Investigation of Spatial Intensity Distribution by Using an Optical Diffuser in the Colorimetric Microscopy Setup

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ABSTRACT— Optical diffusers are optical elements for smoothing the spatial distribution of light through irregular light scattering. Recently, the fabrication and engineering of optical diffusers has attracted many attentions. In this research, an optical diffuser was fabricated using silicon carbide ceramic powder and by placing the diffuser in the optical path of the experimental setup of optical transmission microscope, the spatial intensity distribution was investigated. The uniform and symmetric spatial distribution was achieved after placing the diffuser in the optical path, and the intensity distribution diagrams were obtained corresponding to the Gaussian distribution. Finally, two-dimensional samples based on polydimethylsiloxane substrate and Kapton tape were fabricated using a low cost and simple soft nano-lithography technique and the colorimetry and imaging of the fabricated 2D samples were investigated using this experimental setup.

KEYWORDS: Optical Microscope, Intensity Distribution, Optical Diffuser, Colorimetry, Optical Imaging.

I. INTRODUCTION

Optical diffusers are optical tools that are used to make the light spatially uniform or so-called to soften the light profile. In fact, when the light is non-uniform or carries a pattern before being irradiated on the target sample, it causes noise to be added to the original data. For example, when a light source with non-uniform profile was utilized or a pattern was modulated on the light profile along the optical path, many noises or distortions will be added to the image signal.

Optical diffusers consist of a set of diffusers that uniform the spatial distribution of light intensity through the multiple scattering and refraction of light. These optical tools eliminate any noises or distortions on the light spot through the irregular scattering of light and create a uniform distribution of light by diffusing the incident light in different directions.

Although there are many different types of diffusers, the most common ones consist of organic or inorganic diffusers embedded in a plastic film and their performance is based on multiple scattering and refraction of light. Usually, placing a white light-transmitting object, such as paper, provides a uniform light distribution, but in many cases, softening the light with these objects causes a greater loss of light intensity. Recently, the construction and engineering of optical diffusers has attracted the attention of many researchers [1-4].

In addition to maintaining light intensity, engineered optical diffusers also offer other capabilities. For example, some optical diffusers are effective only at a certain wavelength range [5]. This optical element has attracted various applications such as optical imaging [6-7], holography [8] and liquid crystal displays [9].

In this work, an optical diffuser was produced using silicon carbide powder, and by placing the diffuser along the optical path of the experimental setup of the optical transmission microscope, the spatial distribution of light intensity was investigated.

In addition, two-dimensional samples based on polydimethylsiloxane (PDMS) substrate and Kapton tape were fabricated using a low cost and simple soft nano-lithography technique [10-11] and the colorimetry and imaging of the fabricated 2D samples was performed using the colorimetric microscopy setup.

II. Experimental Methods

A. *Fabrication Process*

One of the simplest and most common types of optical diffusers is a glass with a non-smooth surface. In this work, an optical diffuser was fabricated by directly abrading silicon carbide powder on a glass substrate and it was utilized in the experimental arrangement of the optical transmission microscopy to achieve a uniform spatial distribution of light intensity. It should be noted that silicon carbide powder with a particle size distribution of about 150 microns was used. The real image of the fabricated optical diffuser is shown in Fig. 1(a).

Next step, two-dimensional samples based on PDMS substrate and Kapton tape were fabricated using a soft nano-lithography technique. In this method, the charge-coupled device (CCD) of a camera was used as a stamp, which has a two-dimensional periodic square pattern with excellent resolution. Also, PDMS material was chosen as a substrate, which is a flexible and transparent polymer that makes it a good candidate for soft nano-lithography technique.

A schematic layout of the fabrication process of two-dimensional samples by soft nano-lithography method is shown in Fig. 1(b). First, a CCD was carefully extracted from a camera without damaging its surface. Then, the CCD was placed on a glass and the mold was fixed on it and around it was sealed with thermal glue to prevent leakage. In parallel, PDMS polymer and curing agent were mixed at a weight ratio of 10:1 with a DC stirrer for 5 minutes to obtain a homogeneous mixture. The mixture of PDMS base and curing agent was injected into the prepared mold on the CCD. For degassing, the sample was placed in the vacuum chamber for 15 minutes. Afterward, the PDMS composite was cured for an hour at the temperatures of 50°C to 100°C using a hot plate. Finally, the sample was kept at room temperature for 24 hours to finalize the pattern transferring on the PDMS substrate. After 24 h, the patterned PDMS film was carefully peeled off from the CCD stamp, and a 2D periodic PDMS-based nanostructure was successfully achieved (Fig. 1(b)).

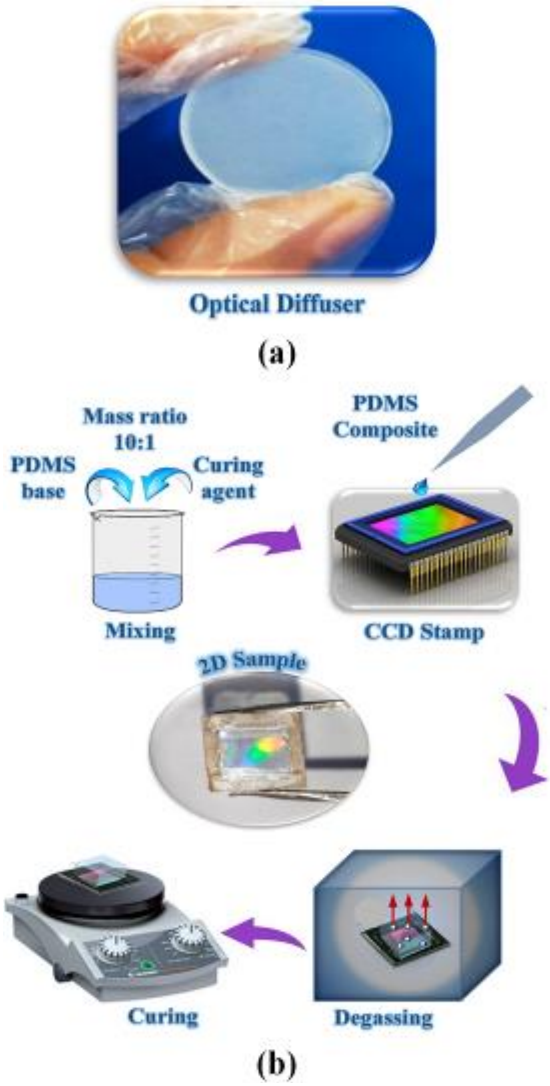

Fig. 1. (a) The real image of the fabricated optical diffuser, and (b) A schematic array of the fabrication process of two-dimensional samples based on PDMS.

A thin layer of TiO_2 and MgF_2 with a thickness of 100 nm was deposited onto the patterned PDMS-based nanostructures using the sputtering technique. In this way, two-dimensional all-dielectric nanostructures were successfully fabricated with a low-cost, and simple design method based on soft nanolithography.

In addition, two-dimensional perforated Kapton tape was prepared as explained in our previous work [10], and this perforated tape was coated by the thin layers of gold, and garnet. Finally, a two-dimensional Kapton-Au-Garnet-Au sample was prepared for imaging and colorimetry in the experimental setup.

B. *Experimental Setup*

A schematic array of the experimental setup of the optical transmission microscopy is shown in Fig. 2. In this arrangement, the broadband halogen lamp was used as a light source. The intensity distribution profile of the halogen lamp is non-uniform, and the fabricated diffuser was utilized to achieve a uniform intensity distribution.

The spatial intensity distribution of the light becomes uniform after passing through the optical diffuser, and the light beam is guided by a mirror towards the objective lens, as shown schematically in Fig. 2. Afterward, the light beam is focused on the sample by an objective lens and the transmitted light through the sample is received by another objective lens. Finally, transmitted light is focused onto a CCD camera (or spectrometer for transmission spectroscopy) using a lens. Therefore, optical transmission imaging and normal transmission spectroscopy of the target sample can be recorded by this experimental setup.

First, the light alignment was adjusted in the optical microscopy setup. After that, the spatial intensity distribution was detected and recorded using the CCD camera by placing the optical diffuser along the optical path and without the diffuser.

To finalize the experimental setup, imaging and colorimetry of the fabricated two-dimensional samples based on PDMS substrate were performed, and the intensity distribution, normal transmission spectrum, and then colorimetry of the samples was investigated using the proposed experimental setup.

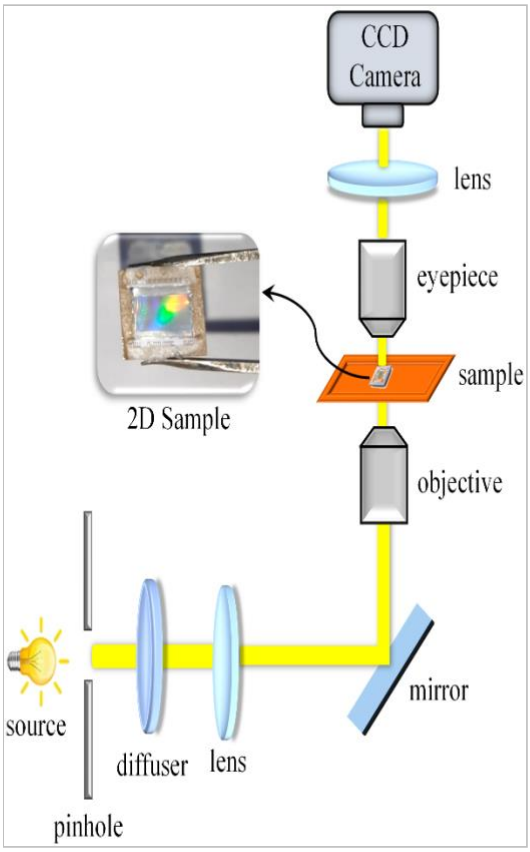

Fig. 2. A schematic of the experimental setup of the optical transmission microscope.

III. Results and Discussion

After adjusting the optical alignment, the intensity distribution profile was detected and recorded by the CCD camera (Fig. 3(a)). As can be seen, the intensity distribution in both x and y directions is asymmetric and non-uniform and does not completely match the Gaussian intensity profile (red curve in Fig. 3(a)).

To achieve a uniform and symmetric intensity profile, the fabricated optical diffuser was placed along the optical path and the intensity distribution profile was recorded in the presence of the optical diffuser (Fig. 3(b)). As expected, after placing the optical diffuser along the optical path, a uniform and symmetric intensity distribution was achieved, and the light spot appeared as a perfect circle. In addition, intensity distribution curves (yellow curves) corresponding to Gaussian distribution (red curves) were obtained.

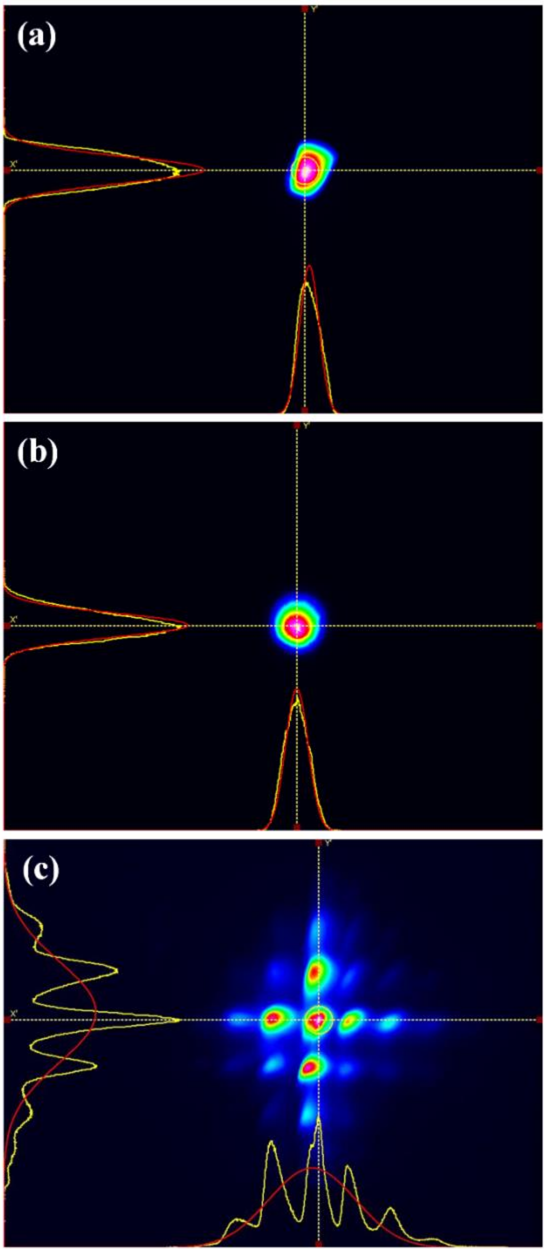

Fig. 3. Recorded images of the spatial intensity distribution for the states: (a) before, (b) after placing the optical diffuser along the optical path, and (c) Spatial intensity distribution of the 2D PDMS-MgF_2 sample by placing the optical diffuser along the optical path. The yellow curves show the measured intensity distribution, and the red curves show the corresponding Gaussian intensity distribution in the x and y directions.

As can be seen, the intensity distribution curves before using the optical diffuser deviate from the Gaussian distribution profile and does not match it. While the light intensity profile was achieved symmetrically and circularly, after placing the optical diffuser along the optical path.

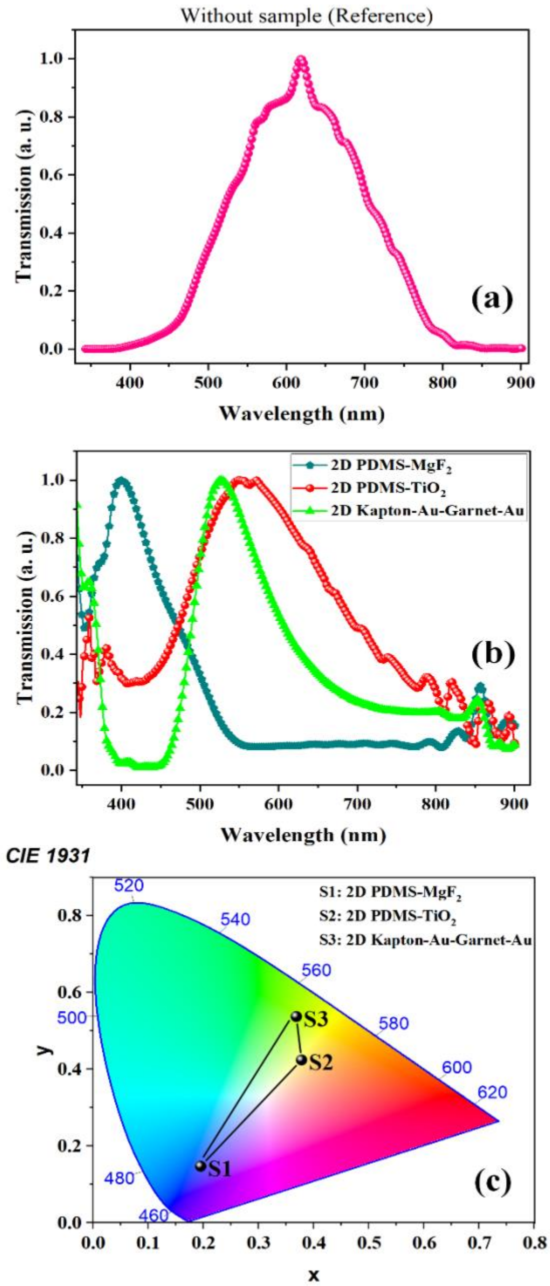

Fig. 4. (a) Measured transmission spectrum of the light source without the presence of the sample, (b) Normalized transmission spectra of the different 2D samples, and (c) The colorimetric diagram of the fabricated 2D samples.

Next step, optical imaging of the fabricated two-dimensional sample was performed using the experimental setup and shown in Fig. 3(c). As seen, the intensity distribution image of the two-dimensional sample was obtained symmetrically and regularly in both x and y directions and diffraction pattern of the 2D grating structure appeared clearly. Each hot spot that appeared in Fig. 3(c) corresponds to the optical excitation of each unit cell of the two-dimensional lattice structure. Different intensity peaks were also recorded in both x and y directions (yellow curve in Fig. 3(c)), which correspond to the excitation of each unit cell.

Furthermore, the normal transmission spectra of the fabricated 2D samples were recorded by placing the spectrometer instead of the CCD camera in the experimental setup (Fig. 2).

First, the transmission spectrum of the light source without the presence of the sample was measured, which is considered as a reference spectrum (Fig. 4(a)). After that, the sample was placed on the sample holder (Fig. 2) and the transmission spectra of different two-dimensional samples were recorded.

For a closer look, the normalized transmission spectra were calculated by dividing T_{Sample} by $T_{Reference}$ and shown in Fig. 4(b). As can be seen, different two-dimensional samples show different transmission spectra duo to the difference in their optical properties such as refractive index.

Finally, colorimetric diagram (CIE 1931) was extracted using the transmission data of the two-dimensional samples and shown in Fig. 4(c). As can be seen, different 2D samples produced different and distinguishable colors, that cover the entire visible range. Structural colors can be adjusted by changing parameters other than refractive index, such as periodicity [12], incident angle [13], and geometric parameters.

The homemade colorimetric microscopy setup equipped with the fabricated optical diffuser allows simultaneous imaging and spectroscopy (as well as colorimetry) of different samples.

IV. CONCLUSION

Optical diffusers are used to create a uniform spatial distribution of light intensity, and these optical elements have attracted the attention of many researchers in the field of optics and photonics due to their various applications. In this research, an optical diffuser was produced by directly abrading silicon carbide powder on a glass substrate and it was utilized in the experimental setup of the optical transmission microscope to achieve a uniform spatial distribution of light intensity. It was indicated that by placing the optical diffuser along the optical path, the spatial distribution of light intensity has become uniform and symmetric, and also the intensity distribution diagrams were obtained according to the Gaussian distribution. Furthermore, two-dimensional samples based on the flexible PDMS substrate were fabricated using a low cost and simple soft nano-lithography method and the colorimetry and imaging of the fabricated 2D samples was performed using the colorimetric microscopy setup.

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