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Carbon–polydimethylsiloxane-based integratable optical technology for spectroscopic analysis

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ABSTRACT

A polydimethylsiloxane (PDMS)-based optical system has been demonstrated. To suppress intense background radiation due to multiple internal scatting in a transparent material, a composite structure of a carbon–PDMS compound and PDMS was proposed. The index matching of the real part of the refractive index can suppress internal scattering, and an absorption of 99–99.7% was attained by using carbon micro particles and carbon nano tubes. The black-PDMS light channel functions as a light filter for straight pass, and an optical density of 5 was obtained by bending the filter.

1. Introduction

Traditionally, an optical system configures optical components in a space [1,2]. It means that the optical path through the components as robust path and the spaces as flexible path. This robust/flexible combination was very useful to attain the tunability and stability of the system simultaneously. The tunability was guaranteed by the flexible path and tuning mechanisms of the components, and the stability was guaranteed by the robustness of the components and a fundamental base. Therefore, the fundamental bases with black optical covers generally render optical systems heavy, hard, and expensive. Since robust material is preferred for optical component, the robust path is generally the path filled with transparent and solid-state medium. We term it “filled path” in this paper as an opposite word of empty traditional path such as a space.

Some of advanced and integrated optical systems (TIRF, SPR, lab on a chip and so on) reported the replacement of the spaces with transparent solids partially in its optical path [3–5]. This replacement increased stability and decreased tunability. Furthermore, it became the system more compact due to the reducing fundamental base. On this view point, an optical fiber based system [6] proposes an important conceptual advancement. Though an optical fiber is filled path, it can simultaneously provide longitudinal robustness and transverse flexibility due to its small cross section. Thus, waveguide technology such as WDM has been studied [7].

Recently, many research groups have studied optical detection in the “lab on a chip” concept [8]. A very simple optical system such as an absorption cell was integrated in the flow-injection system consisting of glass, and a severe internally scattered background was observed in the filled optical path of glass. Thus, external components such as optical filters must be included for sensitive measurement. If a complicated optical system is designed with the filled optical path, multiple internal scattering causes severe background noise in optical detection. However, the use of the filled optical path provides the possibility of constructing an optical system using soft materials such as polydimethylsiloxane (PDMS), if internal stray light can be reduced. In this study, we propose a novel concept for a compact optical system using the soft and flexible material, PDMS, as the optical system based on filled path scheme. To suppress intense background radiation due to multiple internal scatting in a transparent material, a core/clad structure of a carbon–PDMS compound (clad) and a PDMS (core) was proposed. The refractive index matching of the core and the clad can suppress internal scattering, and an absorption of 99–99.7% was attained by using carbon micro particles and carbon nano tubes.

2. PDMS-based optical system

PDMS has suitable optical properties, which are listed as follows:

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0039-9140/

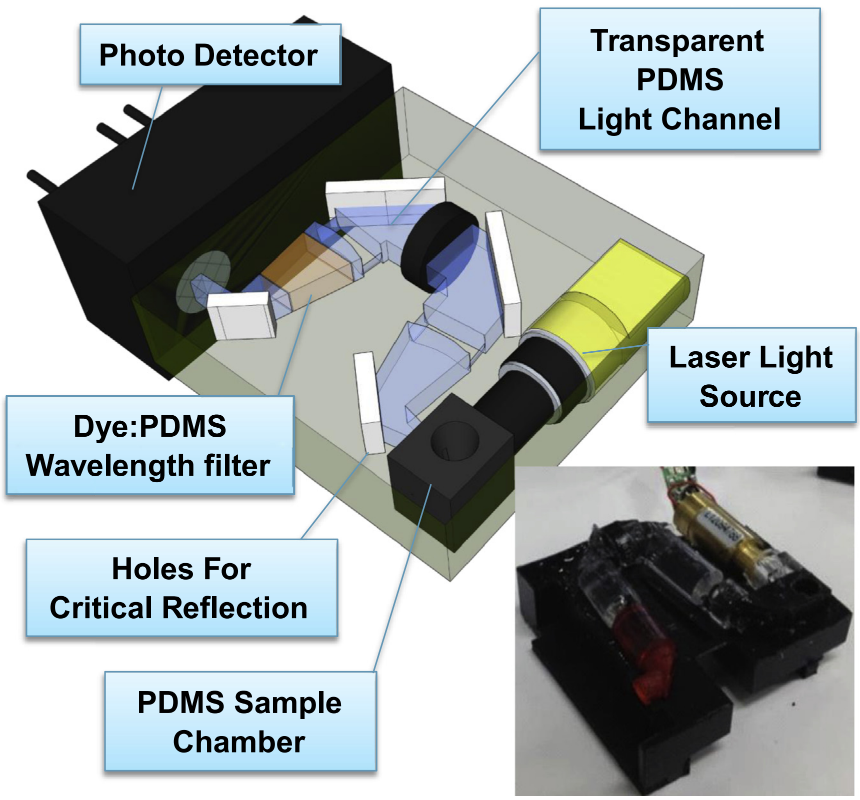

Fig. 1. Schematic of PDMS/Carbon–PDMS module for laser induced fluorescence detection. All optical component is covered black-PDMS molding. Right bottom image is the photo image of the assembled components for the pumping at 532 nm and measuring at 600 nm without covering black-PDMS.

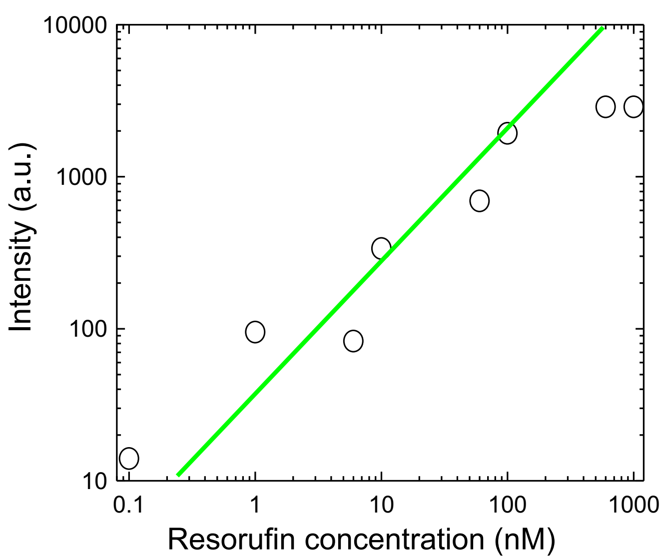

Fig. 2. An example of calibration curve of the Resorufin fluorescence detection using the PDMS module.

- Low fluorescence
- High chemical stability
- Transparency in the UV region.

Fig. 1 shows a schematic of an example of the proposed laser-induced fluorescence (LIF) system for a small sampling tube (such as a PCR: polymerase chain reaction tube) [9,10]. The filled optical path was constructed with transparent PDMS, and it was covered with a similar PDMS material in which absorption particles are diffused. The PDMS material with absorption particles diffused is termed black-PDMS in this article. A mixture of a carbon-particle compound (Shinetsu, KE-COLOR-BL) and room temperature curable PDMS (Shinetsu, SIM-360) was adopted.

A pumping laser was coupled with a PCR chamber consisting of black-PDMS with PDMS windows. LIF was collected 90° relative to the laser-beam axis and propagated in the PDMS light channel. The light channel was folded four times by critical reflection with rectangular parallelepiped holes. Furthermore, two holes with spherical surfaces were used to construct a spatial filter. The PDMS channel was also covered with black-PDMS to reduce unexpected light propagation. The scattered laser beam was trapped by a black-PDMS chamber, laser-blocking filter, and absorbing PDMS channel containing dye and an integrated spatial filter. Finally, the filtered LIF was observed using a photodetector. As a first demonstration, module for pumping at 532 nm and observing at 600 nm was developed. A battery driven diode pumped solid state green laser (DPSS green laser, Lightvision, JSM-6-M, Nd:YVO_4, 532 nm, 1 mW) was used as the pumping laser unit. The mixture of carbon particle compound and PDMS was used as the black-PDMS, and Sudan-II dye was adopted for absorbing dye:PDMS part. The laser blocking filter (Edmund #86-120, OD6@532 nm) was also adopted. The photodetector was a photomultiplier-tube module (Hamamatsu, H10721).

Fig. 2 shows an example for fluorescence detection in a water solution of 7-hydroxy-3H-phenoxazin-3-one (Resorufin) dye in a 50-μL PCR tube. The three data samples were averaged without re-entry. The blank signal corresponds to 150–300 a.u., and the detection limit can be approximated as 2–3 nM. A dynamic range over 1–100 nM was also confirmed.

3. Evaluation of scattering trap performance

The low blank signal level seemed to be due to the trapping effect of scattered light at the boundary between black-PDMS and

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