Supplementary Information

Statistical Modeling of Photo-Bending Actuation of Hybrid Silicones Mixed With Azobenzene Powder

Takuya Taniguchi [1,*], Loïc Blanc [2], Toru Asahi [3,4], Hideko Koshima [4] and Pierre Lambert [2,*]

[1] Center for Data Science, Waseda University, 27 Waseda-cho, Shinjuku-ku, Tokyo 169-0042, Japan
[2] TIPs Department, CP165/67, Université libre de Bruxelles, 50 Av. Franklin Roosevelt, 1050 Brussels, Belgium
[3] Department of Life Science and Medical Bioscience, Graduated School of Advanced Science and Engineering, Waseda University, 2-2 Wakamatsu-cho, Shinjuku-ku, Tokyo 169-8480, Japan
[4] Research Organization for Nano & Life Innovation, Waseda University, 513 Wasedatsurumaki-cho, Shinjuku-ku, Tokyo 162-0041, Japan

Correspondence to takuya.taniguchi@aoni.waseda.jp (T.T.); pierre.lambert@ulb.ac.be (P.L.)

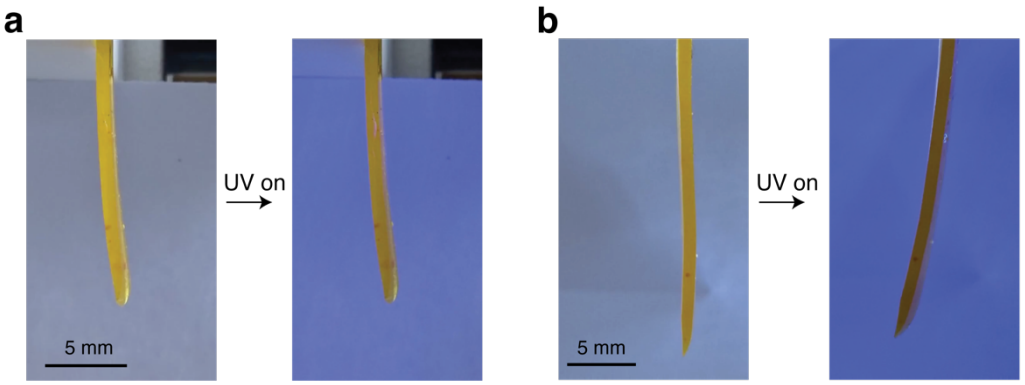
Contents

Supplementary Experimental Detail

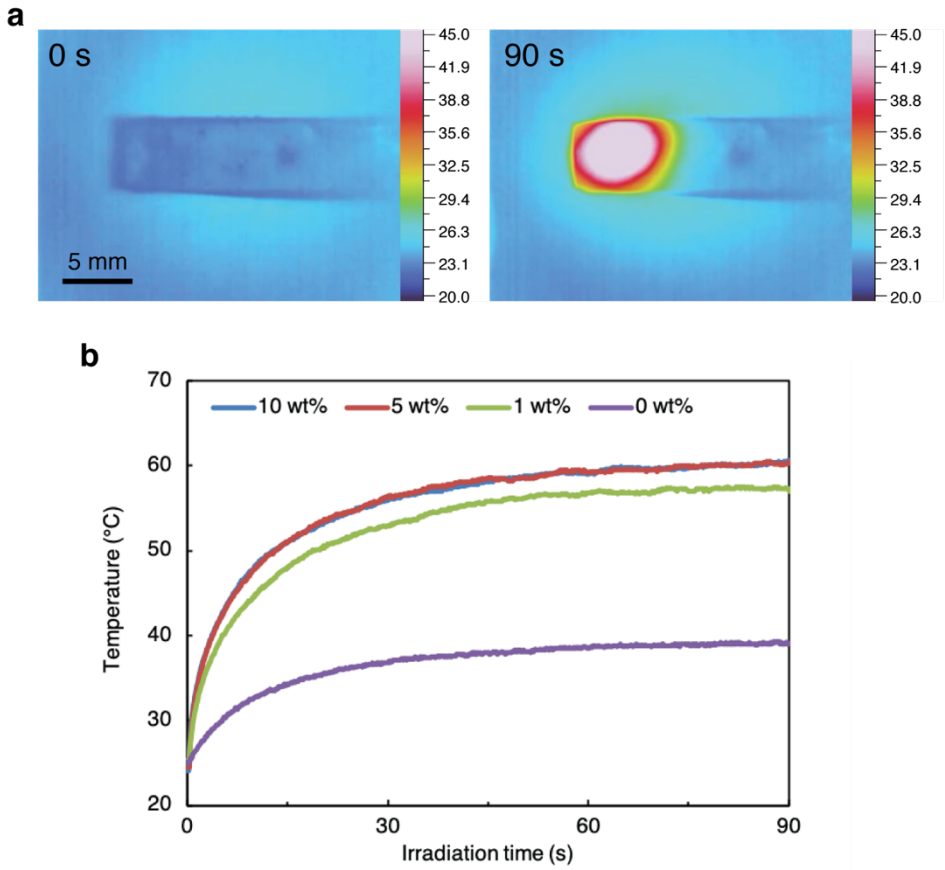
Material Preparation

The silicone (Ecoflex 00-50, Smooth-on) is composed of two viscous liquids named A and B, to be mixed by 1:1. Each viscous liquid was poured by 10 g in a plastic cup, and then mixed well by manually (the net amount is 20 g). The viscous liquid was vacuumed to remove bubbles. The liquid was poured into a mold made by 3D printer, and then vacuumed again to remove bubbles perfectly. Here, the amount of the liquid was too enough for the mold, but allowed easier manual treatment. The mold filled with uncured silicone was kept at room temperature for overnight, and then cured silicone was obtained as the first layer. For the second layer, the net amount 0.5 g of silicone was measured, and 4-aminoazobenzene powder was mixed at different amounts (5, 25, 50 mg for 1, 5, 10 wt%, respectively). The uncured silicone mixed with azobenzene powder was vacuumed, coated onto the first layer, and then kept at room temperature for overnight. After curing, the hybrid silicone was detached from the mold, and then cut for the bending observations.

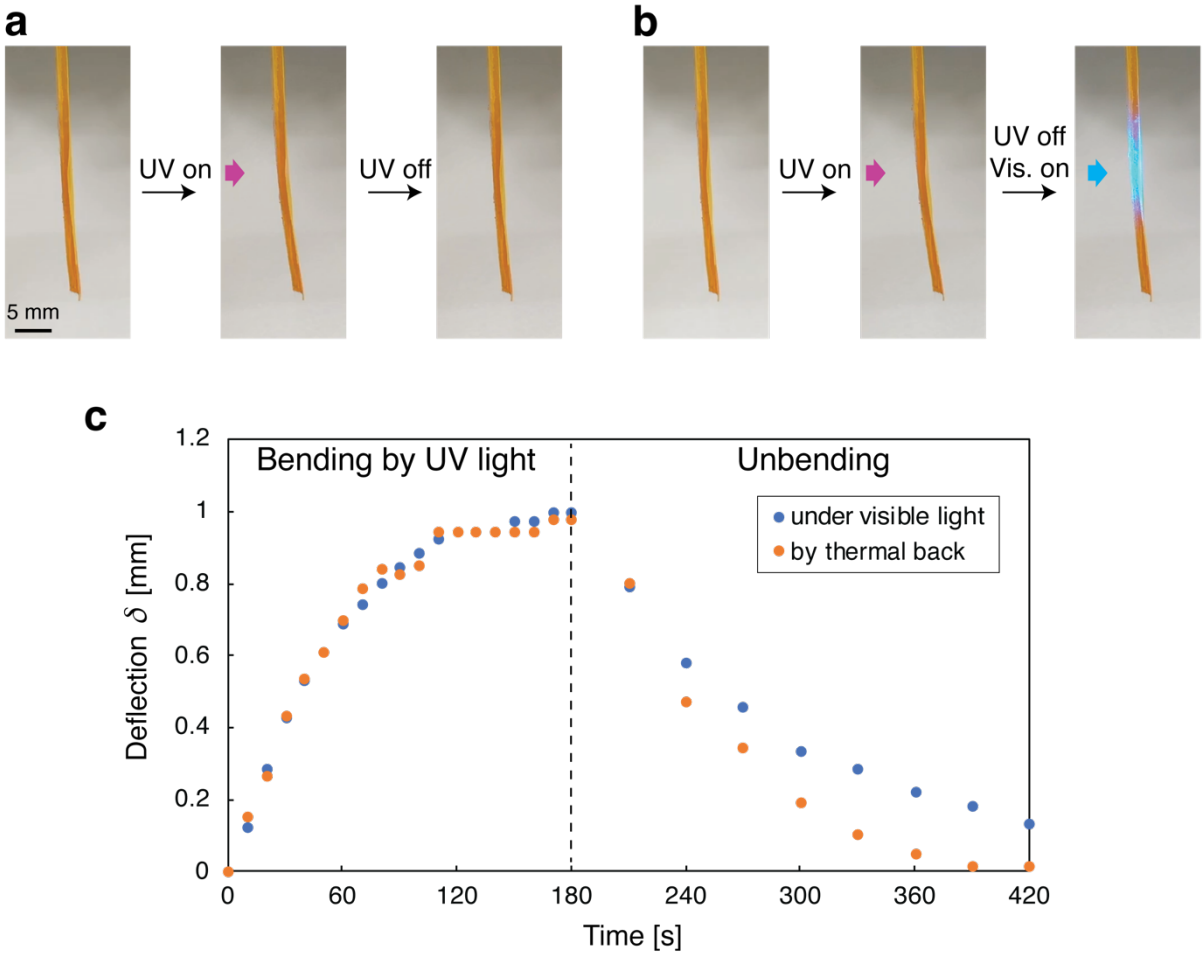
Supplementary Figures



Supplementary Figure 1. Photo-actuation behaviors of a silicone monolayer of 1 wt% homogenously mixed with azobenzene powder. (**a**) Elongation when free to expand. (**b**) Bending when constrained by a paper strip.



Supplementary Figure 2. Surface temperature change upon UV light irradiation. (**a**) Thermograph images of the hybrid silicone of 10 wt% before and under UV light irradiation at 80 mW/cm^2. (**b**) Time dependence of temperature increase of hybrid silicones under the UV light (80 mW/cm^2).



Supplementary Figure 3. Unbending behaviors of the hybrid silicone of 10 wt% by thermal back and visible light irradiation. (**a**) Bending by UV light and unbending by thermal back (just turning off UV light). (**b**) Bending by UV light and unbending under visible light (488 nm, 5 mW/cm^2) irradiation with the removal of UV light. The same condition was applied for UV irradiation (365 nm, 60 mW/cm^2). (**c**) Time dependence of the real tip deflection δ in bending and unbending processes.

Supplementary Tables

Supplementary Table 1. Time dependence of the average of real deflection on three repetitions for photo-bending under light irradiation.

Power (mW/cm^2)	Irradiation time (sec)	Deflection δ (mm)			
		0 wt%	1 wt%	5 wt%	10 wt%
150	0	0.00	0.00	0.00	0.00
	10	0.03	0.10	0.09	0.16
	20	0.05	0.21	0.18	0.29
	30	0.08	0.26	0.25	0.40
	40	0.11	0.32	0.32	0.50
	50	0.14	0.37	0.39	0.59
	60	0.16	0.41	0.45	0.66
	70	0.19	0.43	0.48	0.71
	80	0.20	0.46	0.53	0.76
	90	0.20	0.47	0.56	0.80
	100	0.22	0.50	0.59	0.85
	110	0.23	0.50	0.62	0.89
	120	0.23	0.51	0.64	0.91
	130	0.24	0.51	0.67	0.94
	140	0.24	0.51	0.67	0.95
	150	0.24	0.52	0.67	0.95
	160	0.24	0.53	0.68	0.97
	170	0.24	0.53	0.69	0.97
	180	0.24	0.53	0.70	0.97
300	0	0.00	0.00	0.00	0.00
	10	0.08	0.23	0.22	0.30
	20	0.14	0.39	0.38	0.56
	30	0.21	0.52	0.52	0.79
	40	0.27	0.62	0.66	0.98
	50	0.32	0.73	0.77	1.13
	60	0.35	0.78	0.88	1.25
	70	0.37	0.85	0.95	1.34
	80	0.41	0.89	1.04	1.42
	90	0.44	0.91	1.09	1.49
	100	0.45	0.96	1.14	1.53
	110	0.48	0.97	1.19	1.58
	120	0.48	0.99	1.22	1.63
	130	0.49	1.02	1.25	1.66
	140	0.50	1.03	1.28	1.67
	150	0.51	1.05	1.31	1.67
	160	0.51	1.06	1.33	1.68
	170	0.52	1.08	1.35	1.70
	180	0.52	1.08	1.36	1.72
450	0	0.00	0.00	0.00	0.00
	10	0.13	0.36	0.32	0.46
	20	0.26	0.60	0.57	0.84
	30	0.37	0.81	0.80	1.16
	40	0.45	0.97	0.98	1.41

	50	0.55	1.09	1.16	1.60
	60	0.60	1.19	1.30	1.80
	70	0.67	1.27	1.41	1.93
	80	0.73	1.33	1.48	2.04
	90	0.76	1.39	1.58	2.13
	100	0.81	1.44	1.65	2.19
	110	0.84	1.50	1.71	2.26
	120	0.85	1.54	1.77	2.31
	130	0.86	1.55	1.82	2.32
	140	0.87	1.57	1.86	2.34
	150	0.88	1.59	1.90	2.36
	160	0.88	1.61	1.92	2.38
	170	0.88	1.61	1.94	2.40
	180	0.88	1.61	1.96	2.41
600	0	0.00	0.00	0.00	0.00
	10	0.18	0.42	0.44	0.57
	20	0.34	0.71	0.78	1.05
	30	0.46	0.95	1.05	1.41
	40	0.59	1.14	1.29	1.71
	50	0.68	1.28	1.50	1.92
	60	0.77	1.42	1.68	2.08
	70	0.84	1.53	1.82	2.21
	80	0.90	1.59	1.93	2.31
	90	0.95	1.64	2.03	2.40
	100	1.00	1.69	2.10	2.49
	110	1.02	1.71	2.14	2.52
	120	1.04	1.73	2.19	2.58
	130	1.05	1.76	2.27	2.59
	140	1.05	1.80	2.30	2.61
	150	1.05	1.83	2.32	2.62
	160	1.06	1.83	2.36	2.63
	170	1.07	1.83	2.38	2.64
	180	1.07	1.83	2.40	2.65

Supplementary Table 2. Time dependence of the averages of real deflection on three repetitions for unbending after stopping light irradiation.

Power (mW/cm^2)	Time after stopping light (sec)	Deflection δ / mm			
		0 wt%	1 wt%	5 wt%	10 wt%
150	0	0.24	0.53	0.70	0.97
	30	0.15	0.31	0.49	0.70
	60	0.08	0.18	0.33	0.44
	90	0.03	0.10	0.21	0.29
	120	0.01	0.04	0.12	0.16
	150	0.00	0.02	0.07	0.09
	180	0.00	0.00	0.04	0.03
	210	0.00	0.00	0.02	0.01
	240	0.00	0.00	0.01	0.00
300	0	0.52	1.08	1.36	1.72
	30	0.33	0.60	0.94	1.19
	60	0.17	0.34	0.63	0.79
	90	0.08	0.18	0.42	0.48
	120	0.03	0.11	0.25	0.27
	150	0.00	0.05	0.17	0.15
	180	0.00	0.02	0.08	0.06
	210	0.00	0.00	0.05	0.03
	240	0.00	0.00	0.01	0.00
450	0	0.88	1.61	1.96	2.41
	30	0.52	0.94	1.38	1.72
	60	0.29	0.55	0.92	1.12
	90	0.16	0.33	0.64	0.72
	120	0.07	0.19	0.40	0.44
	150	0.03	0.10	0.24	0.24
	180	0.01	0.06	0.13	0.14
	210	0.00	0.02	0.06	0.06
	240	0.00	0.00	0.02	0.02
600	0	1.07	1.83	2.40	2.65
	30	0.59	1.06	1.73	1.90
	60	0.29	0.59	1.21	1.28
	90	0.12	0.34	0.86	0.84
	120	0.06	0.18	0.59	0.54
	150	0.02	0.09	0.41	0.31
	180	0.00	0.04	0.30	0.17
	210	0.00	0.02	0.18	0.08
	240	0.00	0.00	0.12	0.03