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# Optical properties of monolayer polystyrene microspheres driven by a direct current

Xinbing Jiao*, Qian Pan, Xinwei Zhao, Ruirui Hao, Xue Bai

*Shanghai Key Lab of Modern Optical System, and Engineering Research Center of Optical Instrument and System, Ministry of Education, University of Shanghai for Science and Technology, 516 Jungong Rd, Shanghai, 200093, China*

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Polystyrene microspheres (PSMs) with diameters of 5 μm and 10 μm are prepared on garnet by a self-assembly method. The pressure generated by quartz sheet/PSM/garnet/graphite is measured by a resistance strain sensor as a function of the external direct current (DC) voltage. The surface morphology of the PSMs are observed by optical microscopy. The polarization properties of the linearly and circularly polarized laser beams with a wavelength of 1550 nm reflected from the different PSMs are researched by a Thorlabs PAX 5710 IR3 Polarization Analyzing System as a function of the external DC voltage. The results show that the PSMs with different sizes can be damaged when the external pressure exceeds its critical value of 3.0 MPa, but the critical DC voltages are different. The optical polarization properties of the circularly polarized laser beam can be changed with the external DC voltage, whereas the linearly polarized laser beam cannot be changed.



## 1. Introduction

Polystyrene microspheres (PSMs) with nano- and micro-dimensions have attracted broad scientific interest due to their possible application in display coatings [1], supports for nasal drug delivery systems [2,3], high-sensitivity and highly catalytic sensors [4], the biomedical and environmental fields and in the separation sciences [5,6], during the past few years. PSMs possess a very large surface to volume ratio, and their properties can be changed by surface modification [7]. In addition, the scattering and absorption properties of the PSMs can be accurately calculated by the Mie theory [8]. Xiaoyan Ma et al. [9] researched the complex refractive index of the PSMs from 370 nm to 1610 nm. Britt Kunnen et al. investigated the optical polarization properties of PSMs in water using circularly and elliptically polarized light [10]. Sachiko I. Matsushita observed a phase-contrast and typical fluorescence microscopic image of the PSM particles [11]. Luis M. Fortes et al. researched polystyrene microspheres as strain sensors [12]. On the other hand, the optical properties of a laser beam reflected from a PSM are very important and useful, especially when the external conditions change.

In our previously work, the garnet/graphite interface generated 5.98 MPa when an external DC voltage was applied to the graphite, and the optical splitting effect [13] and optical beam shift effect [14] as a function of an external DC voltage were investigated. However, the optical polarization properties of the linearly polarized and circularly polarized laser beams reflected from the PSMs have not been researched. The mechanical and deformation properties of the PSMs have seldom been studied, especially when external conditions are changed. In this paper, the pressure generated from quartz sheet/PSM/garnet/graphite is measured by a resistance strain sensor, and the surface morphology of the PSMs is observed by optical microscopy. The polarization properties of the linearly and circularly polarized laser beams reflected from the different size PSMs are researched by a polarization analyzing system as a function of the external DC voltage.

### 1.1. Experiments

A monolayer of PSMs with diameters of 5 μm and 10 μm is prepared from alcohol suspensions of commercial non-fluorescent monodispersed PS (Big Goose Technology) by a self-assembly method [15,16].

The pressure generated from quartz sheet (the diameter is 25.4 mm, the thickness is 1 mm)/PSM (diameters of the PSMs are 5 μm and 10 μm)/garnet (Granopt Co., Ltd., GLB1550, the size is

* Corresponding author.
*E-mail address:* Xbjiao2011@gmail.com (X. Jiao).

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2 mm × 2 mm × 0.39 mm)/graphite (the size is 10 mm × 10 mm × 0.3 mm) is measured by a DM-L-S01-2 resistance strain sensor when the external DC voltage is changed, as shown in Fig. 1a. A pair of copper electrodes is in contact with the graphite, and its distance is 1 mm.

The surface morphology of the PSMs can be observed by using a scanning electron microscope [17] and an optical microscope. The PSMs are known as elastic balls, and it is easy to recover its deformation. It is difficult to observe the surface morphology of the PSM in real time, when the external DC voltage interacts with the PSM. In this experiment, the optical morphology of the PSMs with different diameters are observed with an optical microscope. The components of the optical microscope consist of a 10× eyepiece and a 40 × /0.6 objective lens.

Fig. 1b shows the schematic view of the experimental set-up. A near infrared laser beam with a wavelength of 1550 nm is used as an optical source. To avoid the total internal reflection, the incident angle of the laser beam is less than 22.5°. The power of the laser beam is 18 mW. The diameter of the optical spot is approximately 0.5 mm. A sample of quartz sheet/PSM/garnet/graphite is used in this experiment. The laser beam is split by using a non-polarization beam splitter. One part of the beam arrives at an InGaAs detector, and the other part is incident on the PSMs, which is then be reflected and finally arrives at the polarimeter (PAX5710IR3). The power of the laser beam, before arriving and after arriving at the PSMs, is obtained from the InGaAs detector and PAX 5710IR3. The reflectivity of the sample is measured by the ratio of the above power value. The temperature is approximately 25 °C to avoid a thermal stress effect when the external current goes through the graphite.

## 2. Results and discussion

Because the properties of the laser beam interacting with the materials are relevant to its external conditions, especially the external pressure, it is necessary to measure the distribution and trend of the pressure generated from the quartz sheet/PSM/garnet/graphite, when the external DC voltage changes. The PSMs are referred to as elastic balls, and in its elastic range, the principal refractive index is related to the external pressure, which could induce birefringences when the laser beam and PSMs interact in the focal volume [17]. In this experiment, the thermal pressure can be ignored because the temperature is fixed at approximately 25 °C. The major source of the pressure originates from the quartz sheet/PSM(5 μm, 10 μm)/garnet/graphite when the external DC voltage changes. The pressure can be measured and calculated based on the experiment displayed in Fig. 1a, and the results are shown in Fig. 2. For the PSMs (5 μm), initially the pressure is approximately 0 Pa, when the external DC voltage is lower than 0.4 V. Then the pressure increases to 0.3 MPa when the external DC voltage is 1.3 V, which may be induced by the elastic deformation of the PSMs. Next, the pressure decreases to −2.96 MPa when the external DC voltage is 1.4 V. This process is related to the flexibility changes of the PSMs. Finally, the pressure is approximately 3.0 MPa when the external DC voltage is higher than 1.4 V. With regard to the PSMs (10 μm), initially the pressure is approximately 0 Pa, when the external DC voltage is lower than 0.7 V. Then the absolute value of pressure increases to approximately 0.3 MPa, when the external DC voltage is lower than 1.9 V, which may also be induced by the elastic deformation of PSMs. Next, the absolute value of the pressure increases to 2.96 MPa, when the external DC voltage is 2.1 V, and this process is related to the flexibility changes of the PSMs compression pressure. Finally, the pressure is approximately 3.0 MPa when the external DC voltage is higher than 2.1 V. From Fig. 2, the absolute critical values of the elastic deformation pressure and the compression pressure are basically the same, when the diameters

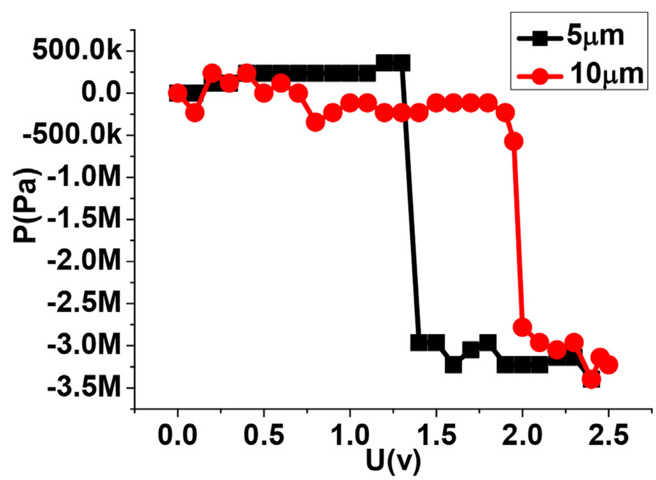


**Fig. 2.** Pressure generated from quartz sheet/PSMs (5 μm (black), 10 μm (red))/garnet/graphite, as a function of the external DC voltage. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

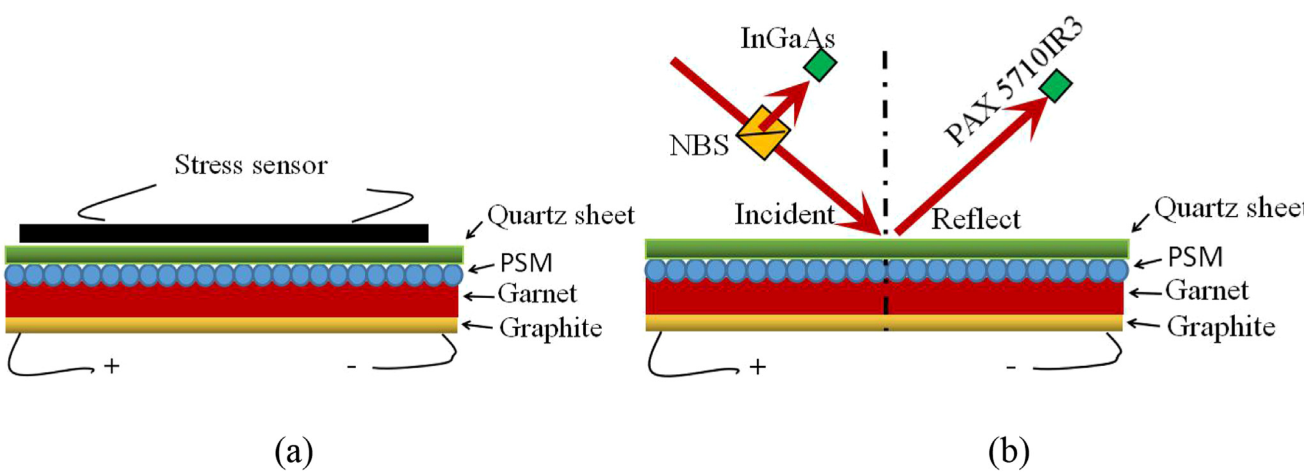


**Fig. 1.** Schematic of the experimental setup. (a)Experimental setup for measuring pressure (b) Experimental setup for measuring polarization properties of a laser beam.