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Determination of a source's temporal coherence function via depolarization in liquid crystal

Cristian Eduardo Hernández Cely[1,*] and *Rafael Ángel* Torres Amaris[1,**]

[1]Universidad Industrial de Santander

Abstract. Based on the fact that the degree of polarization of a light source is given in terms of the absolute value of its complex degree of coherence, we design a depolarization experiment using a variable retarder in which we measured the degree of polarization as a function of the retarder's birefringence. We show that if the incident light is previously linearly polarized we can perform a direct measurement of the light source's coherence using a Stokes meter.

1 Introduction

The temporal coherence function of a light source contains all of its first-order statistical information which specifies its spectral content and its polarization information [1]. Getting to know the coherence function of a given light source becomes useful in many optical situations. As an example we may consider when an interference experiment is performed in which the degree of coherence determines the visibility of the interference pattern. On other hand, a second example corresponds to when a depolarization experiment is performed, in this case, according to Wolf's polarization theory, the change in the degree of polarization depends on the degree of coherence, for instance, when a light beam propagates through a birefringent medium as liquid crystal or wave-plate retarders it not only changes its state of polarization but also its degree of polarization, thus in order to determine the depolarization effect, the source's degree of coherence have to be known [2–4]. Thus we can see that in many experimental setups which imply the phenomena of interference or polarization the measurements depends fundamentally on the light coherence [5].

Those experiments mentioned above are really useful nowadays in optical metrology and microscopy techniques, everything that involves ellipsometry and depolarization measurements, and of course, all the optical systems working with interferometers such as FT-IR spectrometers. In all these techniques it is vital to know, previous to starting any kind of measurement, the coherence function associated with the light source you are working with in order to keep your technique calibrated. For that reason, it is necessary to be able to measure the coherence of a light source. The common methods used to determine the temporal coherence of a light source consist of the measurement of its power spectral density which is the Fourier transform of the coherence function. The other common method is via Michelson interferometer, where the visibility of the interference pattern as a function of the phase difference is also a direct measurement of the degree of coherence [6]. Though both methods are the standard and nowadays can be performed with great precision sometimes it requires highly sophisticated devices such as spectrometers and high sensitive CCD cameras. Thus, in order to perform a much more simple determination of the temporal degree of coherence of a light source, we propose a method to measure it using depolarization. The method set-up consists of a linearly polarized light beam that propagates through a variable retarder, then the degree of polarization as a function of the birefringence induced is measured. We will show that the measurement of the degree of polarization under a given experimental condition is a direct and much more simple measurement of a light source's temporal degree of coherence.

2 Depolarization in birefringent media

In general when a polarized light beam propagates through a birefringent medium such as a wave-plate, characterized by a birefringence Δn and thickness l, an optical path difference Δnl is introduced between the x and y components of the incident light. As a consequence of this, a phase shift is introduced producing a change in the polarization state. For partially coherent light sources, i.e. sources for which δnl is comparable with its coherence length, the polarization change is also accompanied by a depolarization, where now the ellipticity and orientation are not the only polarization parameters that change but also the degree of polarization (DOP). The DOP changes as a function of the degree of cross-coherence γ_{xy} and the amplitudes E_i of each electric field component

$$DOP = \sqrt{1 - \frac{4E_xE_y}{(E_x^2 + E_y^2)^2}\left(1 - |\gamma_{xy}(\Delta nl)|^2\right)}, \qquad (1)$$

*e-mail: cristian.hernandez17@correo.uis.edu.co
**e-mail: Rafael.Torres@saber.uis.edu.co

in that sense, the more $|\gamma_{xy}(\Delta nl)|$ approaches zero the more is the effect of depolarization introduced by the propagation in the wave plate because the DOP will also approach zero. In fact, for a given value of Δnl the maximum depolarization occurs in the particular case when $E_x = E_y$, which can be accomplished with the incident light beam being circularly polarized or linearly polarized. In such a case the DOP will reduce to the following expression

$$DOP = |\gamma_{xy}(\Delta nl)|, \tag{2}$$

which means that the degree of polarization is exactly equal to the absolute value of the degree of cross-coherence, which is basically the same light source's degree of coherence. Then, we can use this theoretical result to develop a new way to measure the coherence of a light source by measuring the change of the DOP as a function of the birefringence of a retarder wave-plate, and that is what we will explain in detail in the following section, the way in how we can accomplish that measurement with the information explained here. For other cases in which $E_x \neq E_y$ and the incident light beam is found to be in a totally polarized state or even a partially polarized state the expression of the DOP can be derived as is shown in the following papers [3, 4, 7].

3 Measurement technique

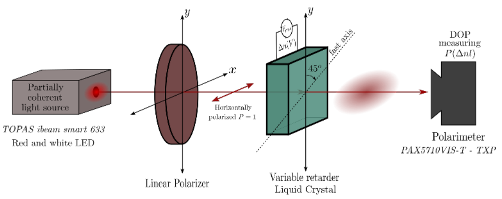

Figure 1. Experimental set up of the depolarization experiment

The experimental setup used to determine the coherence function through the depolarization of a light source is shown in Figure 1. We use a variable retarder consisting of a liquid crystal (*LCC2415-VIS/M* produced by *Thorlabs inc.*) whose birefringence can be varied through and applied voltage. This birefringence can be varied in a range of $\Delta nl\ :\ 0 - 4\,[nm]$ (being l the thickness of the liquid crystal). The incident light beam of the partially coherent light source we want to characterize is polarized linearly along the x axis such that the variable retarder fast axis is rotated to an angle of $\theta = 45^o$ with respect the vertical axis, whit this condition the retarder will introduce the maximum phase shift in the incident horizontally polarized light beam. Thus, the DOP will be given by the equation 2. Now in order to determine the degree of coherence of a given source we just need to measure the DOP for different values of Δnl using a Stokes meter (*PAX5710VIS-T - TXP (Thorlabs, inc)*, and the data obtained is fitted with a linear combination of Gaussian functions such that the function that is adjusted with the experimental data is exactly equal to the light source's degree of coherence $|\gamma(\tau)|$.

In this experiment we use two kinds of light sources, a red LED and a white LED passed through a color glass filter, both being partially coherent light sources. In Figure 2 it is shown how the experimental data were fitted in order to obtain an explicit expression of $DOP = |\gamma|$ as a function of the variable Δnl and so, the explicit function for the degree of coherence for each source. We can see that the red LED source is more coherent than the white LED. If we want to change from distance variables δnl to time variables , we just need to replace the distance variable by $c\tau$ in the expression we found for $|\gamma|$ by the fitting. In that way, we can estimate and determine some statistical information about each source like the coherence length or coherence time associated with each source and so its spectral bandwidth.

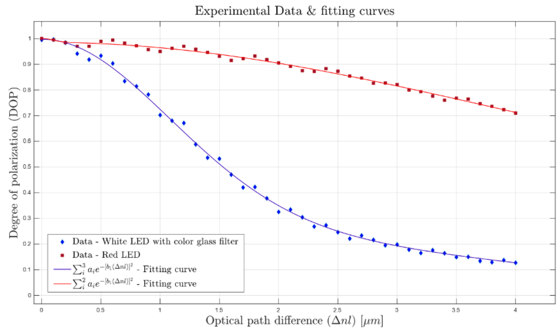

Figure 2. Graphic of the experimental data.

4 Conclusions

A method to determine the degree of coherence by a depolarization experiment was proposed and tested. For the sources used we could determine an explicit function of its degree of coherence which gives us the value of its correlation for optical path length differences in the range of $0 - 4[\mu m]$, if a more coherent source like a laser diode needs to be characterize we may use multiple liquid crystals in the experiment. Additionally we can estimate other statistical parameters as the spectral bandwidth since coherence and power spectral density are connected through Wiener-Khintchine theorem.

References

[1] E. Wolf, *Introduction to the Theory of Coherence and Polarization of Light* (Cambridge university press, 2007)
[2] A. Domański, Opto-Electronics Review **13**, 171 (2005)
[3] A.W. Domański, M. Redek, D. Budaszewski, Photonics Letters of Poland **1**, 67 (2009)
[4] C.E.H. Cely, R.Á.T. Amaris, pp. JTh5A–77 (2021)
[5] E. Wolf, Physics letters A **312**, 263 (2003)
[6] M. Born, E. Wolf, *Principles of optics: electromagnetic theory of propagation, interference and diffraction of light* (Elsevier, 2013)
[7] P.L. Makowski, A.W. Domański, **7745**, 77450J (2010)