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OPTICAL SIGNATURE OF WOOD SAMPLE- MUELLER MATRIX IMAGING POLARIMETRY

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ABSTRACT
Mueller Matrix Imaging Polarimetry is a powerful imaging technique used to provide high precision measurements for the Mueller matrices at every pixel of an image captured with a detector. The system used acquires 16 Mueller Matrix images and these images are further processed to investigate the polarization properties of the sample under consideration. In this communication the optical system used to acquire the Mueller Matrix Images functioning in reflection frame is described and the resulting polarization character of the wood sample is presented.

Keywords: muller matrix polarimetry, anisotropy, polarization, polarimetry, multiple scattering.

INTRODUCTION
The science of polarization measurement is divided into several categories and sample measuring polarimetry is one of these categories in which a relationship between the polarization states of incident and exiting beams for a sample are obtained [1]. The measurements are acquired using a set of polarizing elements located between a source and sample and the exiting beams are analyzed with a separate set of polarization elements between the sample and detector. Complete polarimeter or Mueller polarimeter is thus achieved.

In this paper the Mueller matrix measurement system described consists of a polarization generator and polarization analyzer with sample to be measured in between them, and both of them contain a rotating waveplate as was described in the works of many researchers [2-7]. The optical polarization effects simultaneously occurring in the sample are studied with respect to the 16 Mueller matrix elements obtained. Further, this work is supposed to provide information related to the nature of composition of material and its influence on the input polarization state.

THEORY
The polarization state of light can be characterized by four real parameters called the Stoke parameters. This 4-Stoke vector has the standard form expressed as a column vector [8].

$$S = \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix} \qquad \text{----------------- (1)}$$

The principle of optical equivalence first derived by Stokes (G.G. Stokes 1853) shows that the Stokes vector is a complete representation of the polarization state of light beam. When a light beam which is represented by this Stokes vector (*S*) is changed (scattered) by an optical element, the Stokes vector of the light beam undergoes a linear transformation to a new stokes vector (*S'*) [9]. This transformation is represented by a 4 X 4 matrix called the Mueller or Polarization matrix (*M*) [10] and is generally represented as

$$S' = M \times S \qquad \text{------------ (2)}$$

$$\begin{pmatrix} S_0' \\ S_1' \\ S_2' \\ S_3' \end{pmatrix} = \begin{pmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{pmatrix} \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix} \qquad \text{------ (3)}$$

This Stokes vector gives measurable polarization information of the output light beam and hence Mueller matrix contains all the polarization information in the process.

The Mueller matrix M can be also written as

$$M = m_{11} \begin{pmatrix} 1 & \bar{D}^T \\ \bar{P} & m \end{pmatrix} \qquad \text{------- (4)}$$

Where $\bar{D}^T = \frac{1}{m_{11}} \begin{pmatrix} m_{12} & m_{13} & m_{14} \end{pmatrix}$ and

$\bar{P} = \frac{1}{m_{11}} \begin{pmatrix} m_{21} & m_{31} & m_{41} \end{pmatrix}$ called as Diattenuation and Polarizance vectors respectively and 'm' is a 3 X 3 matrix[5].

The Diattenuation vector characterizes the intensity transmission of the polarization element. The Depolarization vector describes the polarization state produced from an unpolarized input state. In this paper both the Diattenuation and Depolarization are addressed.

EXPERIMENTAL PROCEDURE

A 632.8nm, 20mW output from a He-Ne laser (Suresh Indu laser, India) was used as excitation source. A set of linear Polarizer (P) and Quarter wave plate (Q1) was used to illuminate the sample with predefined polarization states. Another set of linear Analyzer (A) and Quarter wave plate (Q2) was used to analyze the polarization state of light reflected from the sample collected onto a detector. The Analyzer and collection optics were kept at 45^0 from the beam direction while performing measurement. To collect the 4 X 4 Mueller matrix images we generated 49 images by suitably rotating the Polarizer and Analyzer. The sample under consideration is a wood material obtained from natural source (Botanical name Wrightia Tinctoria, belonging to Apocynaceae family), having a common name Pala Indigo Plant, Dyers's Oleander. The leaves are acrid, thermogenic, anodyne and hypotensive and are very useful in odontalgia, vitiated conditions of vata and hypertension. The seeds are bitter, astringent, acrid, carminative, constipating, depurative, anthelmintic and febrifuge. They are useful in vitiated conditions of Pitta and Kapha, dyspepsia etc. Its pungent fresh leaves quickly relieve toothaches. Leaves, flowers and fruits are source of a kind of indigo called pala-indigo. White, close-grained wood looks like ivory and is much used for carving and wood-turning. In piles, fever, diarrhoea, roundworm and colic plant terpenoids are used extensively for their aromatic qualities. They play a role in traditional herbal remedies and are under investigation for antibacterial, antineoplastic, and other pharmaceutical functions. Terpenoids contribute to the scent of eucalyptus, the flavors of cinnamon, cloves, and ginger, and the color of yellow flowers. Well-known terpenoids include citral, menthol, and Camphor [11].

Figure-1. Wrightia tinctoria trunk and flower.

The material obtained is dried for 1 year in order to evaporate the moisture content naturally without loosing the chemical composition and was given for chemical analysis (Vitro labs, Hyderabad, India) and the chemical composition is shown in Table-1.

Table-1. Sample chemical composition.

Wood sample (wrightia tinctoria)					
C (%)	**H** (%)	**N** (%)	**O** (%)	**H_2O** (%)	**Others** (%)
18.92	1.87	1.14	20.39	57.22	0.46

The sample is finely polished to have mean thickness of 1.15 mm and average width and length 58.25mm and 136.45mm respectively. The Schematic experimental setup is shown in Figure-2 and the sample under consideration is shown in Figure-3.

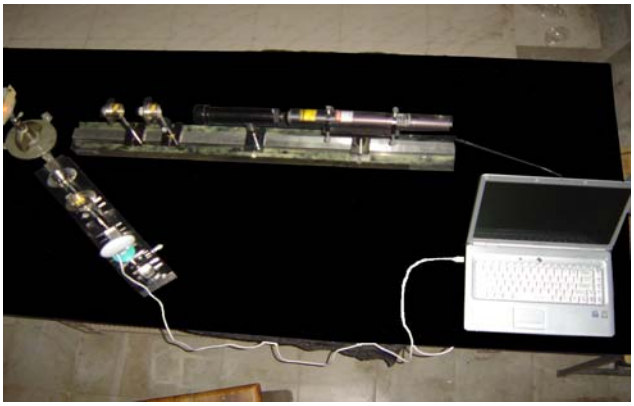

Figure-2. Schematic experimental setup for obtaining Mueller matrix elements.

Figure-3. Wood sample (Wrigtia tinctoria).

EXPERIMENTAL RESULTS

The Mueller matrix gives the optical finger print of the sample. The 49 intensity images with various orientations of Polarizer and Analyzer are necessary to obtain the 16 elements of Mueller matrix images [12]. After acquiring 49 intensity images the 16 elemental Muller matrix images are obtained which are defined as follows?

$$m_{11} = I_{OO}$$
$$m_{12} = I_{HO} - I_{VO}$$
$$m_{13} = I_{PO} - I_{MO}$$
$$m_{14} = I_{LO} - I_{RO}$$
$$m_{21} = I_{OH} - I_{OV}$$
$$m_{22} = (I_{HH} + I_{VV}) - (I_{HV} + I_{VH})$$
$$m_{23} = (I_{PH} + I_{MV})) - (I_{PV} + I_{MH})$$
$$m_{24} = (I_{RV} + I_{LH}) - (I_{RH} + I_{LV})$$
$$m_{31} = I_{OP} - I_{OM}$$
$$m_{32} = (I_{HP} + I_{VM}) - (I_{HM} + I_{VP})$$
$$m_{33} = (I_{PP} + I_{MM}) - (I_{PM} + I_{MP})$$
$$m_{34} = (I_{RM} + I_{LP}) - (I_{RP} + I_{LM})$$

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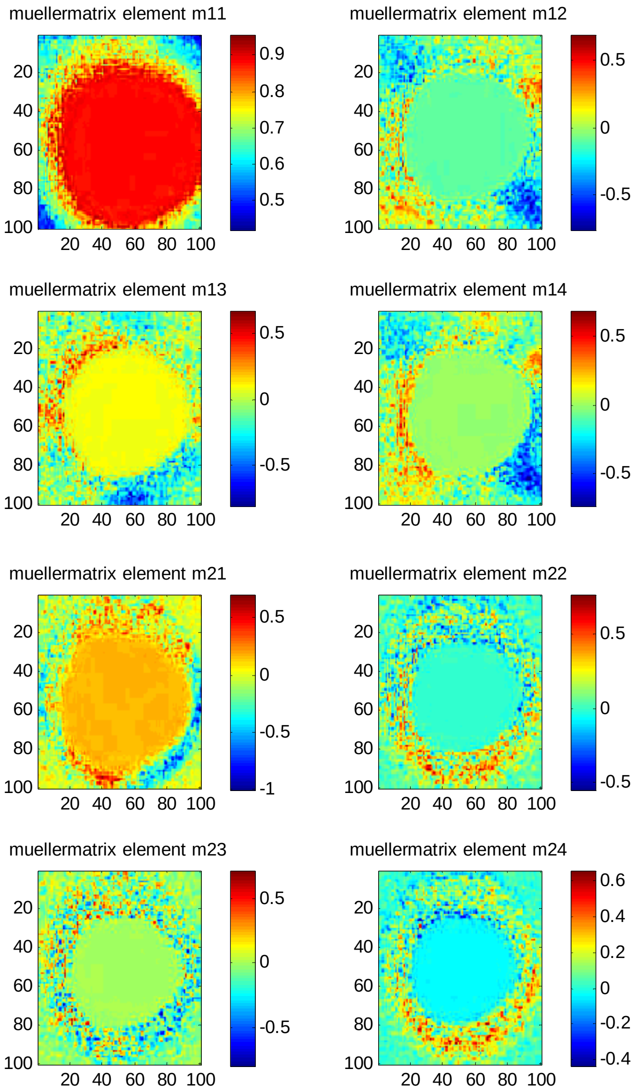
$m_{41} = I_{OL} - I_{OR}$

$m_{42} = (I_{HL} + I_{VR}) - (I_{HR} + I_{VL})$

$m_{43} = (I_{PL} + I_{MR}) - (I_{PR} + I_{ML})$

$m_{44} = (I_{RR} + I_{LL}) - (I_{RL} + I_{LR})$

where the first subscript in the intensity parameters indicates input state, and the second subscript the output state and here, H indicates horizontal polarization, V indicates vertical polarization, P indicates $+45^0$, M indicates -45^0, R indicates right circular polarization and L indicates left circular states of polarization. The corresponding images are shown in Figure-4, obtained using a self developed MATLAB program to crop the image for uniform pixel size and get intensity information pixel by pixel for the image.



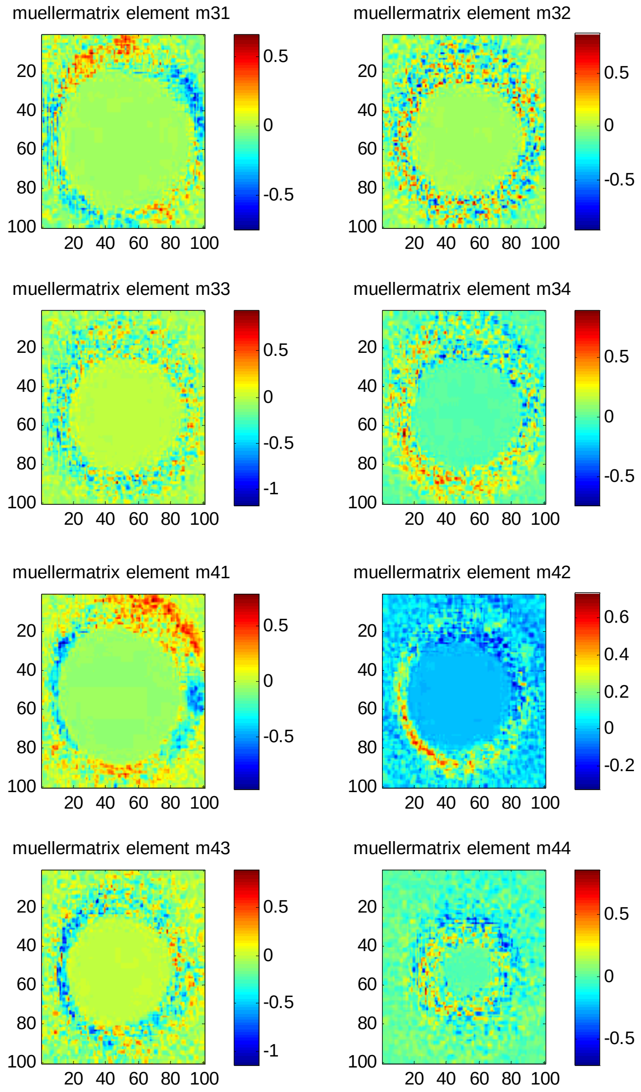


Figure-4. 16 elemental Mueller matrix images.

Once all 16 images are obtained, the images are processed, again using a developed MATLAB program which calculated the intensity component of each and every pixel of the image and then processed to get the overall intensity information of the image. The Muller matrix hence obtained is normalized to m_{11} component which enables the isolation of intensity dependent effects to the polarization effects and also simplifies the analysis. The measured Mueller matrix is shown in Table-2.

Table-2. Mueller matrix of the sample.

(M_{11}) 1	**(M_{12})** -0.195	**(M_{13})** 0.029	**(M_{14})** -0.162
(M_{21}) 0.233	**(M_{22})** 0.124	**(M_{23})** 0.0001	**(M_{24})** 0.381
(M_{31}) -0.381	**(M_{32})** -0.014	**(M_{33})** -0.071	**(M_{34})** -0.057
(M_{41}) -0.048	**(M_{42})** -0.029	**(M_{43})** -0.024	**(M_{44})** -0.005

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From the measured Mueller matrix the Diattenuation and Depolarization images are obtained which are shown in Figures 5 and 6, respectively. Finally the mean values of Diattenuation and Depolarization for the sample is calculated using a developed MATLAB program for Intensity image analysis and the results are shown in Table-3.

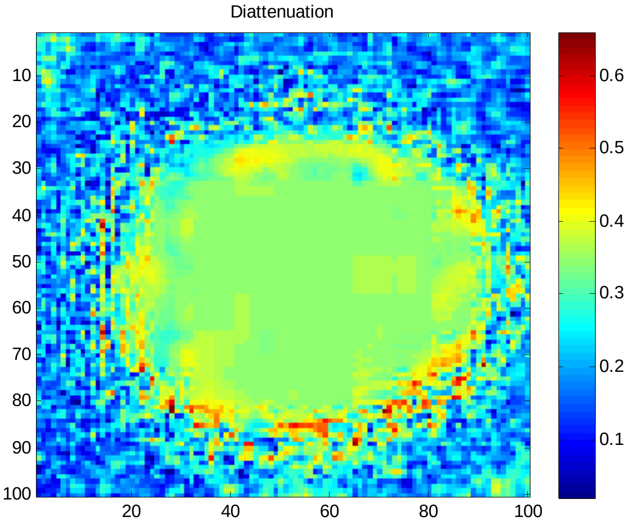

Figure-5. Diattenuation image.

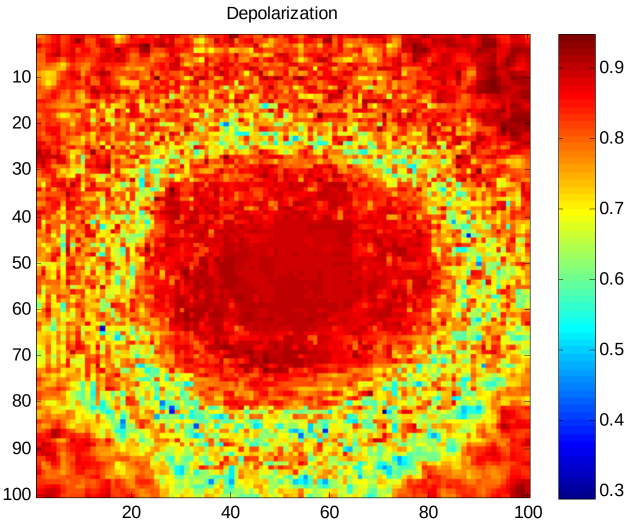

Figure-6. Depolarization image.

Table-3. Mean values of diattenuation and depolarization obtained from the image.

Diattenuation	0.2718
Depolarization	0.7881

RESULTS AND DISCUSSIONS

Analysis in these experiments, where data is in the form of images was done in the following manner. The obtained images were processed and cropped up to the bright spot's size (100 X 100 pixels). These cropped images were then decomposed to give diattenuation, depolarization and retardance values for each pixel. The values of these parameters were averaged over all the pixels and plotted. The Mueller images were also calculated and are compared. These images were normalized with respect to first element of Mueller matrix (M_{11}). The decomposition plots were averaged column wise and corresponding values were plotted for comparison between two or more samples and distinguishing one sample from the other. Similar treatment was also done with the Mueller images.

CONCLUSIONS

From our experimental methods we could achieve optical signature in the form of Mueller matrix of the wood sample. As expected wood sample is exhibiting polarization anisotropic character which is evident from the results.

Depending on different physical parameters variation in the Depolarization and Diattenuation is a subject of interest which reveals the complete character of the sample.

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