Title

Comparing Theoretically Expected Polarization to Experimental Results

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Abstract: The coherent nature of the light analyzed in the model allows for analysis of the wavefronts' resulting polarizations via the Poincaré sphere mathematical model and related equations, helping with limitations of experimental observation.

INTRODUCTION

A polarizing wave splitter is a device which allows a single light source input to be divided into N different outputs. This is accomplished via fiber inputs and outputs. These outputs are all coherent, meaning outputs all carry the same information. The coherent outputs all have the same phase, although the device can additionally change the phase of each of the outputs. This has applications in information transfer for splitting a signal. In the paper, however, the device described facilitates the recombination of seven waves. This is done by splitting an original light source, then using a half wave polarizer, plate beam splitter, and quarter wave polarizer in series to modify the phase and polarization of each split wave to the desired parameters[1]. The waves are then recombined, with the recombined wave being split into two channels. One channel is measured to facilitate automatic stabilization of the light waves via an FPGA. The other channel is used for data collection, where the topology of the interfering waves' phase, amplitude, and polarization are measured. The polarization is of particular interest because it requires measuring several metrics to accurately represent.

Polarization can also be used as a medium to transfer information, so understanding the effects of interference on polarization is relevant to fiber-optic information transfer technology[2]. The Poincaré sphere can be used to represent a wave's polarization, and is expressed with spherical coordinates. This representation can be used to find the Stokes parameters, which provide a concise description of the nature of the wave's polarization.

METHODS

In conjunction with modifying multiple degrees of freedom of the input wave, these being phase and polarization, the paper also analyzes several different parameters of the output. These parameters are magnitude, phase, and intensity. The parameters are represented via a topology over a circular pattern. In many cases, the paper will show multiple topologies of the same beam measuring different things, such as intensity and phase at the same time. This can be used to demonstrate higher level properties of light. For example, that phase has unique patterns at the high intensity points of intersection, then degenerates into a circular pattern as intensity decreases on the outer edges.

Along with representing a light wave with graphs of more direct physical measurements, such as phase and intensity, the paper also represents wavefronts via the Stokes parameters. In order to create the polarization vector map in the paper, the Stokes parameters are measured from the light, with the polarization vectors being found afterwards. Common polarizations of light have simple representations in vector form, where elements of the vector are Stokes parameters.

$$\hat{S} = \left(S_0 \ S_1 \ S_2 \ S_3\right)$$

Linearly Polarized (horizontal)	$(1 \ 1 \ 0 \ 0)$
Linear Polarized (vertical)	$(1 \ -1 \ 0 \ 0)$
Right-Hand Circularly Polarized	$(1 \ 0 \ 0 \ 1)$
Left-Hand Circularly Polarized	$(1 \ 0 \ 0 \ -1)$

Fig. 1. Table of Stokes parameters for common polarization states.

The vectors presented have four dimensions. However, the S_0 represents the magnitude and can often be ignored. What remains is 3 parameters, which are the 3 cartesian coordinates of the Poincaré sphere. In spherical coordinates, the magnitude of the Poincaré sphere is Ip. The angular coordinates are 2ψ, and 2□ respectively, these being the azimuth and ellipticity of the ellipse representation of the polarization.

In general, polarization can be broken down into several different categories. The first is linear polarization, which can be represented by an angle. This angle can be shifted by π radians and still give the same result, which is why 2ψ, and 2□ are multiplied by 2 to indicate the relevance of only π radians. The other type of polarization that is relevant is circular polarization. Circular polarization is a subset of elliptic polarization, when the two orthogonal component vectors of the electric field are out of phase by π/2 radians and of equal magnitude. It can take a left-handed and right-handed form, which is indicated by the sign of S_3 as shown in Figure 1. Notably, left and right handed waves can cancel each other out to create linear polarization. Both forms of polarization are analyzed within the paper.

The paper has a focus on the technical challenge of using cutting-edge equipment to measure short pulses of light. However, it is important to use mathematical tools for data analysis along with physical tools for collecting data in order to improve the understanding of light. Using mathematical models for polarization is especially important because it is more difficult to measure polarization than other factors, such as intensity or frequency. Measurement of polarization usually involves the light being passed through a series of optical elements[3], causing a loss of accuracy. Because of this, using mathematical methods to predict the effects of interference on light polarization is necessary to check if a series of measurements is accurate.

RESULTS AND INTERPRETATION

One light pattern analyzed is a series of 6 linearly polarized light sources in a hexagonal pattern. Each consecutive source is perpendicular to the previous, resulting in 3 horizontal and 3 vertically polarized sources. The expectation at the center would be the presence of circular polarization, given that there are orthogonal vectors which are of equivalent magnitude at this point. The Stokes parameters at the center are roughly equal to $S_1 = 0,\ S_2 = 0.3,\ S_3 = -1$ according to the Stokes parameter topology. This is roughly equal to the left hand polarization parameters which can summarized as $S_1 = 0,\ S_2 = 0,\ S_3 = -1$. Despite this similarity, there is obviously a significant difference in the S_2 parameter which results in the light not being circular, but rather elliptical. It is hard to know what the exact cause of this is. One theory would be to believe that this is a result of error in either the light beams produced or the measurements of the light beams. It is clear that there are imprecise measurements present in the experiment. Looking at the Stokes projection topologies in figure 2, they are very asymmetrical, although aspects of symmetry can clearly be seen. This is despite the fact that in theory, these graphs should be perfectly symmetrical across the y axis, since all three input waves are symmetrical across the y axis.

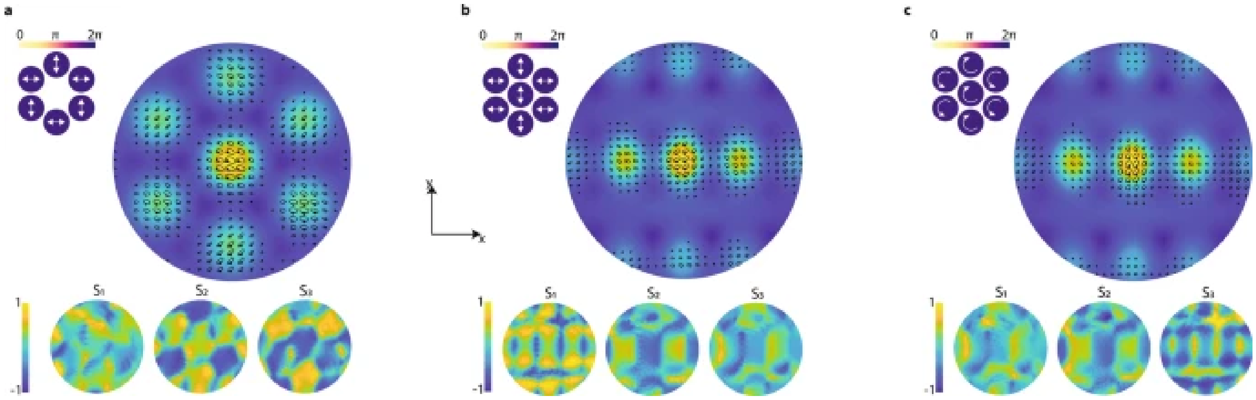

Fig. 2. Experimental results of polarization topography evolution with corresponding near-field configurations (top left) and Stokes projections (bottom)[1]

The interactions of multiple sources of polarized light interact in special ways. While there is no interference in many when polarized waves interact, there often are effects in this interaction and these effects are not necessarily linear. Even a small error in the wave generation, which is unavoidable due to the need for very precise timing, could lead to significant changes in the polarization. This is not even considering errors in the measurement step for the polarization. The centers of the b and c graphs in figure 2 are much harder to analyze. This is because the S2 factor is equal to -1 in both, something only seen in elliptically polarized light, whereas circularly and linearly polarized light have an S2 value of 0. While this is not ideal, it still reveals the elliptic nature of these polarizations. The polarization measurements are difficult to work with because of its multi variable form, causing imprecise measurements to become unclear. Overall, the experiment makes it clear that measuring polarization is difficult.

CONCLUSIONS

From the analysis provided of the issue, it is clear that measuring the effects of different polarizations interacting has notable difficulties, some of which are not present in analyzing other properties of light. One of these is the need for light to be coherent, which requires specialized equipment able to split light from a single source into multiple sources. Another component of this challenge is getting accurate measurements, which as discussed is more difficult for polarization than other factors. One factor which mitigates these problems is the presence of different mathematical models of polarization which can be chosen in order to reach the best conclusions possible from limited information. It is found that the Stokes parameters are extremely valuable in measuring and understanding the polarization of the wavefronts analyzed, due to its simple expressions of common states of polarization. Using this model, it can be determined that the experimental results have significant errors involved. However, a general idea of the polarization patterns present can still be determined using the limited data.

One extension to this research would be to also find theoretical results for other empirically measured factors such as phase and intensity, and compare the agreement of these numbers with the agreement of theoretical and experimental polarization numbers.

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