SAND2013-10127C

Mechanical Properties of Water-Assembled Graphene Oxide Monolayers: Guiding Controlled Transfer

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Background

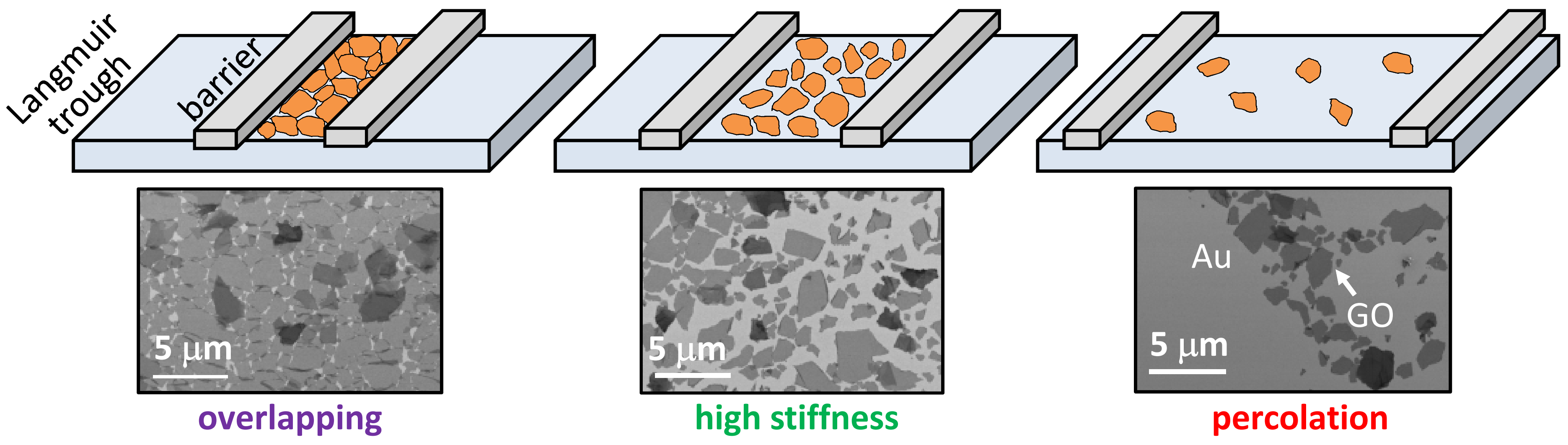
- Graphene oxide (GO) can be assembled on a Langmuir trough by dropping a suspension of sheets on the surface and compressing the monolayer with barriers[1]
- The assemblies can be transferred by Langmuir-Blodgett (L-B) dip coating, but the literature shows that GO transfer is limited to hydrophilic surfaces[1,2,3]

Motivation

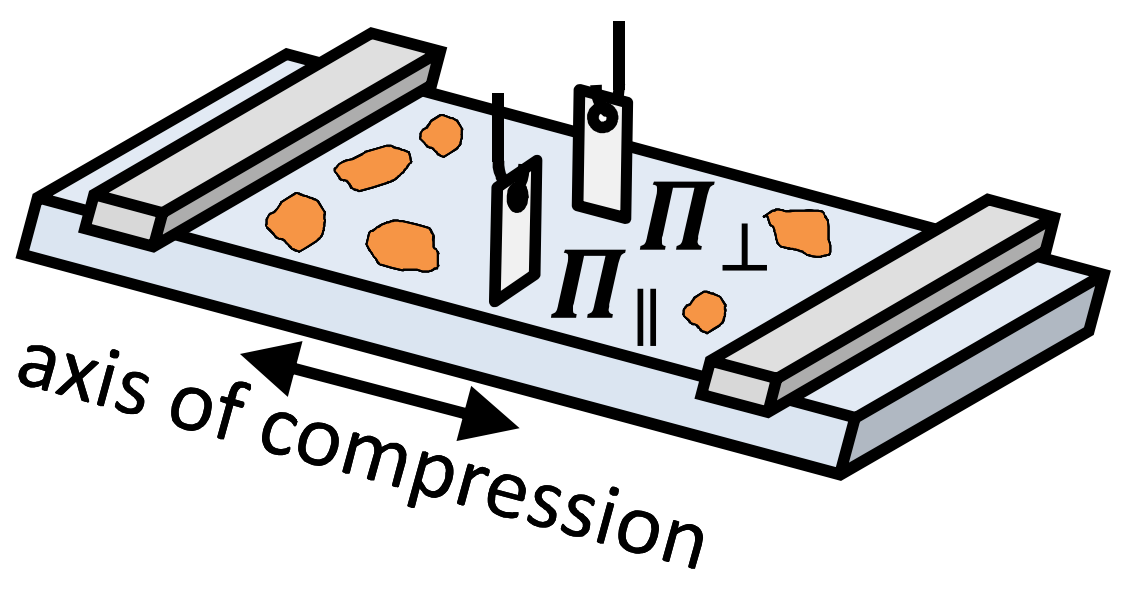
- Graphene-based and other 2D nanomaterials have many potential applications, including electrode materials for energy storage [4,5,6]
- We characterized the mechanical properties of GO and reduced GO (RGO) which we use to guide transfer to both hydrophilic and hydrophobic substrates

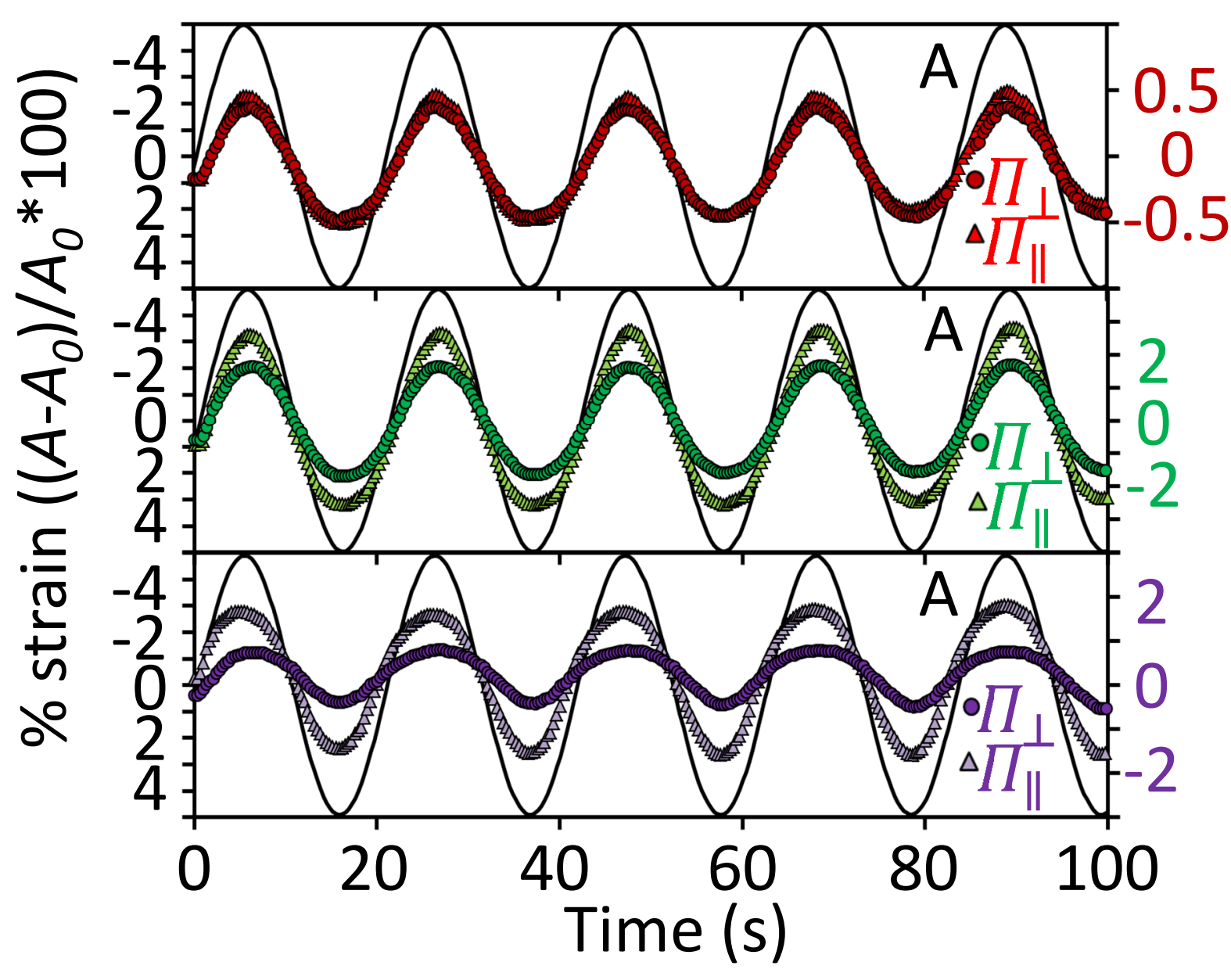
Mechanical Measurements[7] Reveal GO Monolayers Act as Two-Dimensional Solids

GO isotherms exhibit three regimes: overlapping, high stiffness, and percolation

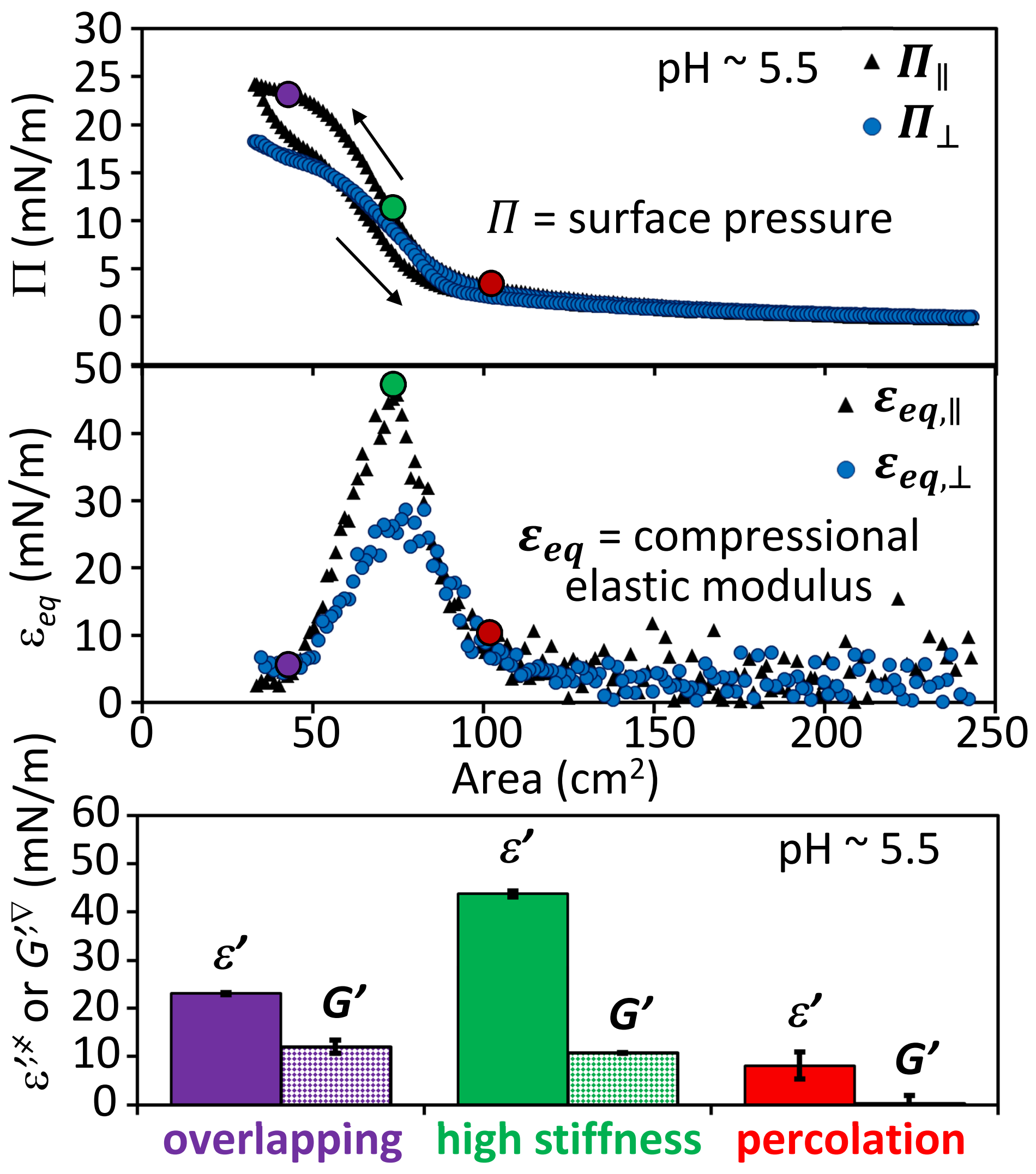


Barriers were oscillated with the Wilhelmy plate ∥ and⊥to the barriers[7]





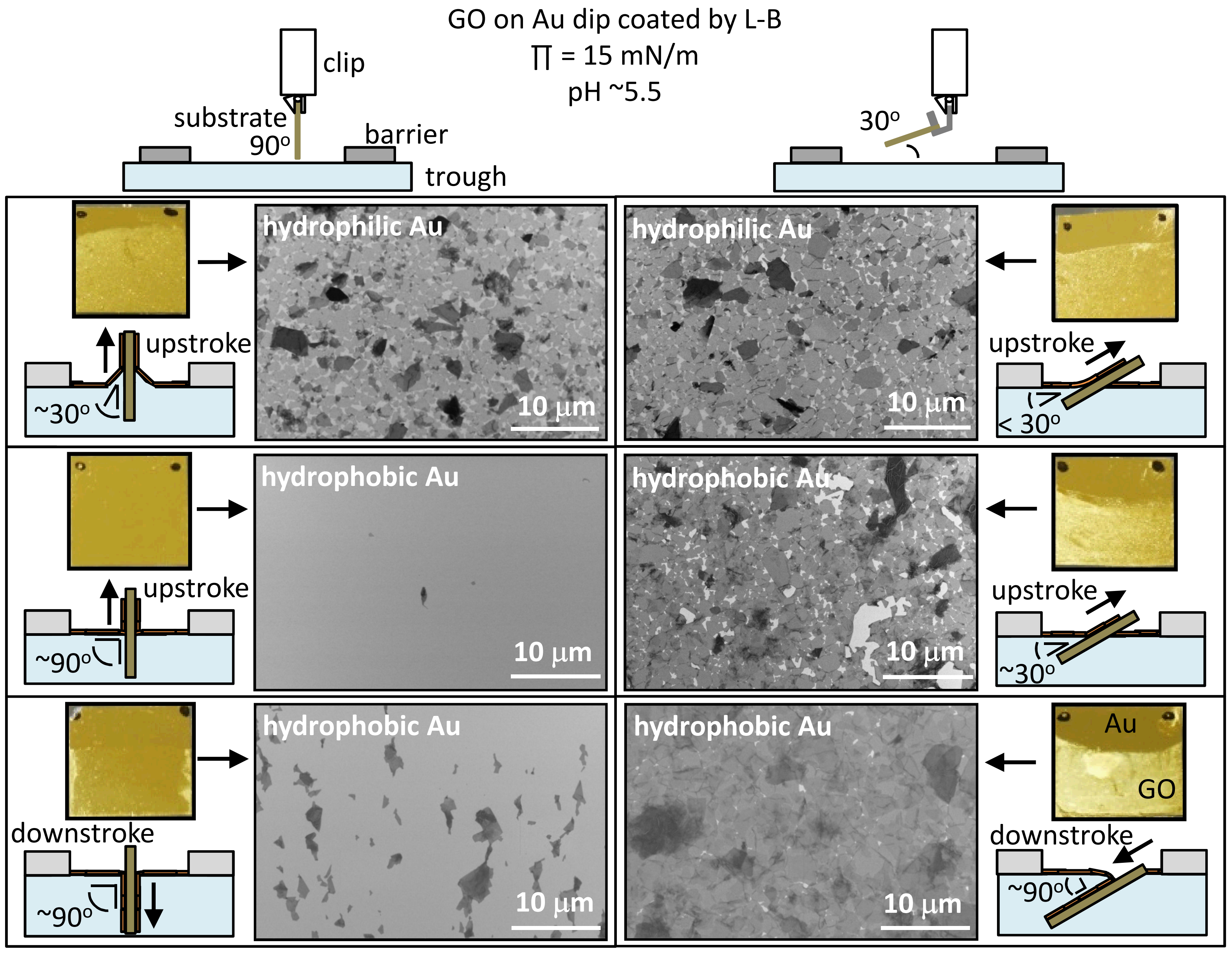
$[\Pi_\parallel > \Pi_\perp]$ = shear modulus (G')



Finite G′ = two-dimensional solid behavior

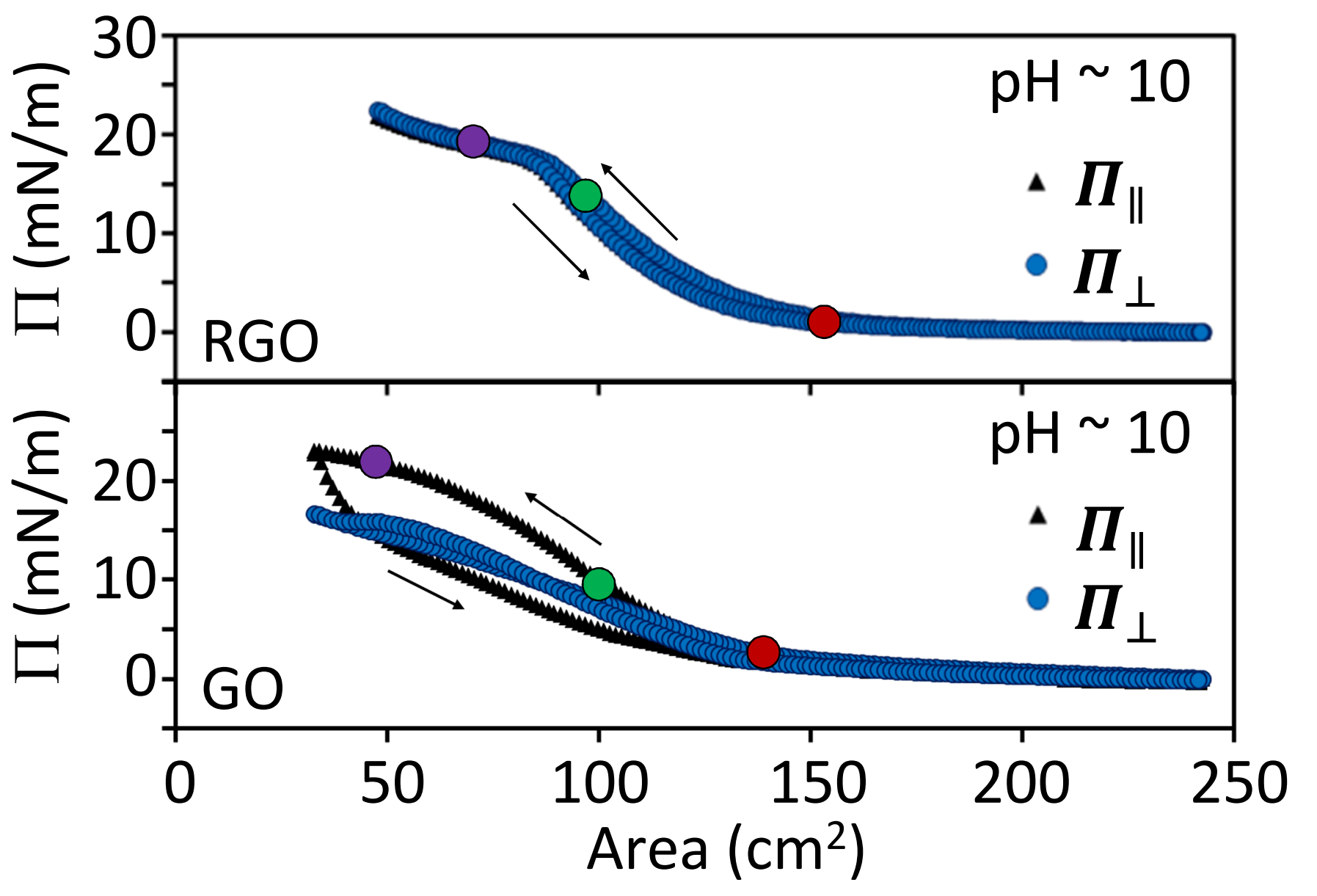
Shallow-Angle Dipping Allows Transfer to Hydrophobic Substrates by Minimizing Stress

Because the GO monolayer behaves as a 2D solid, minimizing stress on the monolayer during transfer should be critical for the 2D solid to remain assembled

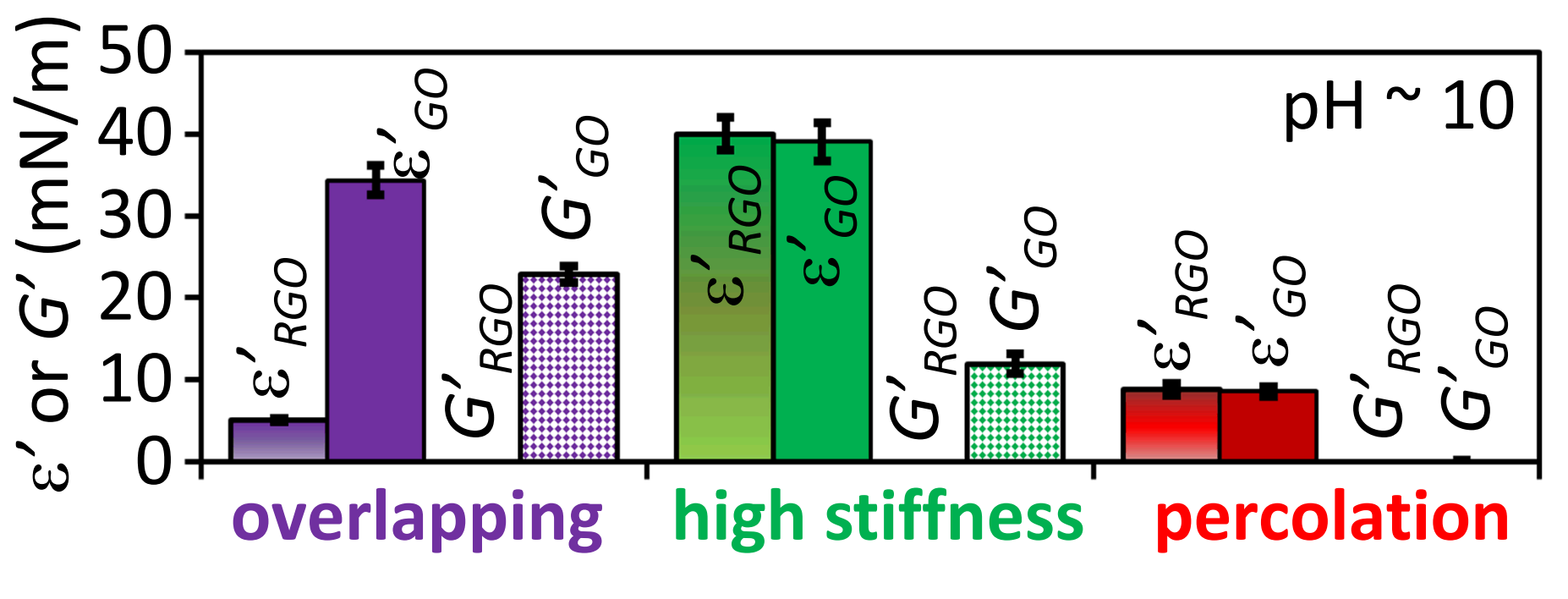


Shallow-angle dipping = the first successful demonstration of GO transfer to hydrophobic substrates!

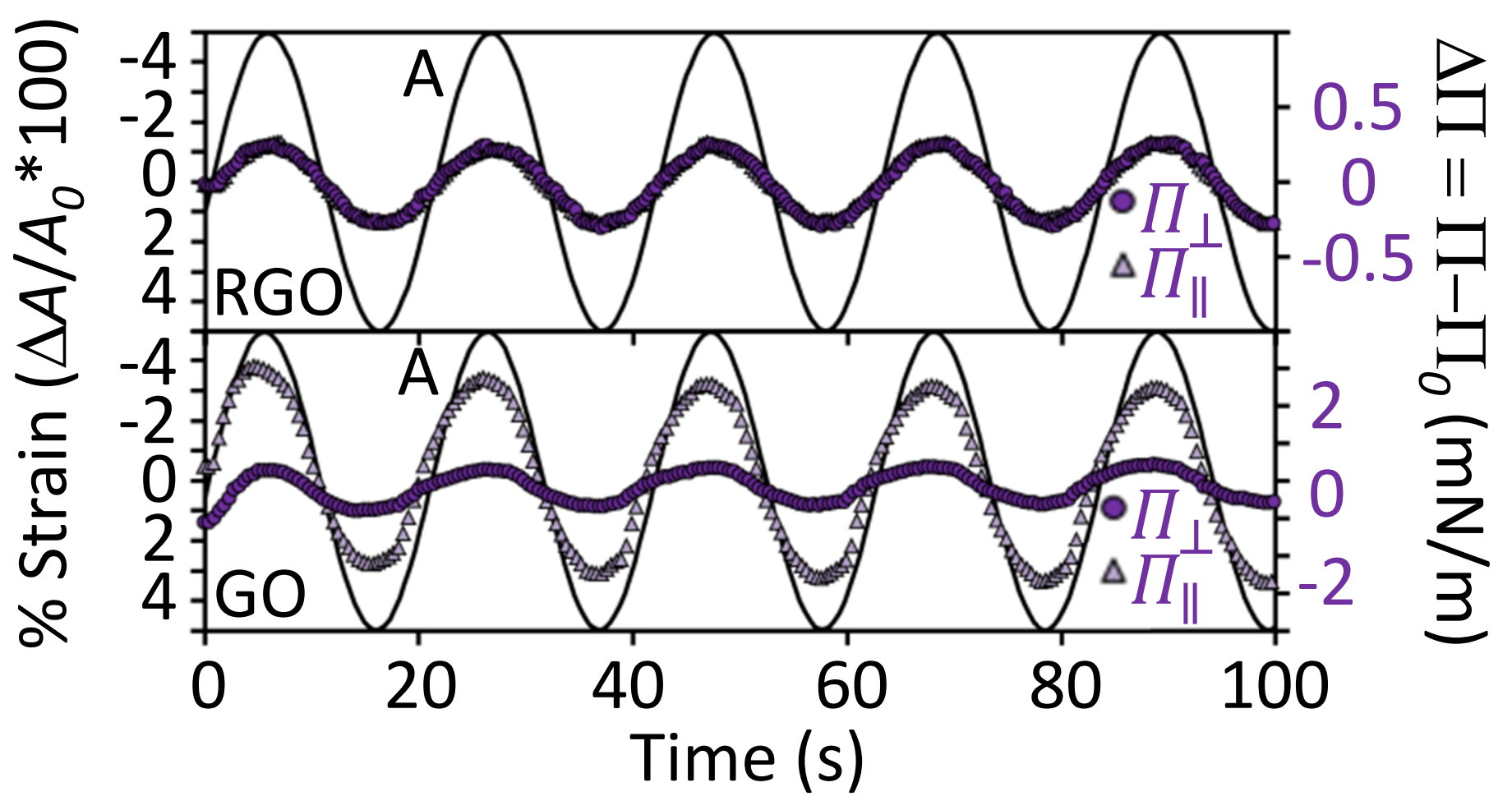
Even with Angled Dipping, Transfer is Poor when Monolayer Exhibits No Shear Modulus



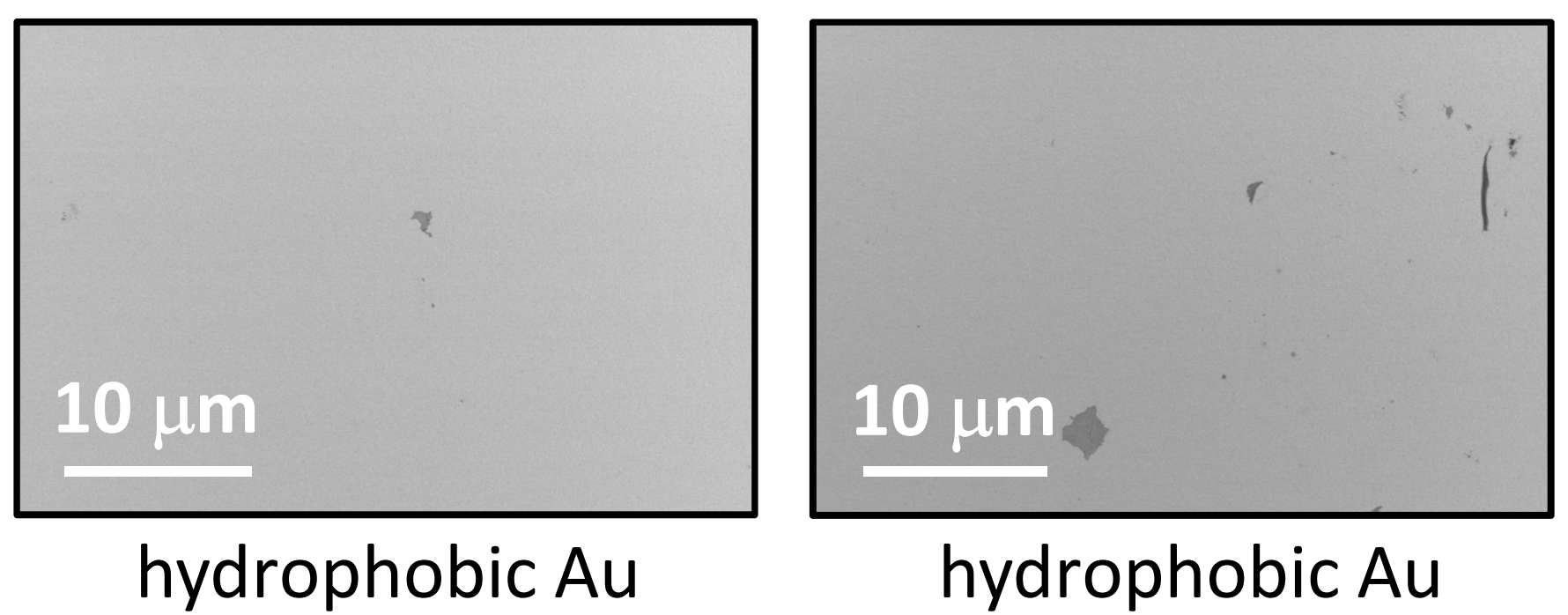
RGO isotherms exhibit three regimes similar to GO



No G′ for RGO = no 2D solid-like behavior



$\Pi_\parallel = \Pi_\perp$ for RGO indicates the absence of a shear modulus in all regimes



hydrophobic Au downstroke, 90°

hydrophobic Au downstroke, 30°

No G′ for RGO = no transfer by L-B even for angled dipping (same results not shown for hydrophilic and hydrophobic upstroke dips)

Conclusions

- GO monolayers exhibit a significant shear modulus, indicating two-dimensional solid-like behavior dominated by strong interactions between GO flake edges
- Continuous monolayers can be transferred to hydrophobic Au surfaces only by using a shallow dipping angle, which minimizes tensile stress on the monolayer
- RGO does not develop a shear modulus and RGO films could not be deposited on hydrophilic or hydrophobic surfaces even with shallow-angle dipping
- Understanding the interplay between film mechanical properties and transfer is essential to utilize liquid-phase transfer of two-dimensional materials
- Our observed correlation between a finite shear modulus and continuous film transfer when dipping at a shallow angle may be widely applicable to 2D materials
- We are currently investigating the correlation between shear modulus and transfer for other 2D materials

References and Footnotes

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$$^{\neq}\ \varepsilon' = \frac{1}{2}A_o\left[\frac{\Delta\Pi_\parallel}{\Delta A}cos(\vartheta_\parallel) + \frac{\Delta\Pi_\perp}{\Delta A}cos(\vartheta_\perp)\right]$$

$$^{\nabla}\ G' = \frac{1}{2}A_o\left[\frac{\Delta\Pi_\parallel}{\Delta A}cos(\vartheta_\parallel) - \frac{\Delta\Pi_\perp}{\Delta A}cos(\vartheta_\perp)\right]$$

ϑ = phase

Acknowledgements

- Supported as part of the Joint Center for Energy Storage Research, an Energy Innovation Hub funded by the U.S. Department of Energy, Office of Science
- Sandia is a multiprogram laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Company, for the U.S. DOE's NNSA under contract DE-AC04-94AL850003
- T. Lambert and D. Davis for providing the graphene oxide material used in this work; R. Grant for producing the SEM images; C. Sanchez and A. Hamilton prepared the gold substrates; T. Beechem, C. Brooks, A. Grillet, D. Wheeler, and S. Brozik, are acknowledged for helpful discussions