Polarization Imaging with a waveplate array of femtosecond laser written nanogratings inside silica glass

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1. Introduction

Nanograting formation inside silica glass by femtosecond (fs) laser writing has attracted much attention [1], because micro birefringent optics can be fabricated by local generation of nanogratings [2,3]. One application of the micro birefringent optics is a waveplate array for polarization imaging [3]. In a polarization imaging camera, the incident light is detected by an imaging sensor after passing through a waveplate array and polarizer (Fig. 1 (a)). Because four intensities through waveplates of different slow axis are detected by four adjacent detectors in the imaging sensor (Fig. 1 (b)), polarization state can be analyzed only by a single acquisition of the light intensity distribution.

However, a waveplate array fabricated by fs laser writing has several problems; non-uniform retardance and transmittance distributions, and difficulty of perfect adjustment of the orientations of waveplates. To overcome these problems, we proposed generalized analytical method which can obtain polarization states regardless of non-uniformity of waveplates and poor adjustment [4]. We will demonstrate polarization imaging using a waveplate array of silica glass fabricated by fs laser writing.

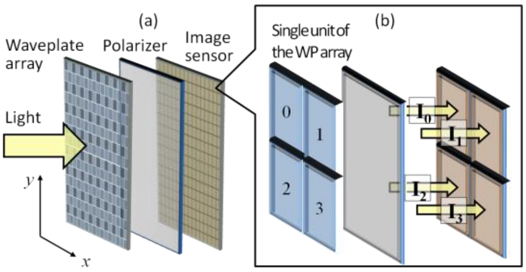

Fig. 1 (a) Configuration of a polarization imaging camera with a waveplate array. (b) A single unit for the plarization analysis.

2. Methods

Polarization analysis

The relation between the Stokes parameters and four light intensities detected after four waveplates and polarizer (I_0-I_3 in Fig. 1 (b)) can be expressed by

$$\mathbf{I}=[\mathbf{A}]\cdot \mathbf{S} \qquad (1)$$

where $\mathbf{I}=(I_0, I_1, I_2, I_3)^{\tau}$, $\mathbf{S}$ is the vector of which elements are Stokes parameters, and **[A]** is the system matrix determined by four waveplates and polarizer in a single unit. If **[A]** is known, the polarization state can be obtained by $\mathbf{S}=[\mathbf{A}]^{-1}\cdot \mathbf{I}$. The problem in the polarization imaging with a waveplate array fabricated by fs laser writing is that **[A]** are not the same. Therefore, we determined the **[A]** for all the units in the camera using known polarizations.

Fabrication of a waveplate array

A waveplate array was fabricated by fs laser writing of birefringent cells inside a silica glass plate. Birefringent cells were written by translating the glass plate normal to the focusing direction during laser irradiation. The slow axes of the waveplates were controlled by changing the polarization of the laser pulses.

3. Results

Before fabricating a waveplate array, we searched better combination of four waveplates to minimize the analytical error. Figure 2 (a) shows the simulated analytical errors plotted against $|\det([\mathbf{A}])|^{-1}$, where det(**[A]**) is the determinant of **A**. The analytical error was defined by the distance in the Poincare sphere between input and calculated polarizations. This plot suggests that the retaradances and slow axes of four waveplates should be selected to minimize $|\det([\mathbf{A}])|^{-1}$ as possible.

Based on the simulation of analytical error, we fabricated a waveplate array by fs laser writing and made a polarization imaging camera with the waveplate array. Figure 2 (b) shows the intensity distribution detected by the camera, which came from a polarized light transmitted through a transparent plastic spoon. Figure 2 (c) shows the polarization distribution analyzed by the image of Fig. 2(b) using eq. (1) and pre-determined system matrices. The polarization distributions of 300×200 pixels were able to be obtained at about 20 Hz using a homemade software and personal computer with a 2.2 GHz CPU.

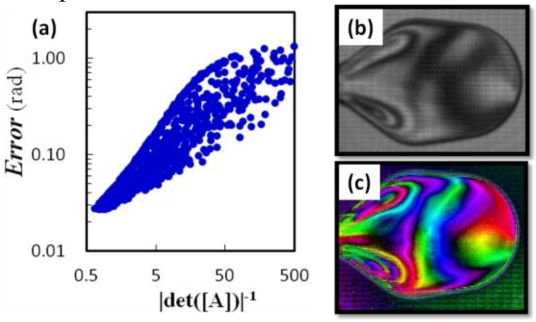

Fig. 2 (a) Simulated analytical errors plotted against $|\det([\mathbf{A}])|^{-1}$. (b), (c) Demonstration of a polarization imaging camera. (b) Detected intensity images, (c) calculated polarization distribution.

[1] Shimotsuma et al., Phys. Rev. Lett. **91** (2003) 247405.
[2] Beresna et al., Appl. Phys. Lett. **98** (2011) 201101.
[3] Gecevičius et al., Opt. Lett. **38** (2013) 4096.
[4] Ohfuchi et al., Opt. Express., Under review.