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Technology Offer

Remote and Spatiotemporal Control for the Actuation of Biocompatible Membranes through the Irradiation with (visible) Laser Light

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The invention relates to the actuation of micro- and nanostructures controlled by external stimuli. Photo-actuation utilizes the conversion of light via phonons into motion through reversible chemical and physical processes and enables remote and spatiotemporal control of the actuation. Here, we report a fast light-to-motion conversion in few-nanometer thick bare polydopamine (PDA) membranes stimulated by (visible) light. Light-induced heating of PDA leads to desorption of water molecules and contraction of membranes in less than 140µs. Switching off the light leads to a spontaneous expansion in less than 20ms due to heat dissipation and water adsorption. Those actuation times remain stable over a large number of cycles (> 50,000). Our findings demonstrate that pristine PDA membranes are multi-responsive materials that can be harnessed as robust building blocks for soft micro-, and nanoscale actuators stimulated by light, heat, and humidity level.

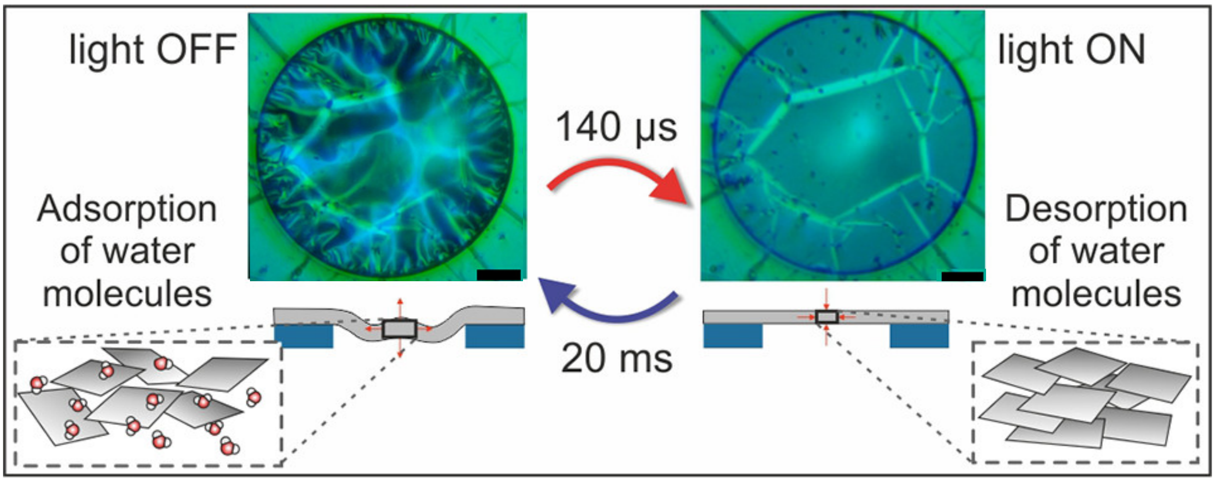

Fig. 1: Scheme incl. optical images of photo-actuation for free-standing PDA film (black scale bar is 10µm). [1]

Background

The recent discovery of PDA fast photo-actuation provides a fascinating opportunity for its implementation in transducers and other light-activated architectures. The strong dependence on the humidity of PDA and the rapid reaction observed in the study opens the door for many applications in which PDA is the active sensing platform and the transductor. This new effect, combined with PDA composites' inherent chromatic and photoactive response, might dominate the organic and hybrid electronics fields.

PDA is known to have excellent photothermal properties over the entire visible spectrum and up to 400 K it remains structurally stable. In other works, this feature was utilized for photo-actuators by combination of PDA heaters with thermo-responsive polymers or graphene oxide (GO). In the works, where PDA is used in combination with GO, the actuation behavior is only observed in layered or gradient geometries that combine GO and PDA. Neither work describes any actuation behavior arising from pure PDA materials. Additionally, the described methods of preparation are not suitable for creating self-supporting, i.e., free-standing, pure PDA films.

Moreover, these heterogeneous structures are bulk structures and accordingly slow, while PDA is used to enhance light absorption or change the hydrophilicity of graphene oxide. Prior to the patent application [2], PDA has not been reported to contribute to light-induced mechanical motion/actuation directly.

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Free-standing PDA films require to be produced via electro-polymerization. So far, no other available technology allows synthesis of PDA films with sufficient mechanical stability for maintaining their morphology upon attachment to a substrate (e.g., in order to form a functional coating). Thus, observing said free-standing PDA films, while impinging external stimuli to them, enables the investigation of morphology changes induced by these stimuli. Figure Fig. 2 (a) shows the experimental setup for the investigation of changes in morphology via a CCD camera chip and the speed of that changes via reflection measurements utilizing a green laser and a photo-diode. Upon exposure of the PDA membrane by means of red laser light (stimulus), the reflection changes from diffuse towards specular (cf. also Fig. 2 (b)). The photo-diode is used to accurately detect the time needed for that change.
Inherently, the PDA responds on the external light stimulus by converting light to heat, which leads to a desorption of water and a negative thermal expansion (shrinking) of the PDA, probably due to an internal rearrangement of the structure. When the actuating light stimulus is switched off, the heat dissipates and water is adsorbed once again by the film, leading to the recovery of its initial structure.

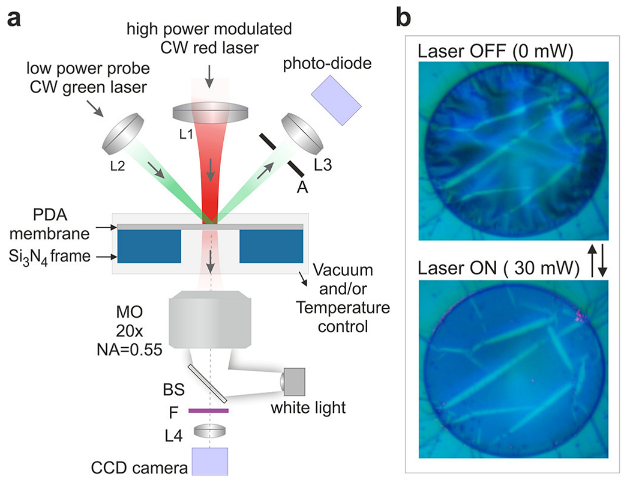

Fig. 2: (a) Scheme of experimental setup for the observation of light-, heat-, or pressure-induced membrane actuation. Sample is mounted in a temperature- and pressure-controlled microscope stage and becomes illuminated with a red (660 nm) laser light that triggers the photoactuation. The laser light spot size approximately matches the membrane area. The change of the membrane morphology is visualized by a CCD camera. Reflectivity measurements using a low power green (532 nm) laser light are used to study fast morphological changes of the membrane. Symbols: L1, L2, L3, L4, lenses; F, optical filter; BS, beamsplitter; A, aperture; MO, microscope objective; CW, continuous wave.
(b) Optical images of a PDA membrane subjected to light-induced contraction at ambient conditions. The power of the incident red laser light is 30 mW. The red laser light in the ON state is not visible due to the optical filter F. [1]

Applications

- Energy harvesting, robotics, sensing, biomedicine, and tunable metamaterials [1].
- Nanoscale actuators controlled over phonons, e.g., a micro-valve.
- Humidity sensor with quick recovery and response time.

Advantage

- PDA films are biocompatible: → Use in combination with living cells, e.g., as biochips.
- PDA films can be used to form functional coatings of substrate materials.

Publications

Vasileiadis, T., Marchesi D'Alvise, T., Saak, C. M., Pochylski, M., Harvey, S., Synatschke, C. v., Gapinski, J., Fytas, G., Backus, E. H. G., Weil, T., & Graczykowski, B. (2022). **Fast Light-Driven Motion of Polydopamine Nanomembranes**. *Nano Letters*, *22*(2), 578–585. https://doi.org/10.1021/ACS.NANOLETT.1C03165

Patent Information

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PCT application WO2023046911A1 filed 23.09.2022

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