# AN ELASTOMER-BASED MEMS FABRY-PEROT INTERFEROMETER FOR PHYSICAL AND BIOLOGICAL SENSING BY DRY TRANSFER TECHNIQUE

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## ABSTRACT

We developed an elastomer-based Fabry-Perot interferometer with 120-1080 nm gap between a freestanding thin film and a substrate using dry transfer technique. A newly developed elastomeric nanosheet using a polystyrene-polybutadiene-polystyrene triblock copolymer (SBS) provides low Young's modulus of 40 MPa, large elastic strain of 40%, and high adhesiveness. A freestanding SBS nanosheet can be formed by dry transfer technique without vacuum and high temperature processes owing to the high adhesiveness of SBS nanosheet. A minimum gap length of 120 nm with an 80 µm in diameter was achieved. With the pressure change, the freestanding membrane was found to deform with good adhesion between the dry transferred SBS and the substrate.

## INTRODUCTION

MEMS-based Fabry-Perot (FP) interferometers are promising technique for wavelength selective filter with high selectivity, which have been widely used for actuator and sensor applications. With actuation of a movable mirror of two parallel reflecting mirrors, tunable transmissive color filters [1,2] and tunable IR bandpass filters [3] have been proposed. On the other hand, spectral shift associated with membrane deflection caused by external force was utilized for physical [4,5] and chemical sensors [6]. In particular, high capability for position detection of minimum 50 pm [7] provides highly sensitive physical and chemical sensors compared with piezoresistive [8,9] or capacitive [10,11] method. Therefore, the optical interferometry have been applied for pressure, tactile, and surface stress sensor which detects molecular adsorption caused by antigen-antibody reaction.

To obtain the spectral shift applying with physical and chemical quantity, a suspended membrane with a narrow cavity above a substrate is required. Conventional FP-sensors used relatively complex fabrication process such as sacrificial release followed by encapsulation process for nanocavity [6] or through silicon via for membrane release and high temperature wafer bonding process [12]. These fabrication processes for the sealed nanocavity structure imposes structural and material restrictions such as chemical stability for etching gas and high-temperature tolerance.

In the case of use for the displacement sensor, the suspended membrane requires a material with low Young's modulus which offers to improve the sensitivity for external force. Capacitive sensors and piezoresistive sensors use semiconductor or metal for deformable membrane because these such materials allow capacitive or piezoresistive change for signal transducing. In contrast to this, the optical interferometric sensors can accommodate organic materials for the deformable membrane. In particular, an elastomer is one of the most promising material for the stress sensor because of low Young's modulus of 1-100 MPa.

We have previously developed an elastomer nanosheet using a polystyrene-polybutadiene-polystyrene (SBS) triblock copolymer whose thickness can be controlled to a minimum 100 nm by a microgravure roll technique [13]. The ultra-thin thick elastomer sheet demonstrated unique physical properties such as flexibility, stretchability, low Young's modulus of 40 MPa, and high adhesiveness [14-16]. In addition, the triblock copolymer provides film thickness controllability by concentration adjustment at the roll-to-roll process, which allows a self-supporting nanosheet with simple method. The freestanding SBS nanosheet was also demonstrated large elastic deformation of 38% strain with cyclic straining [17].

In this paper, we propose an elastomer-based FP

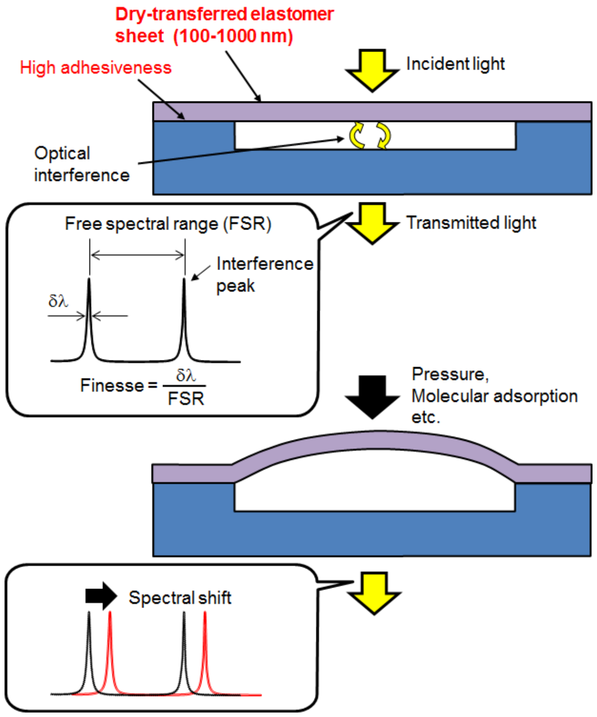


*Fig. 1 Schematic image of an elastomer-based Fabry-Perot interferometer developed by dry transfer technique.*

interferometer by dry transfer technique above shallow trench in a substrate to form a nanocavity without vacuum and high temperature processes. With the pressure change, the freestanding SBS nanosheet was found to deform with good adhesion between the dry transferred SBS and the substrate.

## FABRICATION

Fig. 1 schematically illustrates a MEMS FP interferometer for physical and biological sensing. A flexible sheet is suspended over a nanocavity whose length determines a free spectral range (FSR) of the FP interferometer, namely a narrow gap provides a wide FSR. When an external force such as pressure and molecular adsorption using antigen-antibody reaction is applied to the suspended membrane, interference peaks of reflected or

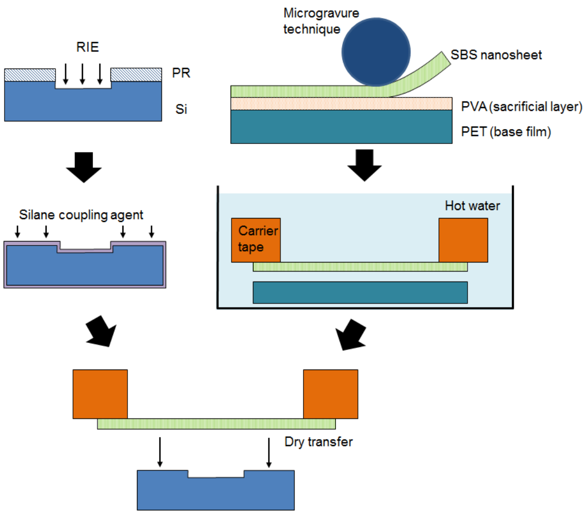


*Fig. 2 Fabrication process*

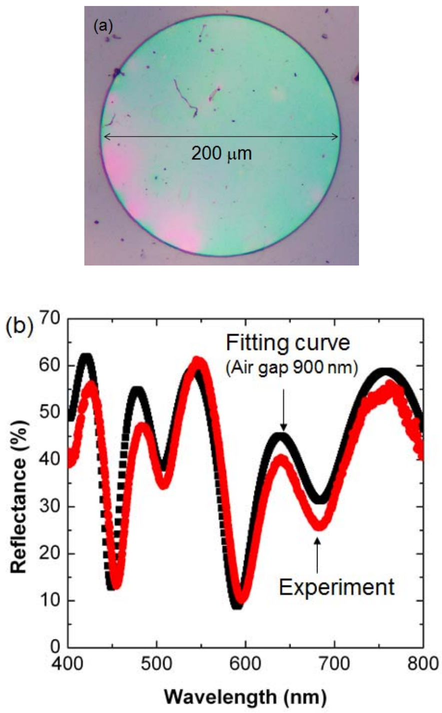


*Fig. 3 (a) Optical microscope image of a Fabry-Perot interferometer using SBS nanosheet. (b) Typical reflection spectrum of the FP interferometer.*

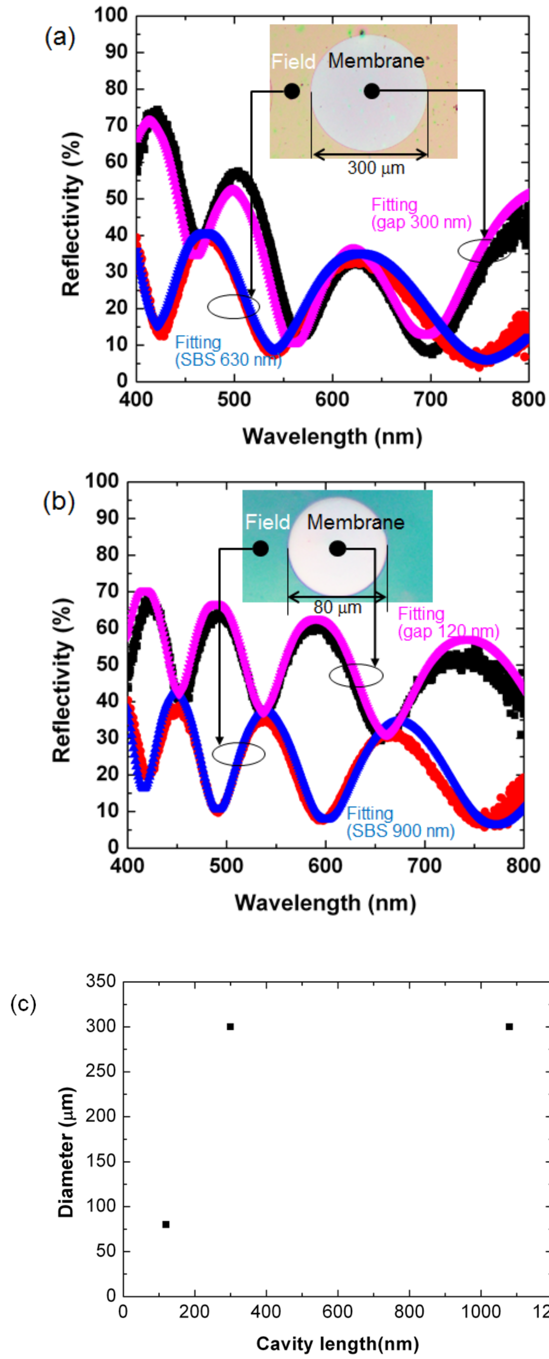


*Fig. 4 Evaluation of aspect ratio dependence dry transfer process. Reflection spectrum with a gap of (a) 300 nm and (b) 120 nm. (c) Maximum diameter corresponding to gap length.*

transmitted light are shifted dependent on the gap length. With high adhesiveness of an elastomer nanosheet, suspended membrane with a nanocavity is formed by dry transfer process.

An SBS nanosheet was developed on a polyethylene terephthalate (PET) film with pre-laminated poly(vinyl alcohol) (PVA) as a sacrificial layer by a microgravure technique. Fig. 2 shows a fabrication process for a MEMS Fabry-Perot interferometer using dry transfer technique. The SBS polymer dissolved in tetrahydrofuran (THF) was coated on the PVA/PET films by a microgravure roll technique (rotation speed: 30 rpm, line speed: 1.3 m/min, drying temperature: 80 °C). The SBS nanosheet supported with a carrier tape was released from the PET film in a hot water at 80 ºC. To form a diaphragm structure above a nanocavity, shallow trenches on a silicon substrate were prepared. For improvement of adhesion, a silane coupling agent was coated on the silicon wafer, followed by transferring nanosheet at room temperature.

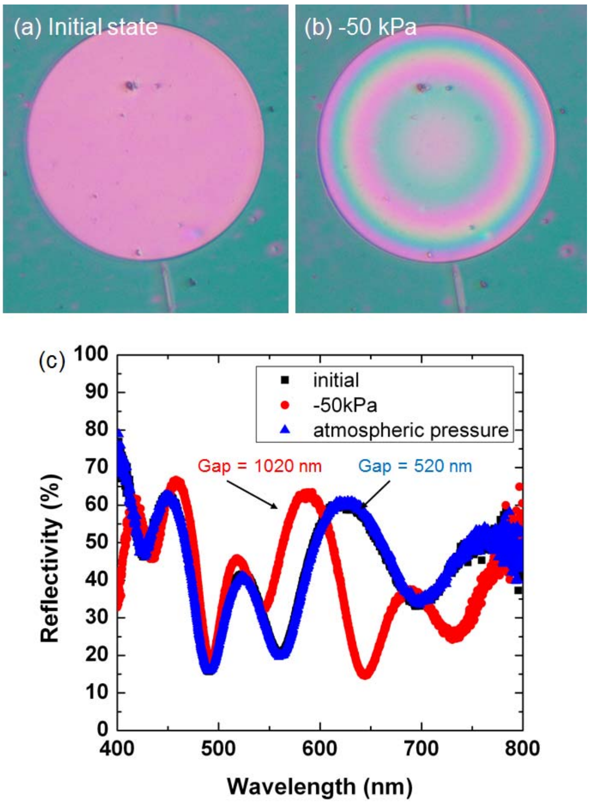


*Fig. 5 Optical microscope image at (a) atmospheric pressure and (b) -50 kPa. (c) Typical spectrum shift by pressure change.*

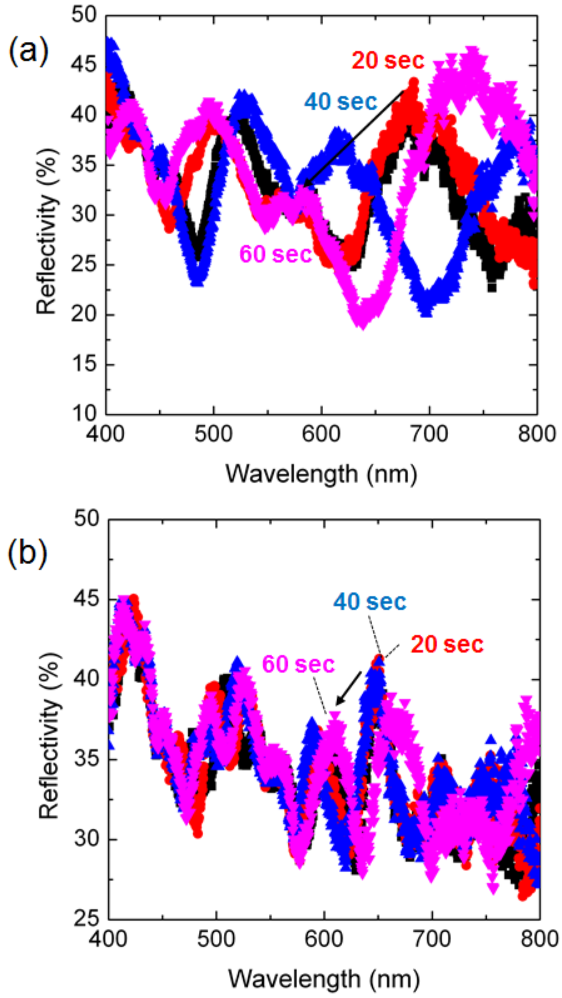


*Fig. 6 Interference peak shift due to gas leakage of (a) single layer of SBS and (b) 100-nm-thick parylene-C deposited on SBS.*

## EXPERIMENTAL

Fig. 3(a) shows an optical microscope image of the developed FP interferometer with a diameter of 200 µm.

For the measurement of the reflection spectra, a vertical illumination type optical microscope (Mitsutoyo, VMU-LB), CCD camera (OLYMPUS, DP22), spectrometer (Ocean Optics, USB2000TR), and a xenon light source (ASAHI SPECTRA, LAX-C100, 100 W) were used. The magnification of the objective lens was 20x and the measurement spot diameter was 10 µm. The reflection spectrum of the interferometer was measured by a microscopic spectroscopy, as shown in Fig. 3(b). The 5 interference peaks of the reflection spectrum from the diaphragm was observed. A fitting curve using refractive index of 1.5 with a thickness of 625 nm and a gap of 900 nm was good agreement with the experimental reflection spectrum. For the evaluation of aspect ratio dependence, the gap length was designed to be 100, 300, and 1000 nm with the diameter range of 10-300 µm. A minimum gap length of 120 nm with an 80 µm in diameter was achieved, as shown in Fig. 4. Figs. 5 (a) and (b) show the micrographs of the SBS nanosheet-based interferometer corresponding to a different pressure. The dry-transferred SBS nanosheet was kept to attach on the substrate under vacuum condition. The interference peaks were red-shifted at -50 kPa, and the gap length was indicated to be 1020 nm by rigorous coupled-wave analysis (RCWA) simulation. The reflection spectrum was completely returned to the initial state at atmospheric pressure, which suggested that the deformed nanosheet was elastically restored. Note, however, that the SBS nanosheet has a slightly permeability to gas, hence an additional thin film is required on the SBS interferometer for pressure sensing. In particular, highly reflective material can improve finesse, which means to become sharper transmission peaks.

To reduce the gas leakage of SBS, 100-nm-thick paryelene-C was deposited on the SBS nanosheet before dry transfer. After that, the nanosheet was released from the PET film by the sacrificial etching and transferred on the Si substrate with the same method mentioned above. Figure 6 (a) and (b) show typical reflection spectra of the F-P interferometer composed by single layer of SBS nanosheet and SBS covered with 100-nm-thick parylene-C at -50 kPa. The peak position of the bare SBS was blue-shift due to the gas leakage. On the other hand, the shift amount of the parylene-C/SBS interferometer decreased while slight leakage was found. Therefore, with the additional thin layer deposited on the SBS nanosheet, optically pressure sensing can be possible. The SBS nanosheet works as the adhesion layer in the dry transfer process.

## CONCLUSIONS

We developed an elastomer-based Fabry-Perot interferometer with a nanocavity between a freestanding SBS nanosheet and a substrate using dry transfer technique. A newly developed elastomeric SBS nanosheet provides low Young's modulus of 40 MPa, large elastic strain of 38%, and high adhesiveness. A freestanding SBS nanosheet can be formed by dry transfer technique without vacuum and high temperature processes owing to the high adhesiveness of the SBS nanosheet. A minimum gap length of 120 nm with an 80 μm in diameter was achieved. With the pressure change, the freestanding membrane was found to deform with good adhesion between the dry transferred SBS and the substrate.

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