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Abstract

Soft Optomechanical Devices Featuring Intrinsic Redox Activity †

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Abstract: Soft optomechanical sensors have the ability to combine the high tunability and elasticity of soft polymers with the distinctive optical properties of photonic structures, thus offering unprecedented opportunities for the development high-performance colorimetric sensors. Herein, we demonstrate for the first time the use of optomechanical devices made of off-stoichiometry thiol-ene (OSTE), a polymeric material that features intrinsic redox activity, overcoming some limitations of conventional materials (e.g., polydimethylsiloxane or silicon). Remarkably, this work provides the foundation for a new generation of highly tunable and versatile optomechanical sensors, enabling unexplored functionalities.

Keywords: soft optomechanical sensors; mechanochromic devices; off-stoichiometry thiol-ene; redox activity; color imaging; color analysis

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1. Introduction

The interest in so-called soft optomechanical sensors has increased exponentially in recent years. These systems have the ability to combine the high tunability and elasticity of soft polymers with the distinctive optical properties of photonic structures, thus offering previously unimaginable opportunities for the development of new optomechanical sensors for a variety of applications. Remarkably, soft optomechanical systems can be interrogated by color imaging, enabling a 2D mapping of the mechanical deformations, and hence opening the possibility of monitoring a large number of sensors in parallel [1].

In the last years, we have demonstrated the sensitivity of polydimethilsiloxane (PDMS) optomechanical sensors for detecting photo-induced biomolecular conformational changes, photothermal and magnetic-induced deformations of bimorph structures, and pressure changes. However, PDMS and the other materials typically utilized for building optomechanical devices (e.g., silicon) present a low chemical reactivity, thus requiring harsh treatments (e.g., plasma, silanization) for further functionalization. Herein, we demonstrate for the first time the use of optomechanical devices made of off-stoichiometry thiol-ene (OSTE), a polymeric material that features intrinsic redox activity, due to the presence of surface thiol groups. As a proof of concept, the reduction of 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazoliumbromide (MTT) by the mechanical structures is monitored in real time by color imaging. Remarkably, this work provides the foundation for a new generation of highly tunable and versatile optomechanical sensors, enabling novel functionalities.

2. Materials and Methods

For manufacturing the OSTE devices, commercial linear (1D) diffraction grating (GT50-06V Thorlabs (Newton, NJ, USA)) was used as a master mold. First, a PDMS replica was obtained and the OSTE polymer (OSTE 2020 Litho, Mercene Labs (Stockholm, Sweden) was spin-coated at 2000 rpms (90 s) over the PDMS mold, achieving a thin layer (~15 µm thickness) after curing with UV light (60 s, BlueWave QX4, Dymax (Torrington, CT, USA).

The sensors' shapes were defined by laser cutting using an Epilog Mini 24 (4% power, 8% speed). Then, the structures were released with the help of a piece of pressure-sensitive adhesive, obtaining arrays of suspended bridges with one periodically nanostructured surface (d = 1600 nm) and dimensions L = 4000 µm, h = 15 µm, w = 50 µm (Figure 1a). A transparent polymethyl methacrylate (PMMA) microfluidic system (v = 160 µL) was fabricated by laser cutting, allowing for the fluid management and simultaneous color imaging of the sensors. The light diffracted by the sensors surface was measured in a Littrow configuration using a home-made black PMMA structure integrating a collimated white light source, a beam-splitter and a USB microscope (Dino-Lite, (New Taipei City, Taiwan) (Figure 1b). Real-time color analysis was performed using the *colorevo* open-source code (https://doi.org/10.5281/zenodo.5646732) by pre-selecting one or more regions of interest (ROIs).

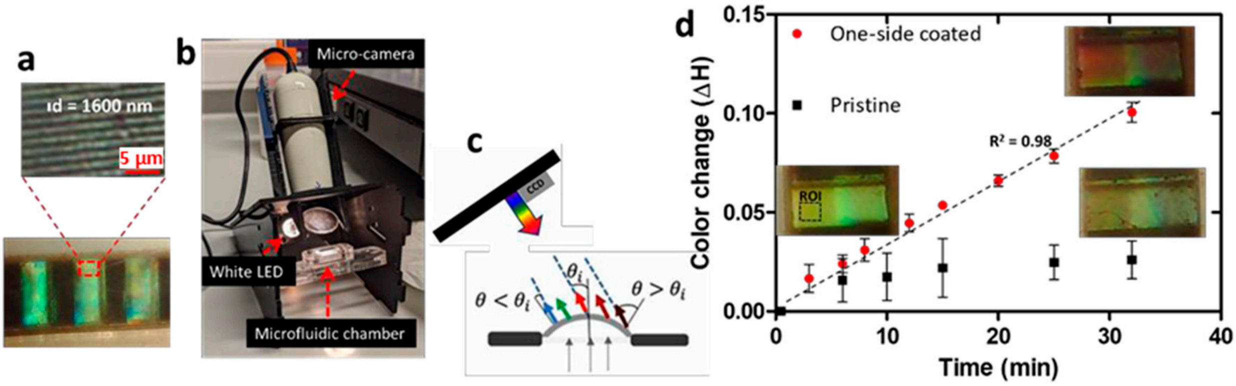

Figure 1. (**a**) Image of the OSTE optomechanical bridges and optical microscopy image (50×) of the periodical surface structure. (**b**) Color imaging setup. (**c**) Working principle of the sensors. (**d**) Color changes during the reduction of MTT for pristine sensors and sensors coated on one side with PEI.

3. Discussion

As illustrated in Figure 1c, the soft polymeric devices presented structural color due to their periodical surface nanostructure, featuring mechanochromic properties according to the diffraction equation. The intrinsic reductive activity of the OSTE devices was evaluated using MTT as an oxidant, since our previous studies indicated that this polymer is able to reduce MTT, producing a purple formazan end-product. As already reported, the redox activity of the OSTE polymer is derived from the excess thiol groups within the polymer matrix [2]. The bending response after the addition of MTT (10 mM) was monitored by color imaging in pristine bridges and bridges coated on one side with a layer of branched polyethylenimine (PEI, MW~25.000). As plotted in Figure 1d, the pristine bridges did not show any color evolution (in Hue color scale (H)), which is most likely due to the fact that the reaction was occurring on both sides of the suspended structures, producing null-effective surface stress. In contrast, the bridges coated on one side with PEI displayed steady color changes, showing a linear time-dependent response, which may be attributed to the difference in the surface stress between both sides of the bridges. These results highlight the potential of these novel optomechanical structures as functional transducers for a variety of applications.

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