Sub-THz Circular Dichroism using Wire Grid Polarizers

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Abstract— **This paper revises the methodology for enabling Circular Dichroism (CD) measurements without the need for rotating transmit or receive horns in a quasi-optical (QO) measurement setup. This is achieved by using a set of wire grid polarizers, obtaining the values of Jones matrices of the sample in order to reconstruct the co-polarized and cross-polarized transmissions through the sample under test (SUT) These transmission values can then be used to create a CD signature for a SUT possessing chiral properties.**

I. Introduction

Circular Dichroism (CD) is well explored at UV (Ultra-Violet) wavelengths, where it finds applications in detecting enantiomers in pharmaceuticals, as well as analysis of protein conformal states [1]. A CD signature is found by determining the difference between the clockwise and anticlockwise circular polarized transmission of the signal propagating through a sample under test (SUT).

For light at frequencies corresponding to millimetre and sub-mm wavelengths, CD signatures of samples are not as extensively measured as in the optical light domain. One large hurdle for CD spectroscopy at mm and sub-mm wavelengths is the difficulty in obtaining wideband signatures of the SUT, due to a lack of broadband circular polarizers. It is however possible to use analytic combinations of linear polarization responses from quasi-optical (QO) measurements, to build an equivalent circular polarization response; viz. obtaining co-polarization (CP) and cross-polarization (XP) measurements of the SUT and computing: $T_+ = CP - jXP$, and $T_- = CP + jXP$. T_+ and T_- are, respectively, the clockwise and anticlockwise circular polarized signals when looking in the direction of propagation towards the receive horn [2].

The measurement of CD signatures using linear polarization would normally require the rotation of the receive horn to obtain the cross-polar information. Cheng *et al* [3], developed methods to remove the need for this (thereby avoiding the introduction of phase errors with respect to prior calibration procedures inherent with the operation of vector network analyser (VNA).

The sub-Terahertz (sub-THz) and THz CD implemented by Cheng *et al*, was with the use of a magnetized strontium hexaferrite ceramic plate (FP). A linearly polarised signal beam propagating through the FP would suffer Faraday rotation in the usual way. The FP was used to accentuate measurement of the XP signal also generated by transmission through a chiral sample. This, together with transmission measurements incorporating a 45°wire grid polariser, constituted a full set Jones' matrices needed to describe CD response. This is outlined in section II.

The FP thickness is milled to obtain a Faraday rotation of 45° for a given operational frequency domain. This in an inherent limitation to the methodology of Cheng et al [3]. Hence, in this paper we propose an alternate approach for measuring the dispersive CD response of the SUT, omitting entirely the need for the FP. The proposed method is based on the use of wire grid polarizers during measurements and Jones matrix formulation in post-processing to obtain the CD signatures.

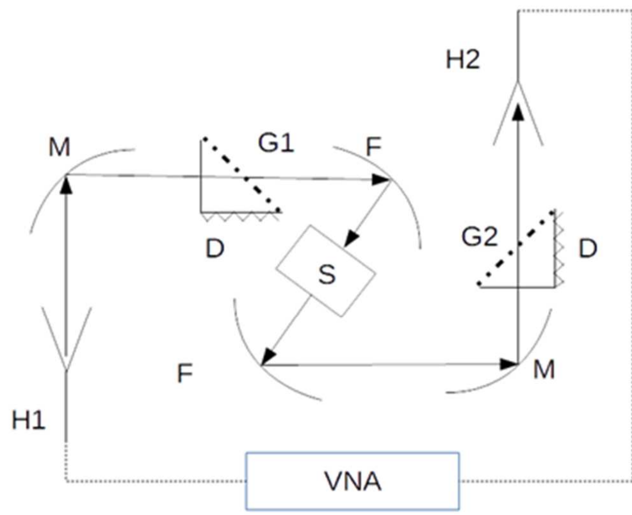

Fig. 1. The proposed measurement setup using a Quasi-Optical bench. H1 and H2 are vertically polarized transmit and receive horns, respectively. M are off-axis ellipsoidal mirrors and F are the Fast focusing parabolic mirrors. G1 and G2 are the locations for wire grid polarizers. D are power dumps. S is the sample under test.

Jones matrices are used to model the transmission or reflection in a system by representing each component as a matrix with transmission or reflection parameters. We propose a new measurement scheme using a free space transmission-based system, as illustrated in Fig. 1.

II. Jones Matrices

The proposed setup is a free space QO bench, with wire grid mounts placed before and after the sample under test. The wire grids used are for polarizations of 0°, 45°, 30°, and 60°. The angles used are the angle of anticlockwise rotation from the positive horizontal axis (henceforth denoted +x).

The SUT will have a Jones matrix S, and S_{90° when the sample is rotated by 90° anticlockwise from the +x axis [4][5]:

$$S = \begin{bmatrix} t_H & t_{HV} \\ t_{VH} & t_V \end{bmatrix}, \qquad S_{90^\circ} = \begin{bmatrix} t_V & -t_{VH} \\ -t_{HV} & t_H \end{bmatrix}$$

t_H and t_V are, respectively, the complex transmission coefficients for horizontal and vertical polarization. t_{HV}, and t_{VH} are the complex coefficients with notation conventions similar to S-parameters, where t_{HV} denotes the complex coefficient for a vertical component which is converted to a horizontal component by the SUT. These components are unknowns for the SUT.

The normalized Co-polarized (Vertical polarization, titled "CP" herein below) and Cross-polarization (Horizontal, polarization, titled "XP" herein below) measurements should consist of the following components when irradiated with linear polarization angled at 45°.

$$CP = t_V + t_{VH}$$
$$XP = t_H + t_{HV}$$

The input vector denoting a vertical, linearly polarized beam, with arbitrary complex amplitude A:

$$I = \begin{bmatrix} 0 \\ A \end{bmatrix}$$

The representation of each grid in Jones matrix form is:

$$G_{30^\circ} = \begin{bmatrix} \frac{3}{4} & \frac{\sqrt{3}}{4} \\ \frac{\sqrt{3}}{4} & \frac{1}{4} \end{bmatrix},\ G_{60^\circ} = \begin{bmatrix} \frac{1}{4} & \frac{\sqrt{3}}{4} \\ \frac{\sqrt{3}}{4} & \frac{3}{4} \end{bmatrix}$$

$$G_{45^\circ} = \begin{bmatrix} \frac{1}{2} & \frac{1}{2} \\ \frac{1}{2} & \frac{1}{2} \end{bmatrix}, G_{0^\circ} = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}.$$

The horn antennas in this setup are assumed to have ideal polarization purity. As such the receive horn is represented as a 0° grid here. If this is not the case, a 0° grid can be placed between grid location G2 and H2 to enforce this.

When placing the wire grid polarizers, or rotating the sample, it is important to keep track of the orientation of the +x axis throughout the test setup. This is to ensure that the equations used here match the physical setup. Which can be confirmed by placement of a 30° or 60° grid at locations G1, S, and G2 then comparing measurement data with the expected transmission coefficient for the grid chosen. Expected theoretical values expected from those manipulations are -12 dB or -2.5 dB, respectively.

III. Methodology

Six measurements are required to obtain the four values of the Jones matrices of the SUT using this setup. A reference measurement is first to be taken where the grid location used for the 45° grid can be either G1 or G2.

$$Ref = G_0^\circ \cdot G_{45^\circ} \cdot I = \begin{bmatrix} 0 \\ \frac{A}{2} \end{bmatrix}$$

In the following set of measurements, the angled grids will be placed in location G1, thus the suffix GBS (Grid Before Sample) is added:

$$30^\circ GBS = G_{0^\circ} \cdot S \cdot G_{30^\circ} \cdot I = \begin{bmatrix} 0 \\ \frac{A}{4} \cdot (t_V + \sqrt{3} \cdot t_{VH}) \end{bmatrix}$$

$$60^\circ GBS = G_{0^\circ} \cdot S \cdot G_{60^\circ} \cdot I = \begin{bmatrix} 0 \\ \frac{A}{4} \cdot (3 \cdot t_V + \sqrt{3} \cdot t_{VH}) \end{bmatrix}$$

$$45^\circ GBS = G_{0^\circ} \cdot S \cdot G_{45^\circ} \cdot I = \begin{bmatrix} 0 \\ \frac{A}{2} \cdot (t_V + t_{VH}) \end{bmatrix}$$

Next we remove the grid in location G1, and insert a 45° grid in location G2. This condition and will have the suffix SBG (Sample Before Grid).

$$45^\circ SBG = G_{0^\circ} \cdot G_{45^\circ} \cdot S \cdot I = \begin{bmatrix} 0 \\ \frac{A}{2} \cdot (t_V + t_{HV}) \end{bmatrix}.$$

Finally, the sample is to be rotated 90° anticlockwise with respect to the +x axis. The grid will once again be placed after the sample:

$$45^\circ SBG_{90^\circ} = G_{0^\circ} \cdot G_{45^\circ} \cdot S_{90^\circ} \cdot I = \begin{bmatrix} 0 \\ \frac{A}{2} \cdot (t_H - t_{VH}) \end{bmatrix}.$$

As can be seen in all matrices above, there is no horizontal component received. As such, the measured data shall be treated as a single equation rather than a matrix. To isolate the individual components, manipulation of the measurements obtained without normalizing the data is first carried out:

$$M_1 = 60^\circ GBS - 30^\circ GBS = \frac{A}{2} \cdot t_V$$
$$M_2 = 45^\circ GBS - M_1 = \frac{A}{2} \cdot t_{VH}$$
$$M_3 = 45^\circ SBG - M_1 = \frac{A}{2} \cdot t_{HV}$$
$$M_4 = 45^\circ SBG_{90^\circ} + M_2 = \frac{A}{2} \cdot t_H$$

With each element now being isolated from the others, the individual components of the Jones' matrices of the SUT can be obtained by normalizing M_1 to M_4 using the reference measurement Ref. From these values, CP and XP components can now be reconstructed, and the CD signature calculated as:

$$CD = |T_+| - |T_-|$$

IV. Conclusions

In this paper, a new methodology for obtaining a CD signature has been proposed, which no longer relies on the Faraday rotator element [3]. Instead, the proposed method relies only on wire grid polarizers, which intrinsically operate over a wider frequency domain.

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