ACT 1.
Hierarchical Structures for Water Management

Co-Leaders


Shu Yang (Penn)


Robert Riggleman (Penn)


Michel Langlet (GIANT)

Penn


Randall Kamien


Daeyeon Lee


Kathleen Stebe


Arjun Yodh

GIANT


David Riassetto


Céline Ternon

CNRS/Solvay


Remi Dreyfus

PhD Students: Neha Manohar and David Ring (Penn)

December 7, 2015

Water Problems in Arid Regions

Namib desert: precipitation only 2-200 mm/year

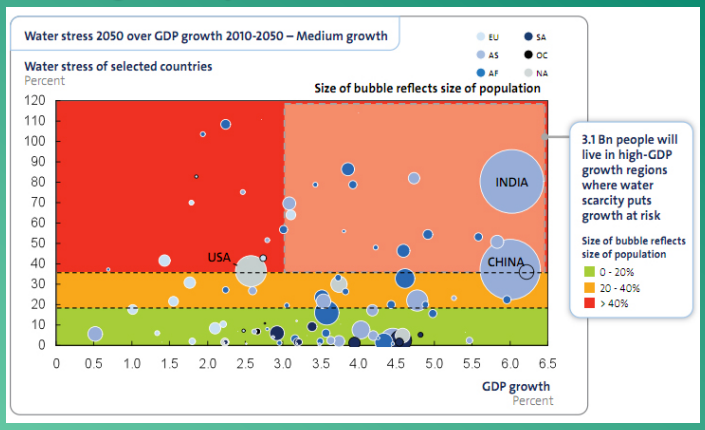
"In Peru water is a high price for Lima's poor",
-- John Mervin New York business editor, BBC News

Lima, Peru:

- High humidity, but no rain fall (1.5 cm/year)
- 70% population lives on the arid Pacific coast where <2% of the water resources are located
- > 1 million people are not connected to the city's water utility network
- ~ $25/month to a family
- Delivered by truck to a plastic tank everyday

Water Problem is a Global Crisis

Over 5 billion people expected to be in high water stress regions by 2050



"Finding the Blue Path to a Sustainable Economy" White paper by Veolia Water (2011).

Global Collaborative Efforts

Penn — University of Pennsylvania

GIANT — Innovation Campus

ACT 1 **ACT 2** **ACT 3**

Our technological goal is to create coatings that will

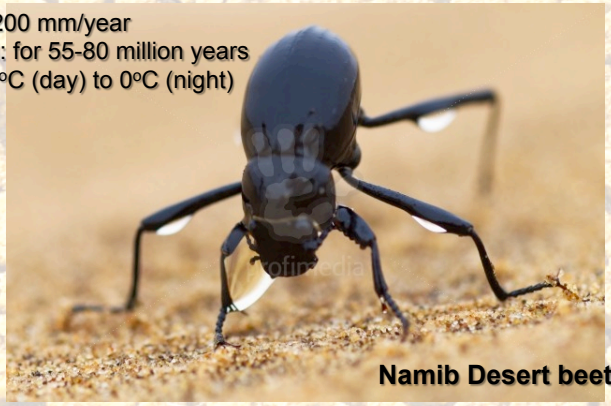
- **Capture water via condensation or trapping of droplets**
- **Divert, recover, and purity water via filtration or anti-fouling**

fundamental questions associated with wetting and energy flow for water on complex substrates

Collaborations between Penn and GIANT researchers to exploit unique capabilities

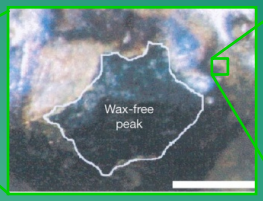
Collecting Water in the Desert: Digging Cues from Nature

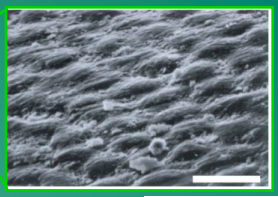
Precipitation: 2-200 mm/year
Arid or semi-arid: for 55-80 million years
Temperature: 45°C (day) to 0°C (night)



Namib Desert beetle

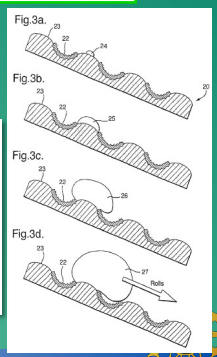
Collecting Water in the Desert: Digging Cues from Nature





A.R. Parker *et al. Nature* 2001 414, 33

Beetle scale: hydrophilic patches surrounded by hydrophobic regions on a topographic surface



Ju, J. *et al. Nat Comm* 2012

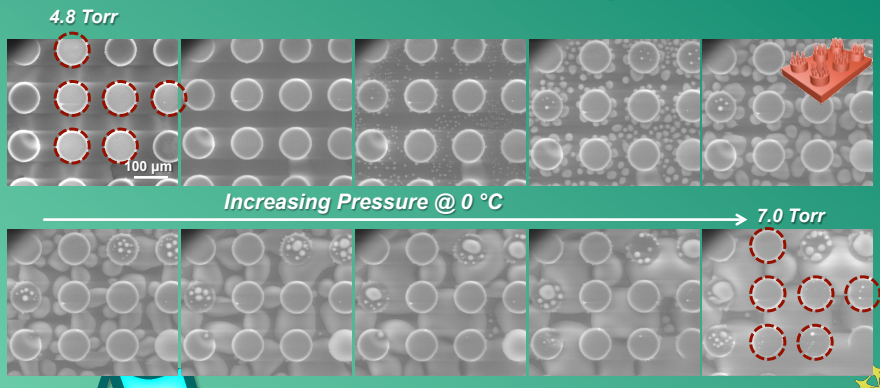
December 7, 2015

Questions We Aim to Address

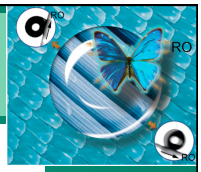
- What are optimal sites for water collection and drop growth?
- What feature geometries best steer droplets to locations for collection?
- While many wetting studies consider capillary phenomena based on equilibrium wetting states and uniform surface tensions and energies for water transportation, kinetic and non-equilibrium behaviors play important roles.
- Can we create pinning sites for water collection, but overcome that pinning for water flow?
- Can we exploit evaporation gradients and the associated surface tension/energy gradients to drive drop motion?
- How robust are the tailored surfaces?
- Can we scalable manufacture the coatings at a low cost?

Localize Water Droplet Nucleation & Growth on Hierarchical but Chemically Homogeneous Surfaces

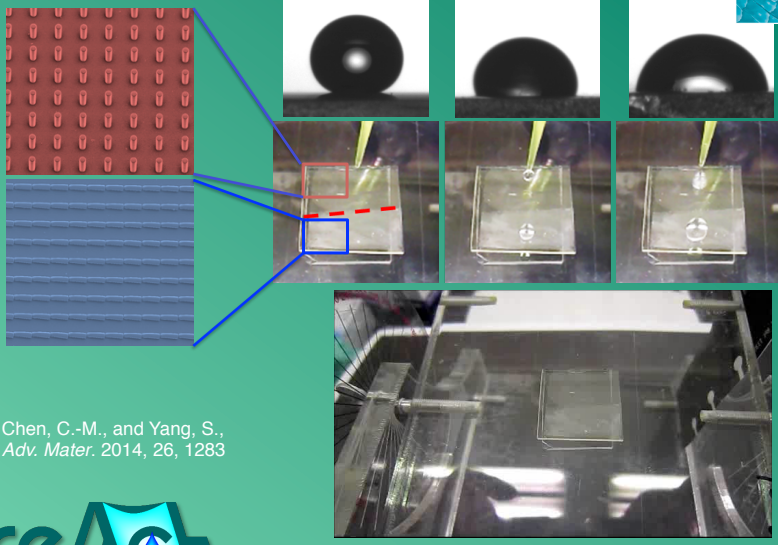
Cho, Shim, Yang, Adv. Mater. 2016



Directing Water Shedding via Structural Anisotropy



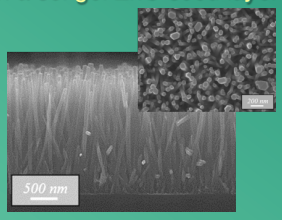
Xia, F.; Jiang, L. Adv. Mater. 2008, 20, 2842



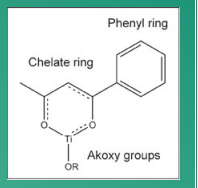
Chen, C.-M., and Yang, S., *Adv. Mater.* 2014, 26, 1283

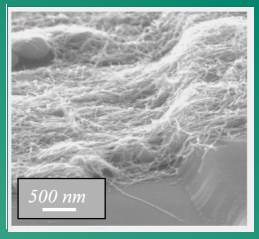
Photocatalytic Nanoparticle/Nanowires for Controlled Wetting and Anti-fouling

ZnO nanowires hydrothermally grown on a sol-gel ZnO seed layer

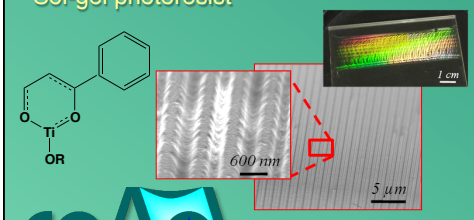


Flexible ZnO nanonet

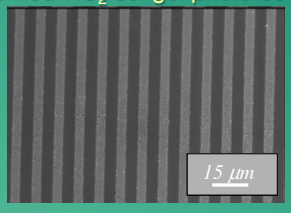




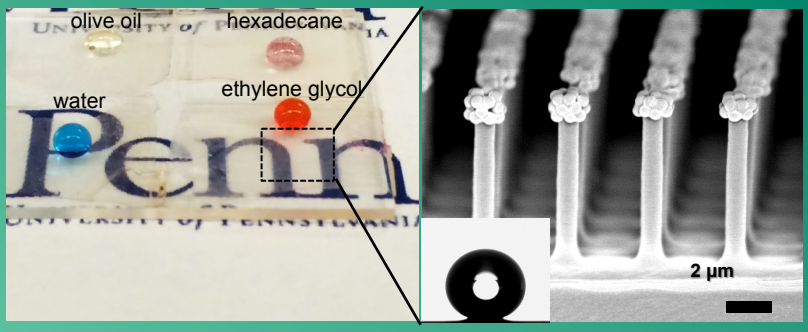
Sol-gel photoresist



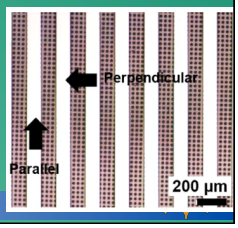
Ag° nanoparticles *in situ* grown on a patterned TiO_2 sol-gel photoresit



Transparent, Superamphiphobic Surfaces from Mushroom-like Micropillar Arrays



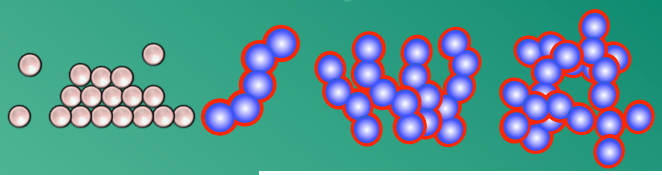
Lee, S. Y.; Rahmawan, Y.; and Yang, S., *ACS Appl. Mater. Interfaces.*, 2015, 7, 24197

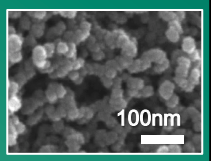


reAct

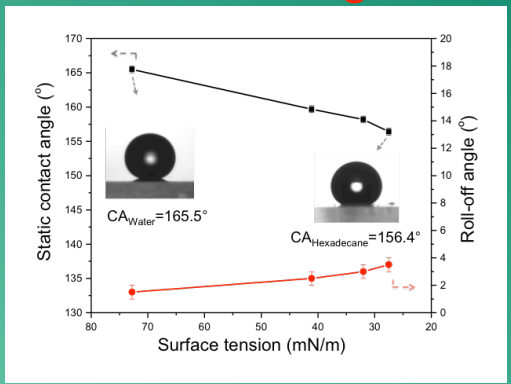
December 7, 2015

Superamphiphobic Coatings from Chained Nanoparticle Assemblies





Ge, D., Yang, L., Zhang, Y., Rahmawan, Y. and Yang, S. *Part. & Part. Sys. Charact.*, 2014

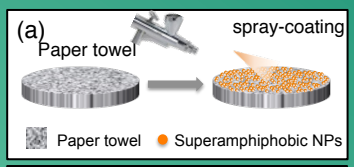


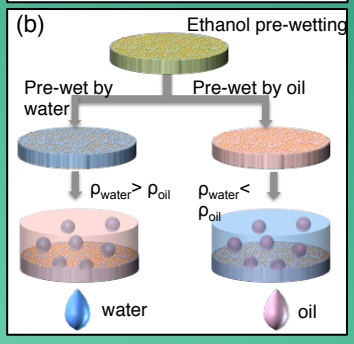
reAct

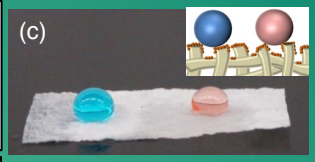
December 7, 2015

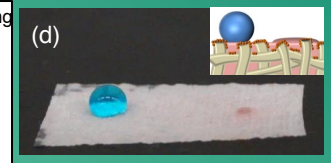
NSF

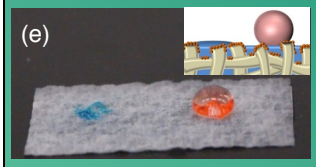
Gravity-driven, Cost-effective Membranes from Chained Nanoparticle Assemblies





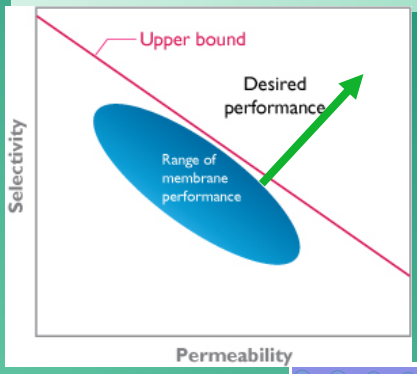




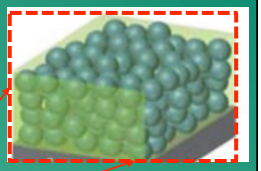


Ge, D., Yang, L., Wang, C., Lee, E. and Yang, S, *Chem Commun.* 2015

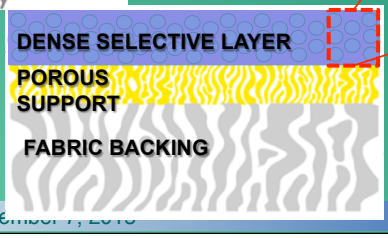
Nanocomposite Membranes (NCOMs) Offer Promises for Water Treatment



Trade-off between SELECTIVITY and PERMEABILITY

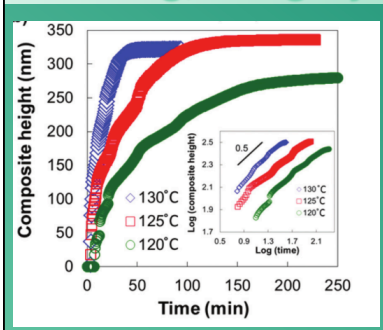


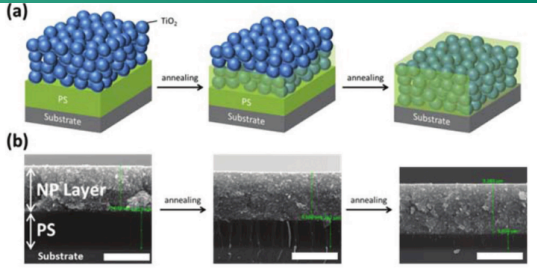
NCOMs



Difficulty in large-scale fabrication

Capillary Rise Infiltration (CaRI) – no physical mixing, a highly scalable bilayer approach





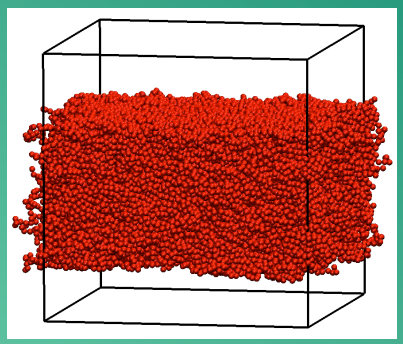
possible Lucas-Washburn dynamics

$$h^2 = \frac{\sigma R \cos\theta}{4\tau^2 \mu} t$$

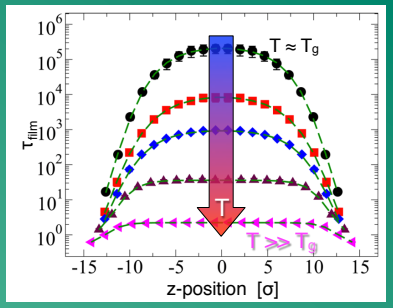
Huang, Y.-R. *et al. Nanoscale* 2015, 7, 798

- CaRI potentially provides a cheap, scalable method to make nanocomposite materials
- Nanocomposites can have improved selectivity, permeability for purification applications

Mobility at Polymer Surfaces



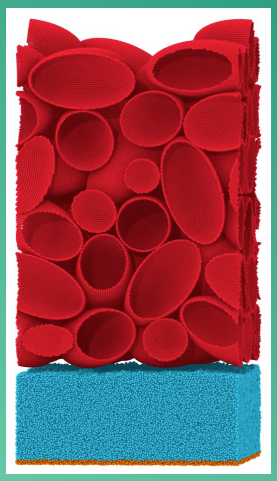
Coarse-grained polymer model

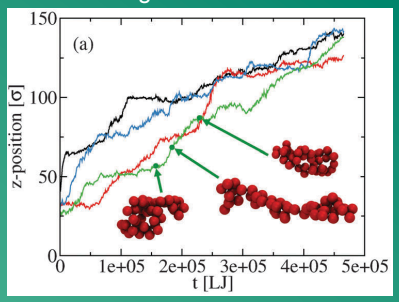


- Polymer glasses have enhanced mobility near free surfaces
- Mobile layer is soft, even far below T_g

Molecular Dynamics of CaRI: Polymer Chain Length Dependence

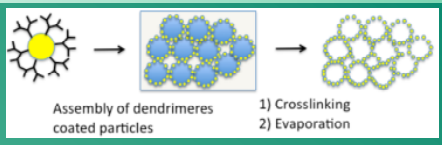
Assuming polymers are unentangled



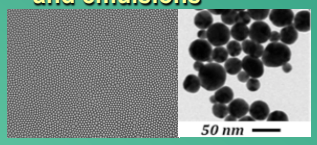


- Simulations provide a molecular view of CaRI process
- Polymer chain infiltration occurs through "stretch and hop" mechanism between cavities (green line)
- Overall, the dynamics appears to follow Lucas-Washburn behavior

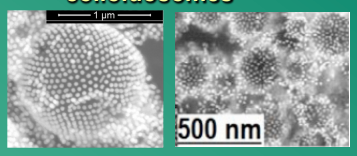
Shaping Membranes for Portable Water Purification



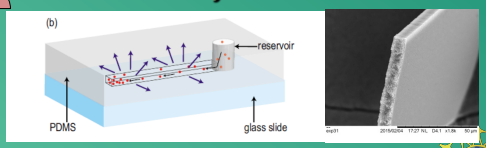
Controlled synthesis of NP and emulsions



Controlled synthesis of colloidosomes



Assembly of membranes



Performance testing; interface of Act 1 and Act 2