Design of a Simple and Robust Asymmetric Ellipsometer for Terahertz (THz) using COMSOL Ray Optics Module

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Abstract: Ellipsometric study has been the most efficient and accurate method for determining optical constants of a given material over a long time for optical wavelengths. In this article we present here a novel concept for designing an ellipsometer for Terahertz (THz) frequencies based on reflection geometry THz Time Domain Spectroscopy (TDS). The present ellipsometers for THz are either based on parabolic mirrors cavities or lens based cavities. The former one has a problem of critical alignment of the optics to achieve variable angular incidence and the later one, though free of aforementioned issue, is having inherent issue of aberration. To solve the aforesaid shortcomings of the two existing type set ups we propose a set of two asymmetric ellipsoids with a common focus. We have achieved maximum angular variation of incident wave up to ~65°.

Keywords: Terahertz, THz TDS, Reflection, Ellipsometry.

1. Introduction

THz spectrum broadly falls in the far infrared in the EM spectrum which lies in between the microwave and optical regime. 0.1THz to 10 THz (1THz=10^{12} Hz) is popularly known as THz regime. Unlike the other spectral bands in the EM waves, THz is least explored till now. But lately with the advancement in the research of THz sources and detectors, the research community is gaining interest in exploring different research aspect within THz regime. Also due to the non-ionizing and greater penetration qualities of THz radiation, it makes THz a suitable candidate to replace existing imaging technologies. Apart from this, many other exciting application like spectroscopy of chemical and biological samples, sensing and short range ultrafast communication are being explored[1].

Being a vastly unexplored area, the proper characterization of most of the material in THz is absent. Ellipsometer technique has proved itself over the years in optical domain extremely useful in this regard. Therefore, ellipsometer designed for THz region is the most obvious choice. The existing designs of ellipsometers in THz are mostly based on lens based cavities and reflector based cavities. The lens based cavities has aberration problem while the parabolic and plane mirror based system are having extremely critical alignment issues. The THz being invisible to the human eye, it becomes even more critical. Also the variable angular incidence for reflection geometry becomes even more critical for the mirror based cavities.

We propose a novel approach for reflector based cavity design by using a combination of two ellipsoid with a common focus point. In this design we have to only rotate sample under test unlike the previously reported work with more than two synchronized rotating stages [2-5]. With two identical ellipsoids we can achieve less than 45° angular variation (straight forward ray diagram calculation). Introducing asymmetry in the two ellipsoid but keeping the common focus point, we are able to increase the range of angular scan up to ~65°. Also we have introduced a large scope for design optimization and tailoring the dimensions of the cavity according to the requirements with constraints coming from the beam shape and parameters. Also the entire cavity becoming a complete one unit, the robustness in the alignment is ensured and finally the source, sample and detector being collinear, the alignment also becomes trivial.

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2. Use of COMSOL Multiphysics

We have used the ‘Ray Optics’ module for verifying our concept and optimize the design for maximum scan angle. The cavity length being in centimeters and the operating wavelength is in hundreds of microns we have limitations in using the 'RF' module or the 'Wave Optics' module. Though we can simulate this concept there with actual beam shape, both this module will require huge computational resources and time. Therefore, 'Ray Optics' module saves lots of time and resource in this simulations. Parametric variation of incident angle also becomes feasible. We have used 'Geometrical Optics' physics and wall conditions (boundary conditions) like 'disappear' for perfect absorption, 'Mixed diffuse and specular reflection' for reflecting surfaces, 'pass through' for refractive index matched surfaces. For lensing 'material discontinuity' is used. The frequency selected for incident ray is 1THz.

3. Results

We designed our set up for 1THz. The optimized design has a smaller ellipsoid for the source side with major axis length 2 inches and eccentricity is 0.65 while the bigger ellipsoid on the detector side with major axis length 4 inches and eccentricity is 0.55. Though, theoretically there is no limit in these values the soul concern is to accommodate the beam within the cavity.

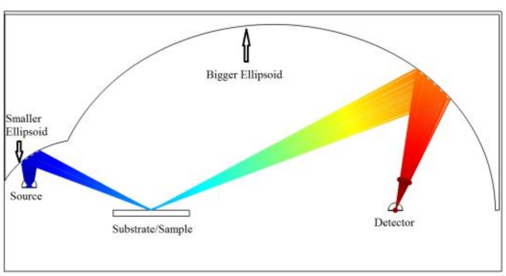

Figure 1. Ray Diagram when the substrate is placed at 0° position.

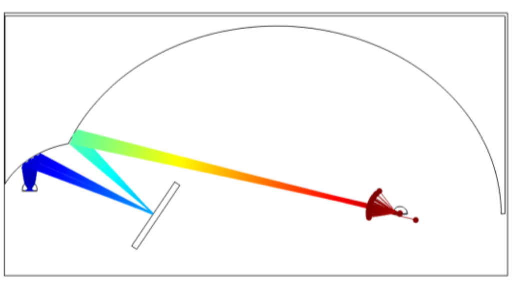

Figure 2. Ray Diagram when the substrate is placed at 56° position.

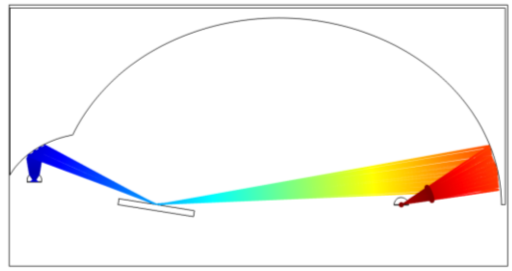

Figure 3. Ray Diagram when the substrate is placed at -9° position.

It is quite evident from figure 2 and 3 that we can achieve total ~65° (56°+9°) variation of the incident angle. Also from the figures it is quite clear that the THz path length also remains same throughout. Due to this special property, ellipse becomes our natural choice for reflection geometry THz TDS.

4. Conclusions

We simulated using COMSOL, a novel design-setup for realizing a reflection geometry THz TDS based ellipsometer. The design is a simple, robust and can be easily aligned. We have maximized the incident angle variation to 65° by introducing asymmetry in the design.

8. References

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