# Photomechanical gel: Fabrication of photothermal bi-layered actuators by adhesion of PEDOT/PSS and thermoresponsive gels

**Megumi Nakamura[1], Tatsuya Shoji[1], Hiroshi Uyama[2], Yasuyuki Tsuboi[1], Taka-Aki Asoh[2]***

*[1]Division of Molecular Materials Science, Graduate School of Science, Osaka City University*
*3-3-138 Sugimoto, Sumiyoshi-ku, Osaka 558-8585, Japan*
*[2]Department of Applied Chemistry, Graduate School of Engineering, Osaka University*
*2-1 Yamadaoka, Suita, Osaka 565-0871, Japan*

*E-mail: asoh@chem.eng.osaka-u.ac.jp*

**Introduction:** Poly(*N*-isopropylacrylamide) (PNIPAAm) hydrogels are well-known thermoresponsive materials which show a volume phase transition upon being heated at a temperature corresponding to the lower critical solution temperature (LCST). The mechanical bending of PNIPAAm hydrogels in response to external stimuli is important for artificial muscles and switching devices.[1,2,3] Recently, we prepared bi-layered soft actuators by adhesion of PNIPAAm hydrogels.[4,5] In this study, we prepared photothermal actuators by adhesion of PNIPAAm hydrogels and poly(3.4-ethylenedioxythiophene)/poly(sodium 4-styrenesulfonate) (PEDOT/PSS) films, which bent in an arc by laser irradiation (**Fig. 1**).

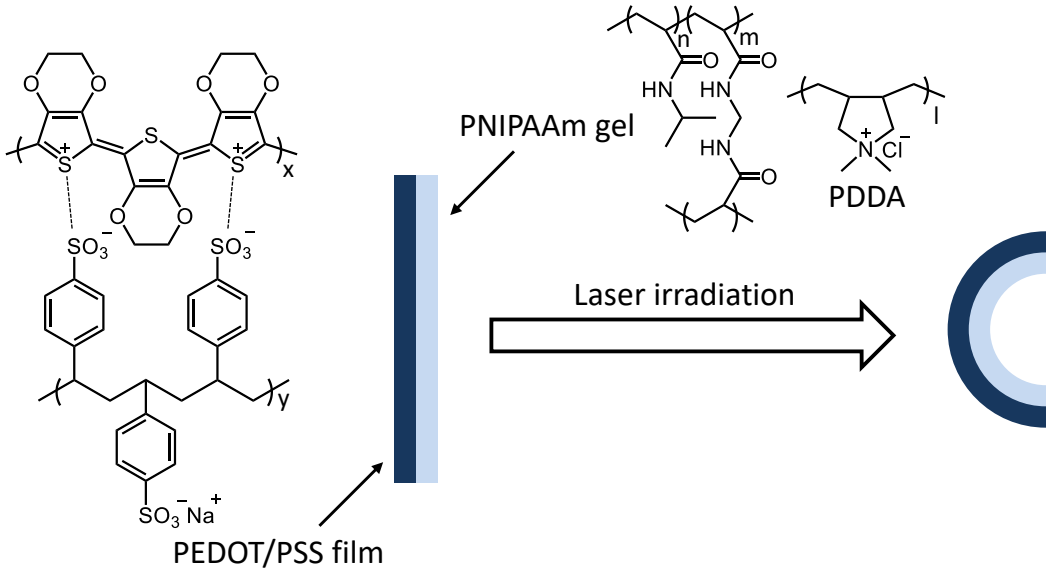


**Figure 1**. Schematic illustration and a chemical structure of photothermal bi-layered actuators, which bend in an arc in response to laser irradiation.

**Experimental:** Bi-layered actuators were prepared by adhesion of poly(3.4-ethylenedioxythiophene)/poly(sodium 4-styrenesulfonate) (PEDOT/PSS) films and cationic polymers incorporated PNIPAAm hydrogels. The PNIPAAm hydrogels were prepared by photo-polymerization using NIPAAm as a monomer, *N,N'*-methylenebis(acrylamide) (MBAAm) as a cross-linker, irgacure 2959 as a photo-initiator, and poly(diallyldimethylammonium chloride) (PDDA) as a cationic polymer. Thus, two layers were adhered by the electrophoretic adhesion.[4,5]

**Results and Discussion:** It is well-known that PEDOT/PSS shows high conductivity and sulfonate ion of PSS is dopant. Because of an excess amount of PSS, the PEDOT/PSS films are negatively charged. Therefore, anionic PEDOT/PSS films are able to adhere on cationic hydrogels. Adhesion of cationic PNIPAAm hydrogels and anionic PEDOT/PSS films was carried out *via* electrophoresis. During electrophoresis, cationic and anionic polymers move to a cathode and an anode, respectively, and then form a polyion complex at the contact interface between the two materials for adhesion.[4,5] In this study, we prepared bi-layered actuators consisting of PNIPAAm and PEDOT/PSS by electrophoretic adhesion (**Fig. 1**).

When CW-808 nm laser (9.0 W $cm^{-2}$) was irradiated to the bi-layer, it bent toward the PNIPAAm layer (**Fig. 2a, b**). PEDOT/PSS releases thermal energy from photoexcitation of materials, so-called photothermal effect, by laser irradiation. As shown in **Fig. 2c-f**, temperature of bi-layered actuators changed from 19.5ºC to 32.2ºC by laser irradiation. Because LCST of PNIPAAm hydrogels is ca. 32ºC, the PNIPAAm hydrogels shrunk by laser irradiation, and then bi-layered actuators changed their shape **(Fig. 2a, b)**. After turning off laser irradiation, the shape of bi-layered actuators went back to the original shape in water **(Fig. 2a)**.

In conclusions, laser-driven hydrogel actuators were prepared by adhesion of thermoresponsive hydrogels and conductive polymer films. We believe our novel, photothermal bi-layered actuators will further advance the development of functional gels for intelligent soft-actuator systems.

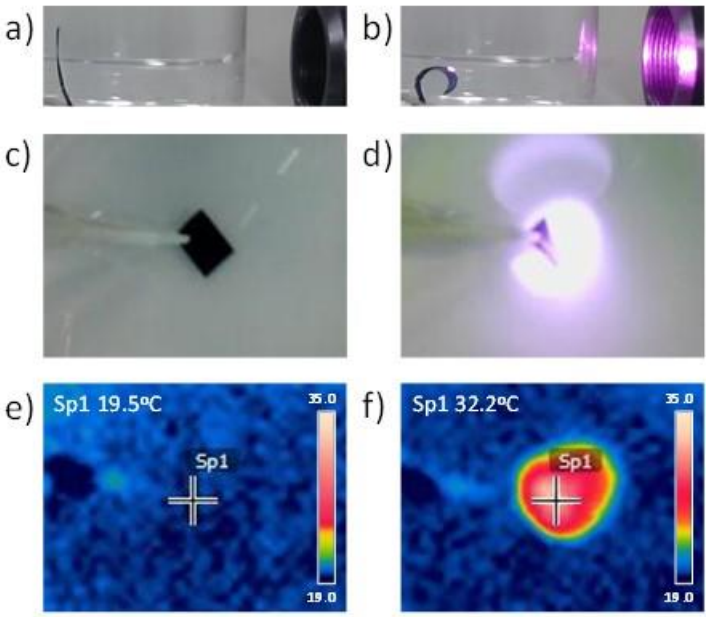


**Figure 2**. (a, b) Bending motion of photothermal bi-layered actuators prepared by adhesion of PEDOT/PSS and PNIPAAm hydrogels. Optical (c, d) and thermal (e, f) images of adhered gels. (a, c, e) and (b, d, f) indicates without and with laser irradiation, respectively.

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**References:**

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