.3THz.

From the figures 2-4 we can clearly see the propagation of THz wave in the cavity. It also evident that the beam waist is playing and important role in the reflection THz TDS. Thus we will a have clear insight about the samples area which could be studied in the set up. All curved mirror being in perpendicular arrangement alignment becomes easier.

We have used 2 inch focal length (parent focal length) off-axis parabolic mirrors and the final size of the cavity was optimized to 12inch×8inch. Our optimization is done considering the lower bound of frequency is 0.3THz (limited by the emitter response). The Gaussian beam for THz is launched with horizontal polarization, 1mm beam waist and variable wavelength.

4. Conclusions

With this simulations we are able to design a perfect set up for reflection geometry THz TDS prior to installation. The alignment will be much easier if one has knowledge about how the beam is going to propagate as THz is invisible to human eye. The frequency limitation for dispersion can be derived from the simulation.

8. References

1. 1. M. Tonouchi, Cutting-edge terahertz technology Nature Photonics, Volume 1, 97-105 (2007)
2. A. Pashkin et.al. , Phase-sensitive time-domain terahertz reflection spectroscopy, Review of Scientific Instruments, Volume 74 NO.11, 4711-4717 (2003)
3. N. Hiromoto et.al. , Precise and Convenient Reflection THz-Time Domain Spectroscopy with a Movable Transparent Sample Holder, Infrared, Millimeter, and Terahertz Waves (IRMMW-THz), (2013)
4. D. Hashimshony et.al. , Characterization of the electrical properties and thickness of thin epitaxial semiconductor layers by THz reflection spectroscopy, Journal of Applied Physics, VOLUME 90, NUMBER 11, 5778-5781, (2001)