Liquid Crystal-Infused Porous Polymer Surfaces: A "Slippery" Soft Material Platform for the Naked-Eye Detection and Discrimination of Amphiphilic Species

Harshit Agarwal,[1] Kayleigh E. Nyffeler,[2] Uttam Manna,[1,#] Helen E. Blackwell,[2,*] and David M. Lynn[1,2,*]

[1]Dept. of Chemical & Biological Engineering, Univ. of Wisconsin-Madison, 1415 Engineering Dr., Madison, WI 53706 USA; [2]Dept. of Chemistry, Univ. of Wisconsin-Madison, 1101 University Ave., Madison, WI 53706 USA; [#]Current Address: Department of Chemistry, Indian Institute of Technology-Guwahati, Guwahati, Assam-781039, India. E-Mail: (H.E.B.) blackwell@chem.wisc.edu; (D.M.L) dlynn@engr.wisc.edu

SUPPORTING INFORMATION

Table S1. Bacterial strain and *plasmids* used in this study.

	Referred to herein	**Description**	**Reference or Source**
Staphylococcus aureus			
RN6390b	*S. aureus* WT	Wild type, *agr* group I (NTCC8325 cured of prophages[1])	Novick[2]
RN9222	QS mutant	RN6911 with pRN7062	Lyon et al.[3]
RN6911	N/A	*agr*::*tetM,* from RN6390b (agr-null)	Novick et al.[1]
Plasmid			
pRN7062	QS mutant	Contains *agrCA* and *P3-blaZ* fusion	Lyon et al.[3]
Pseudomonas aeruginosa			
PAO1	N/A	Wild type, isolated from wound	Holloway[4]
mPAO1	PAO1, WT	Wild type, derivative of Holloway's isolate	Gift from E.P. Greenberg[5]
PAO1-T	N/A	Wild type, derivative of Holloway's isolate	WT from PA two-allele library[6-7]
PAO-SC4	Δ*lasI*Δ *rhlI*	In-frame deletions of *lasI* and *rhlI*	Gift from E.P. Greenberg[5]
PAO1 Δ*rhlB*	Δ*rhlB*	Unmarked, in-frame *rhlB* deletion	Smalley et al.[8]
PAO1-T Δ*rhlA* (PW6886)	Δ*rhlA*	*rhlA*-E08::IsphoA/hah	PA two-allele library[6-7]

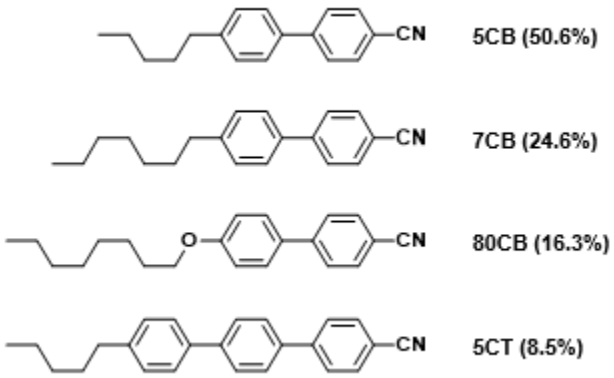

Figure S1. Thermotropic liquid crystal E7 is a proprietary combination of four different liquid crystals - 5CB, 7CB, 80CB, and 5CT.

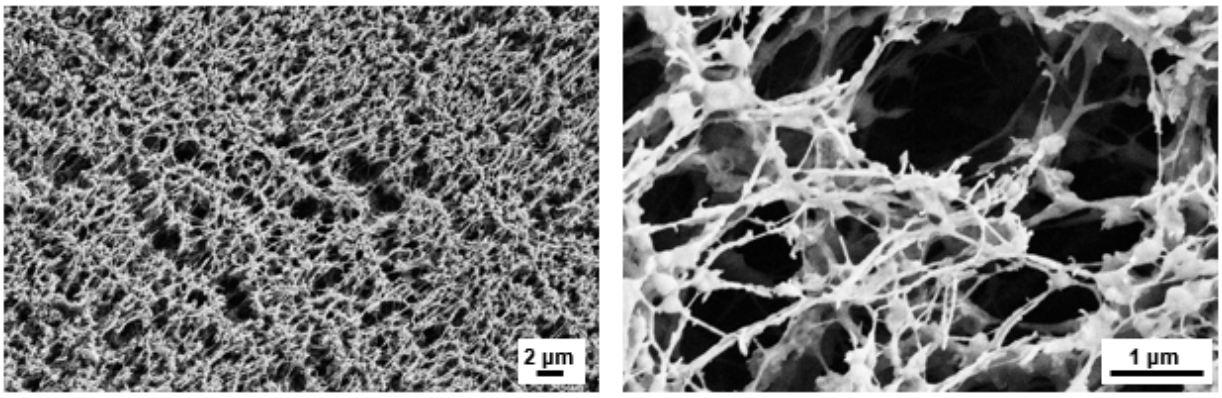

Figure S2. Low and high magnification 'top-down' SEM images of PTFE membrane showing nanoporosity.

Table S2. Evaluation of the stability of 5CB-and E7-SLIPS in presence of water droplets.

Parameters	5CB-SLIPS	E7-SLIPS
$\Theta_{ws(a)}$	114 ± 1	114 ± 1
$\Theta_{os(a)}$	51 ± 3	48 ± 3
γ_{ow}	28.1 ± 0.4	27.5 ± 0.8
γ_{oa}	31.2 ± 0.6	29± 0.5
γ_{wa}	72.1 ± 0.2	72.1 ± 0.2
$S_{os(w)}$	20.8 ± 5.7	21.2 ± 5.8

Note: Unit of contact angle is in degree. The contact angles are measured on a flat smooth PTFE surface using 5 μL water droplet for $\Theta_{ws(a)}$ and 5 μL 5CB and E7 for $\Theta_{os(a)}$. The unit of surface tension and interfacial tension is mN/m. Surface tension (γ_{oa}, γ_{wa}) and interfacial tension (γ_{ow}) measurements were performed by the pendant drop method at ambient conditions (temperature = 22 to 24 °C and relative humidity = 12 to 20 %). Density of water used for measurements was 0.997 gm/ml and density of 5CB and E7 is 1.03 gm/ml. The values denote mean of three independent measurements and error denotes standard deviation. $S_{os(w)} = \gamma_{oa} \cos \Theta_{os(a)} - \gamma_{wa} \cos \Theta_{ws(a)} - \gamma_{ow} \geq 0$ and the units of $S_{os(w)}$ is in mN/m. $\Theta_{os(a)} > 0$ suggests that surface of PTFE membrane can emerge out of the lubricating liquid phase into air.

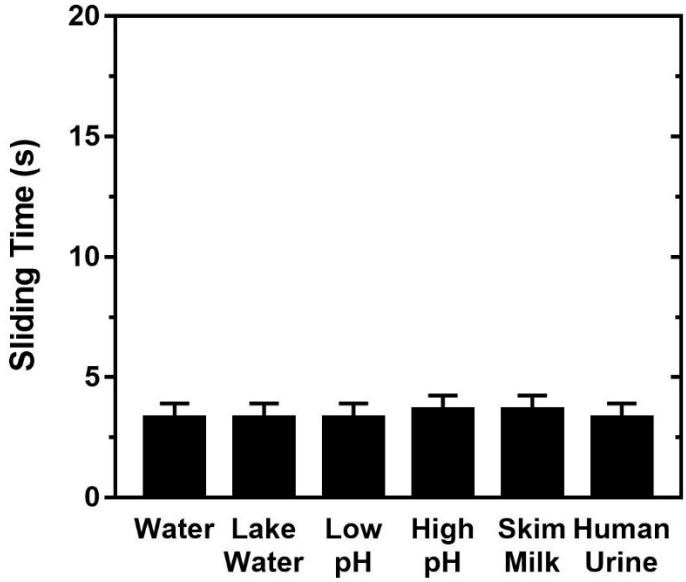

Figure S3. Plot showing sliding time of 50 μL droplets of various liquids (Milli-Q water, unfiltered eutrophic lake water, acidic (pH 1) and alkaline (pH 11) solution, skim milk and pooled human urine) sliding on E7-infused SLIPS tilted at 20°.

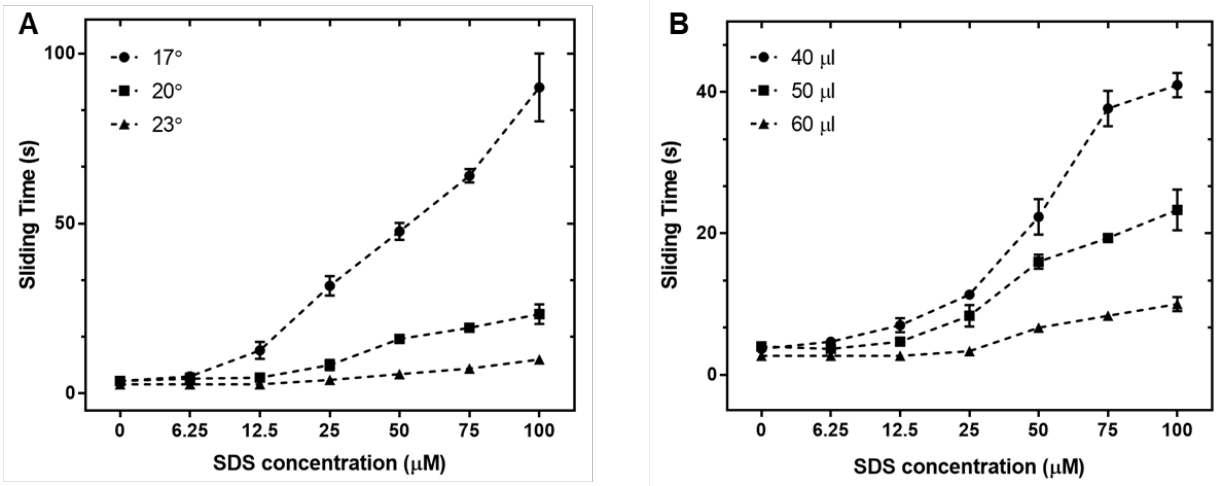

Figure S4. Plot showing the sliding time as a function of the concentration of SDS in PBS droplets for (A) different tilt angles (17°, 20°, and 23°) at a fixed droplet volume (50 μL) and (B) different droplet volumes (40 μL, 50 μL, and 60 μL) at a fixed tilt angle (20°).

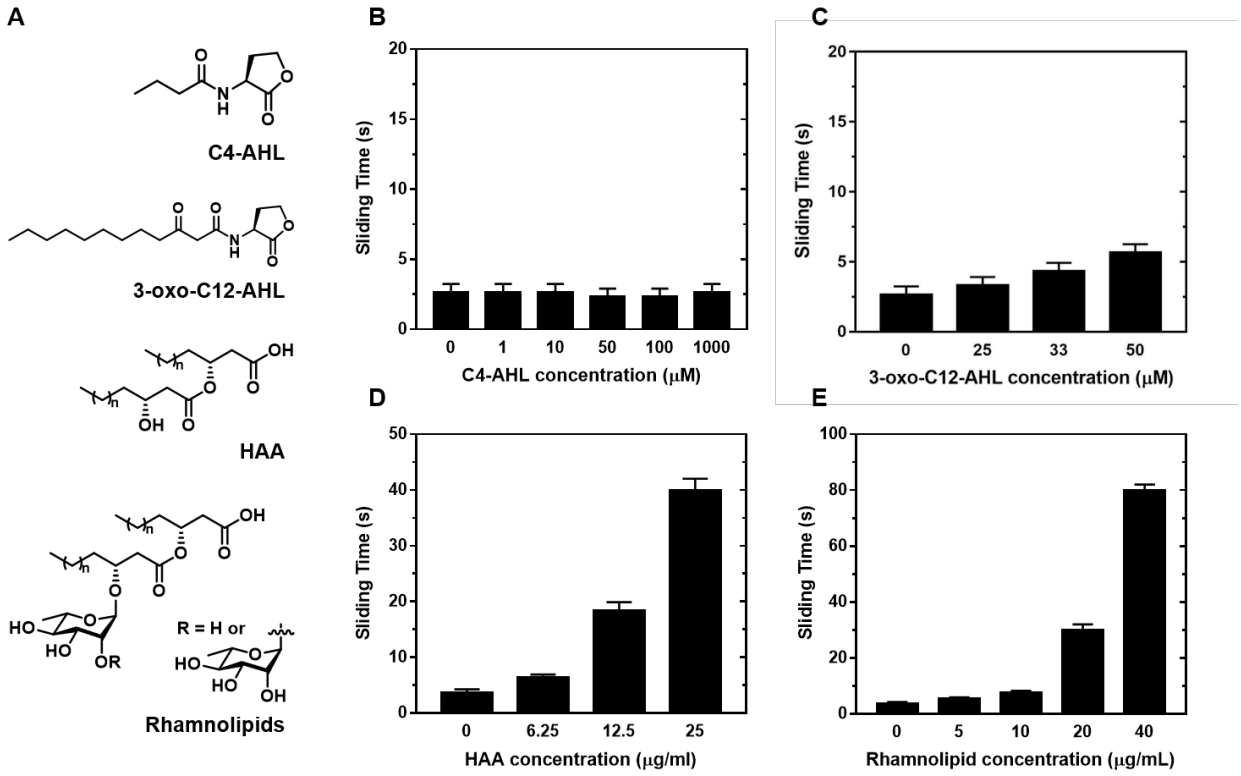

Figure S5. (A) Structures of the AHLs and bacterial biosurfactants investigated in this study (n = 3−11 for rhamnolipid and HAA). HAA was evaluated as a mixture of stereoisomers (see Materials and Methods). (B-F) Plots showing sliding time of droplets of (B) C4-AHL, (C) 3-oxo-C12-AHL, (D) HAA, and (E) rhamnolipids on E7-infused SLIPS. 50 μL droplets of C4-AHL, 3-oxo-C12-AHL and HAA solutions were used for the sliding time measurements and the SLIPS were tilted at angle of 20°. For measuring the sliding time of rhamnolipid solutions 42 μL droplets were used and the SLIPS were inclined to 15°.

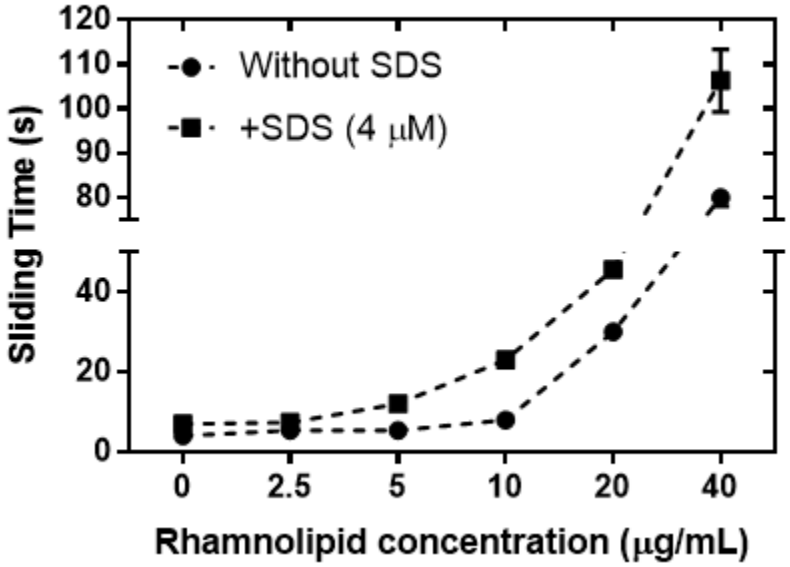

Figure S6. Plot showing the sliding time of rhamnolipid (0- 40 μg/ml) containing droplets on LC-SLIPS with SDS (4 μM; black squares) and without SDS (black circles). 42 μL droplets were used in each case and the SLIPS tilt angle was fixed at 15°.

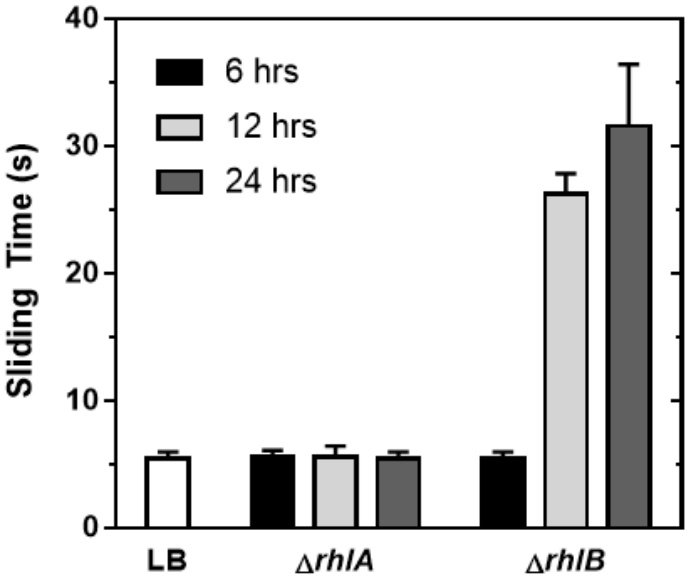

Figure S7. Plot showing the sliding time of LB media, Δ*rhlA*, and Δ*rhlB* at 6 hrs (black), 12 hrs (light gray), and 24 hrs (dark gray). 35 μL droplets were used in each case and the LC-infused SLIPS was tilted to 20°.

Supporting Videos

Video S1. Video showing 50 μL droplets of PBS and PBS droplets containing 100 μM SDS sliding down E7-infused SLIPS tilted at 15°.

Video S2. Video showing 50 μL droplets of PBS (colored green) and PBS droplets containing 100 μM SDS (colored red) sliding down E7-infused SLIPS tilted at 20°.

Video S3. Video showing 35 μL droplets of WT *P. aeruginosa* culture (4x diluted in LB media before measuring the sliding time) (colored blue) and QS-mutant (*ΔrhlI lasI*) (colored orange) sliding on E7-infused SLIPS tilted at 20°. Companion to still images shown in Figure 3C.

Video S4. Video showing 35 μL droplets of *S. aureus* WT (2x diluted in BHI media before measuring the sliding time) (colored blue) and QS mutant (lacking AgrBD, proteins critical for QS) (colored orange) sliding on E7-infused SLIPS tilted at 20°.

Video S5. Video showing 35 μL droplets of *S. aureus* WT cultured with AIP-III D4A (at a concentration of 1 μM) (colored green) and QS mutant (lacking AgrBD, proteins critical for QS) (colored orange) sliding on E7-infused SLIPS tilted at 20°.

References

1. Novick, R. P.; Ross, H. F.; Projan, S. J.; Kornblum, J.; Kreiswirth, B. N.; Moghazeh, S., Synthesis of staphylococcal virulence factors is controlled by a regulator RNA molecule. *EMBO J.* **1993**, *12* (10), 3967-3975.
2. Novick, R. P., Properties of a Cryptic High-Frequency Transducing Phage in *Staphylococcus aureus*. *Virology* **1967**, *33*, 155-166.
3. Lyon, G. J.; Mayville, P.; Muir, T. W.; Novick, R. P., Rational design of a global inhibitor of the virulence response in *Staphylococcus aureus*, based in part on localization of the site of inhibiton to the receptor-histidine kinase, AgrC. *Proc Natl Acad Sci U S A* **2000**, *97* (24), 13330-13335.
4. Holloway, B., Genetic recombination in *Pseudomonas aeruginosa*. *Microbiology* **1955**, *13* (3), 572-581.
5. Ortiz, B. J.; Boursier, M. E.; Barrett, K. L.; Manson, D. E.; Amador-Noguez, D.; Abbott, N. L.; Blackwell, H. E.; Lynn, D. M., Liquid Crystal Emulsions That Intercept and Report on Bacterial Quorum Sensing. *ACS Appl. Mater. Interfaces* **2020**, *12* (26), 29056−29065.
6. Jacobs, M. A.; Alwood, A.; Thaipisuttikul, I.; Spencer, D.; Haugen, E.; Ernst, S.; Will, O.; Kaul, R.; Raymond, C.; Levy, R.; Chun-Rong, L.; Guenthner, D.; Bovee, D.; Olson, M. V.; Manoil, C., Comprehensive transposon mutant library of *Pseudomonas aeruginosa*. *Proc Natl Acad Sci U S A* **2003**, *100* (24), 14339-44.
7. Held, K.; Ramage, E.; Jacobs, M.; Gallagher, L.; Manoil, C., Sequence-verified two-allele transposon mutant library for *Pseudomonas aeruginosa* PAO1. *J. Bacteriol.* **2012**, *194* (23), 6387-9.
8. Smalley, N. E.; An, D.; Parsek, M. R.; Chandler, J. R.; Dandekar, A. A., Quorum Sensing Protects *Pseudomonas aeruginosa* against Cheating by Other Species in a Laboratory Coculture Model. *J. Bacteriol.* **2015**, *197* (19), 3154-9.