

ANALYSIS OF POLARIZATION DEGREE OF THE LIGHT EMERGENT FROM THE NANOPARTICLES SUSPENSIONS

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Abstract. In this work I have determined the degree of polarization, with a polarimeter setup, of a laser beam which passes through nanoparticles suspension. The main idea is to see how the degree of polarization of the laser is modified after it passes through different nanoparticle suspension media. With this setup we can find the Stokes parameters (S_1 , S_2 and S_3) and determinate the degree of polarization. The Stokes parameters, which characterize the state of polarization, are provided as analog output powers. The samples are different metallic nanoparticles in suspension with different dimensions and concentrations.

1. INTRODUCTION

The degree and the state of polarization can be found and represented in terms of observables, known as Stokes polarization parameters. First parameter (S_0) represents the total intensity, and the others three parameters (S_1 , S_2 , S_3) refer to the polarization state [1].

The four Stokes parameters form the state of polarization of emergent light from the optical element, form a Stokes vector, S' , which is given by relation: $S' = MS$, or in the matrix form:

$$S' = \begin{pmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{pmatrix} \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix} \quad (1)$$

where m_{ij} are the M Mueller matrix elements and S_i are the Stokes vector elements of the incident light [2, 3]. The parameter S_1 represents the amount of linear vertical or horizontal polarization, S_2 the amount of linear $+45^\circ$ or -45° polarization, and the last parameter, S_3 , represents the amount of right or left circular polarization.

2. THEORY

The Stokes vector S , can be determinate, in polarimetry, by measuring six light intensities: I_H (with horizontal linear polarizer), I_V (with vertical linear polarizer), I_{+45} , I_{-45} (a $\pm 45^\circ$ linear polarizer), I_R , I_L (right and left circular analyzer) [2, 3, 4, 5]:

$$S = \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} = \begin{pmatrix} I_H + I_V \\ I_H - I_V \\ I_{+45} - I_{-45} \\ I_R - I_L \end{pmatrix} \quad (2)$$

From the eq. (2) result that the degree of polarization it is:

$$DOP = \frac{\sqrt{Q^2 + U^2 + V^2}}{I}, \quad (3)$$

and for linear polarization (in the case of the experiment):

$$DOLP = \frac{\sqrt{Q^2 + U^2}}{I}. \quad (4)$$

The degree of polarization P can be determinate, according to Stokes parameters by using the following formula, for any state of polarization:

$$P = \frac{\sqrt{S_1^2 + S_2^2 + S_3^2}}{S_0}, \quad 0 \leq P \leq 1. \quad (5)$$

Experimentally, the Stokes parameters can be measured by using a quarter wave plate and a polarizer. With a photodiode we can record the intensity ($I(\alpha, \beta)$, where α is the angle of quarter wave plate and β is the polarizer angle), of the beam when pass through the quarter wave plate, which makes an angle with a polarizer. From this result that Stokes parameter has the following expressions [6]:

$$\begin{cases} S_0 = I(0^\circ, 0^\circ) + I(0^\circ, 90^\circ) \\ S_1 = I(0^\circ, 0^\circ) - I(0^\circ, 90^\circ) \\ S_2 = I(0^\circ, 45^\circ) - I(0^\circ, 135^\circ) \\ S_3 = I(45^\circ, 45^\circ) - I(45^\circ, 135^\circ) \end{cases} \quad (6)$$

At ellipsometer setup, the polarized beam pass through different optical devices (e.g.: analyzer, polarizer) which produces a change in the state of polarization [7].

3. EXPERIMENTAL

As light source, I have used a He-Ne laser (632,8 nm) linearly polarized as shown in Figure 1. The laser beam is expanded with a spatial filter, and then collimated with lens L. The beam was expanded to cover a big part of the sample.

The light emergent from the sample pass through the polarization state analyzer, which consist in quarter wave plate (QWP) and polarizer (P). As photodetector I have used a powermeter for measuring the powers of the samples and determinate the intensities, and a CMOS camera for recording the beam image and the histogram.

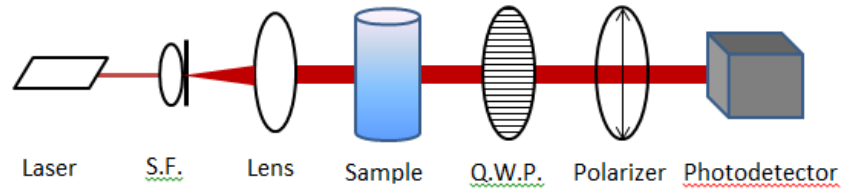


Fig. 1 – Experimental setup for determination of the Stokes parameters.
S.F. – spatial filter; Q.W.P. – quarter wave plate.

The state of polarization of the light which passes through the sample and detected on the photodetector it is linearly (vertical), because after the measurements, the result is close to the following Stokes vector expression:

$$S = \begin{pmatrix} 1 \\ -1 \\ 0 \\ 0 \end{pmatrix} \quad (7)$$

4. RESULTS

In the next table (Table 1) I have introduce the intensities of the light obtained with the experimental setup presented previous for different metallic nanoparticles suspensions. As cuvette I have used from quartz, because the one from plastic influence very much the polarization of the light (it depolarized the beam).

Table 1

Values of the Stokes parameters and the determination of the degree of polarization (DOP)

	I(0,0)	I(0,45)	I(0,90)	I(0,135)	I(45,45)	I(45,135)	S ₀	S ₁	S ₂	S ₃	DOP	DOP (%)
Laser Beam	0.2	49.2	99.2	49.4	46.0	51.6	99.4	-99.0	-0.2	-5.6	1.00	99.60%
Plastic Cuvette	17.8	29.4	51.3	41.4	46.5	43.7	69.1	-33.5	-12.0	2.8	0.48	48.48%
Quartz Cuvette	0.3	33.5	66.8	34.3	32.8	35.9	67.1	-66.5	-0.8	-3.1	0.99	99.11%
Distillated water	0.1	40.0	81.8	39.5	37.3	41.5	81.9	-81.7	0.5	-4.2	1.00	99.76%
Al 0.4	0.1	39.5	77.8	37.6	37.0	40.6	77.9	-77.7	1.9	-3.6	1.00	99.74%
Al 1	0.5	27.0	53.9	26.8	26.0	29.3	54.4	-53.4	0.2	-3.3	0.98	98.16%
Ag 0.004	0.1	37.8	75.3	38.3	36.3	39.8	75.4	-75.2	-0.5	-3.5	1.00	99.73%
Ag 0.008	0.1	17.9	35.0	16.9	17.2	18.6	35.1	-34.9	1.0	-1.4	0.99	99.43%

The values of $I(\alpha, \beta)$ (α – degree of QWP and β – degree of polarizer) from the table represent the measurements taking with the powermeter after the beam passes through the each sample and it is measured in μW . The S_0, S_1, S_2 and S_3 was calculated according to relation (2). Then the degree of polarization ratio it was found as: $P = \frac{S_1}{S_0}$. The polarization it is: $P = \frac{I_{\parallel} - I_{\perp}}{I_{\parallel} + I_{\perp}}$, where I_{\parallel} and I_{\perp} are the intensity measurements of the emitted signal made parallel to, or orthogonal to, respectively, the direction of the electric field of illumination light.

Al 0.4 represents nanoparticle suspension of aluminum with the density of 0.4 mg/ml, Al 1 it have the density of 1 and the Ag 0.004, Ag 0.008 is the silver with the density of 0.004, respectively 0.008 mg/ml.

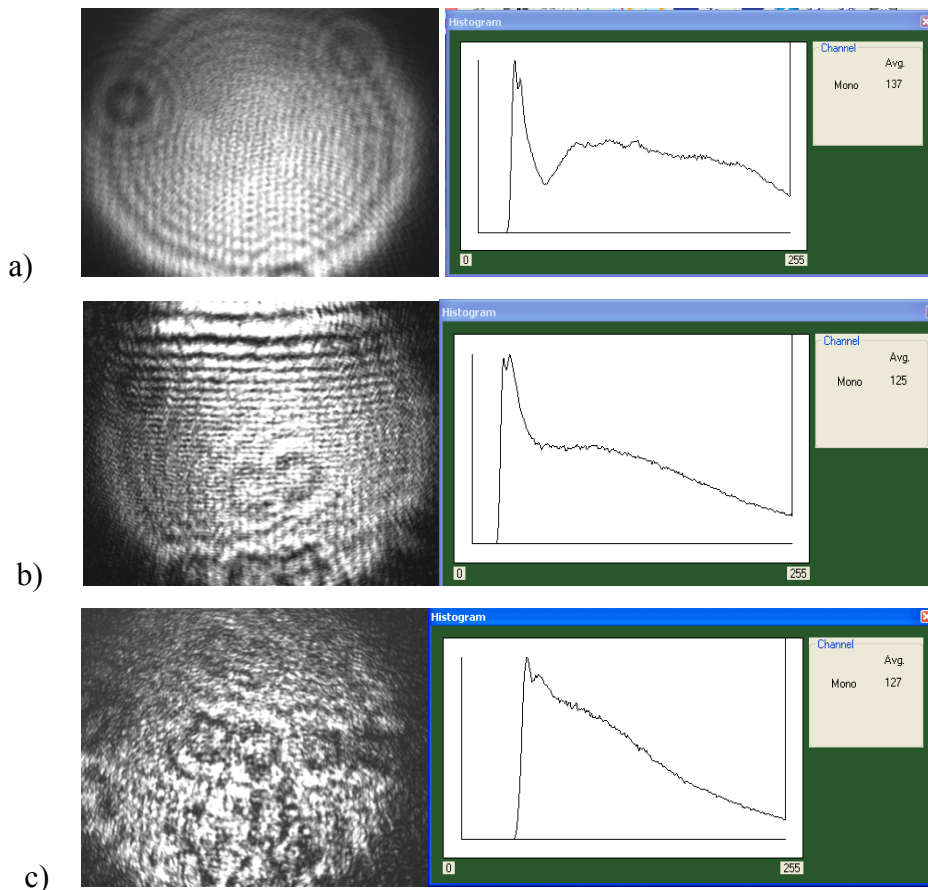


Fig. 2 – Images and histograms recorded with CMOS for the following samples:
a) laser beam; b) Al 0.4, c) Al 1.

The nanoparticles of silver are very small with dimension of 20–30 nm, that's why the degree of polarization it isn't influenced so much. An obvious difference of polarization it is seen at the aluminum particles, where the dimension can reach at 100 μm . Here we see that when we raise the concentration, the degree of polarization decreases.

The images above are recorded with a CMOS camera (Thorlabs DCC1545M) when the beam laser pass through the samples and the QWP and polarizer at 0° degrees.

5. CONCLUSIONS

As conclusion, I have observed that the degree of polarization it is reduce (depolarized the laser beam) when we have big particles, greater than 100 nm, and the concentration of the nanoparticle suspension is quite big, the quantity of the nanoparticles it is almost equal with the quantity of the solution from the suspension, the ratio between them it is almost 1.

For the small nanoparticles (with the size of 30–40 nm) the effect of depolarization wasn't observed. One of the reasons is that in such cases, when the nanoparticle it is much smaller than the wavelength, the scattering is of a Rayleigh type, without depolarization.

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