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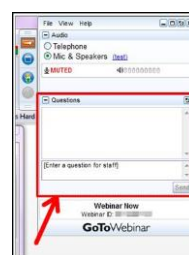


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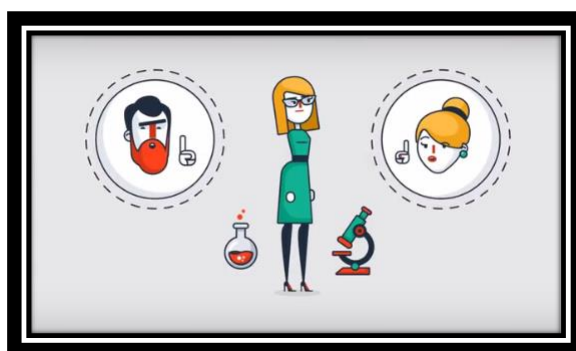


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Thursday, October 12, 2017



Metacommunication: Conveying Passion and Engaging Others

Matt Grandbois, Strategic Market Manager, Dow Chemical Company

Patricia Simpson, Director of Academic Advising and Career Services for the School of Chemical Sciences, University of Illinois

Thursday, October 19, 2017



Avoiding the Next Chemical Catastrophe: Strategies for Chemical Threat Reduction

Andrew Nelson, Postdoctoral Appointee, International Biological and Chemical Threat Reduction Program, Sandia National Laboratories

Ralph Stuart, Chemical Hygiene Officer, Keene State College and Chair, Safety Advisory Panel, ACS Committee on Chemical Safety

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Free Nano Day Events, Activities, and Resources!



Celebrate Nano Day with ACS!

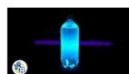
October 9 is National Nanotechnology Day in honor of the nanometer scale, 10^{-9} meters. Nano Day is a joint project of the [National Nanotechnology Coordination Office](#), scientific societies, and other organizations across the country. The goal of Nano Day is to raise awareness of nanotechnology, how it is currently used in products that enrich our daily lives, and the challenges and opportunities it holds for the future.

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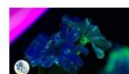
Videos



The World's Smallest Robots: Rise of the Nanomachines



Fluorescence is Awesome (Here is How It Works)



How To Grow Fluorescent Flowers

Podcasts



World's Tiniest 'Monster Truck' Reveals Surprising Discovery



A New Way to Diagnose Prenatal Conditions



Fighting Back Against Cancer



Up-to-the-minute news about nanoscience and nanotechnology, brought to you by our weekly magazine *Chemical & Engineering News (C&EN)*.

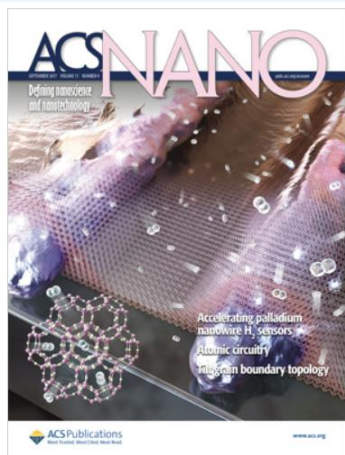
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 Editor-in-Chief:
Paul S. Weiss

 September 26, 2017
Volume 11, Issue 9
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Fan of the Week
 Dr. Rob Meagley, Chief Scientist & Co-founder, nR, LLC and Founder, ONE nanotechnologies, LLC


JAMES M. TOUR
James is a synthetic organic chemist with over 600 research publications and over 130 patents. He was named among "The 50 Most Influential Scientists in the World Today" by The Scientist in 2014.
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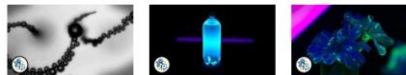


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A New Way to Diagnose Prenatal Conditions

Fighting Back Against Cancer



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"Nano 2.0: Multi-scale Nanomaterials" In Celebration of National Nanotechnology Day!



Teri W. Odom

Charles E. and Emma H. Morrison Professor and Associate Director of the International Institute of Nanotechnology, Northwestern University and Executive Editor, *ACS Photonics*



Laura Fernandez

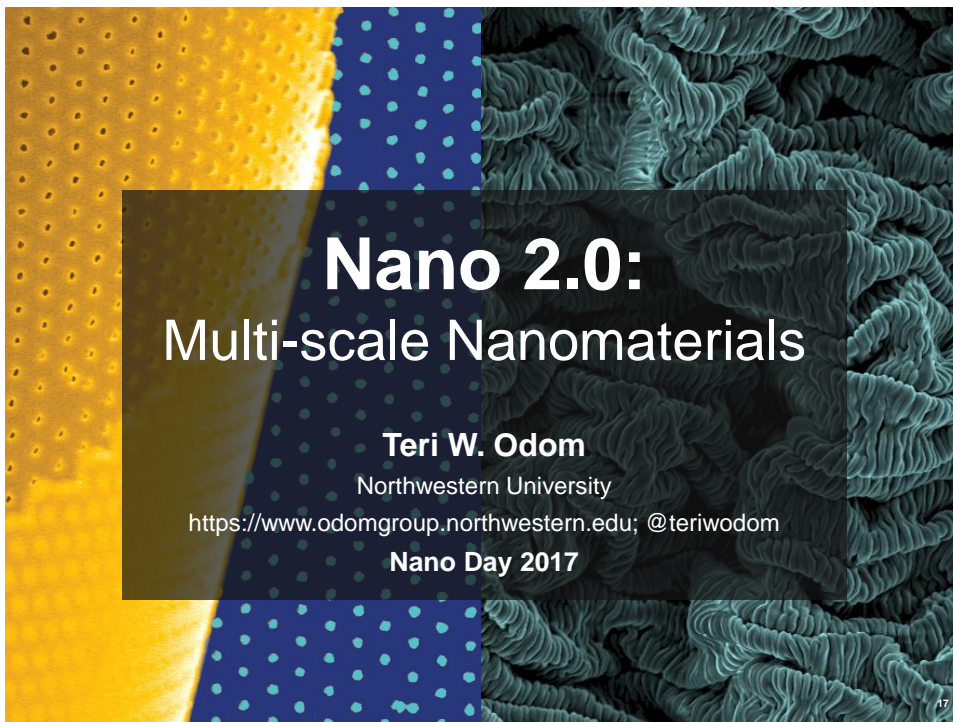
Managing Editor, *ACS Nano* and *Nano Letters*

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Nano 2.0: Multi-scale Nanomaterials

Teri W. Odom
Northwestern University
<https://www.odomgroup.northwestern.edu>; @teriwodom
Nano Day 2017

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Nano 2.0

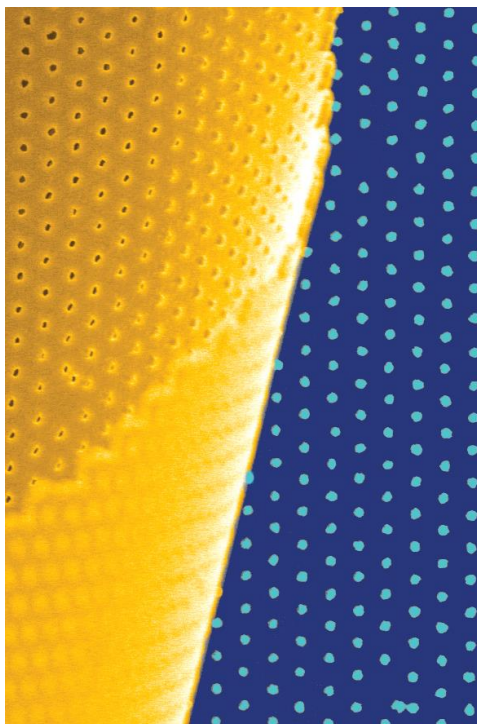


Connect to macroscale world


- Preserve nanoscale property
- Amplify nanoscale characteristic
- Integrate into super-structures
- Independent control over multiple length scales
- General design rules

Hard materials **Soft materials**

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Multi-scale Plasmonic Nanomaterials



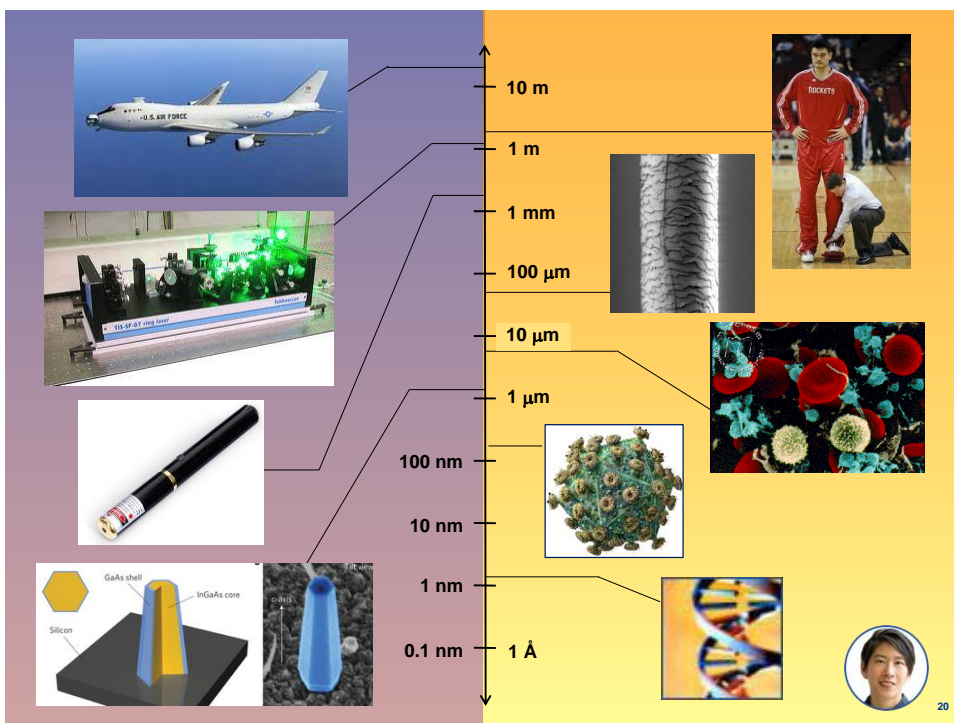
Metals

Periodicity

Multiple length scales

Lasing

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10 m

1 m

1 mm

100 μm

10 μm

1 μm

100 nm

10 nm

1 nm

0.1 nm

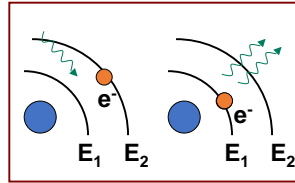
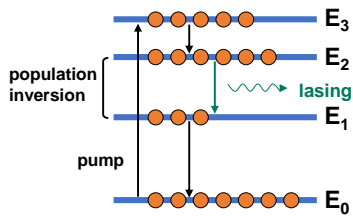
1 \AA

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Reminder: Two Aspects of a Laser

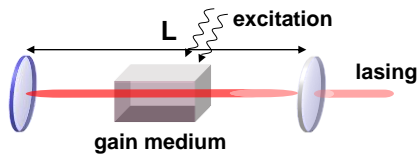


• Gain Medium: population inversion



Stimulated emission • Amplification
• Coherence

• Resonator or Cavity: feedback



Resonance condition:

$$\lambda = \frac{2nL}{q}, q = 1, 2, 3$$

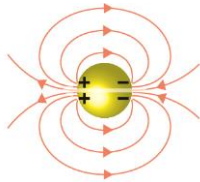
Smallest resonator size: $\approx \left(\frac{\lambda}{2n}\right)^3$

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Plasmonic Lasers and Nanocavities

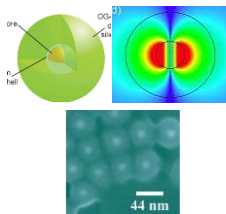


Plasmonic nanocavity



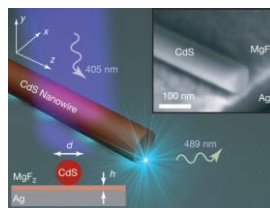
Nano-localized, ultrafast, coherent light sources

Core-shell NP



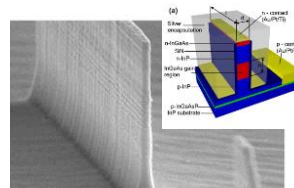
Nature 460, 1110 (2009)

1D metal-dielectric waveguide



Nature 461, 629 (2009)

M-I-M waveguide

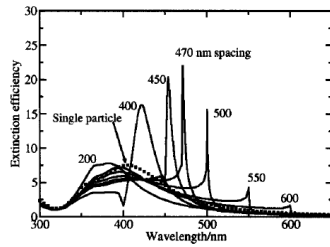


Opt. Express 17, 11107 (2009)

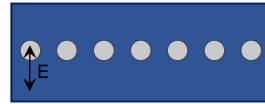
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Single vs. Nanoparticle Arrays

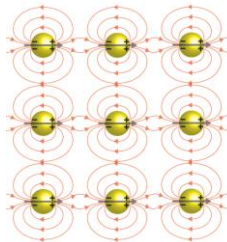


Plasmonics: High-field enhancements
Photonics: High-quality resonances



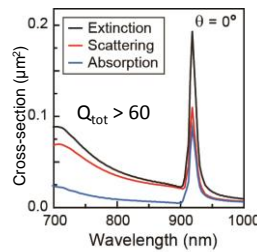
G.C. Schatz, et al. *J. Chem. Phys.* 120, 10871 (2004)

Nanoparticle array



Strong dipolar interactions

- ➔
- Enhanced local fields
- Reduced radiative loss
- Slowed depletion of plasmon energy

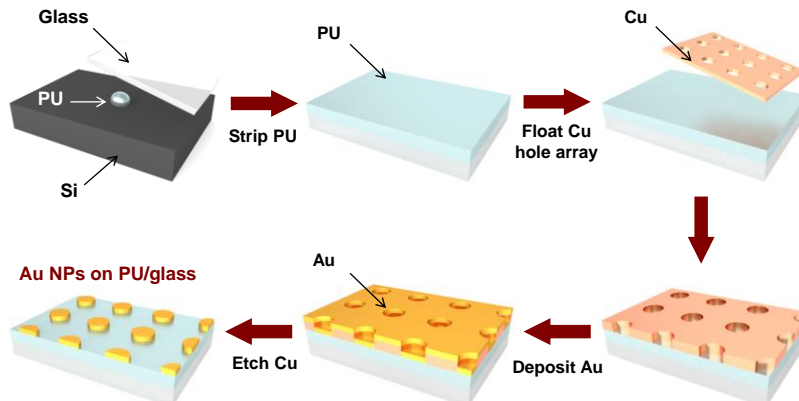


W. Zhou and T.W. Odom, *Nature Nanotech.* 6, 423 (2011)

W. Zhou, Y. Hua, M.D. Huntington, and T.W. Odom, *J. Phys. Chem. Lett.* 3, 1229 (2012)

See also: W. Barnes, J. Gomez Rivas, A. Grigorenko, P. Torma...²³

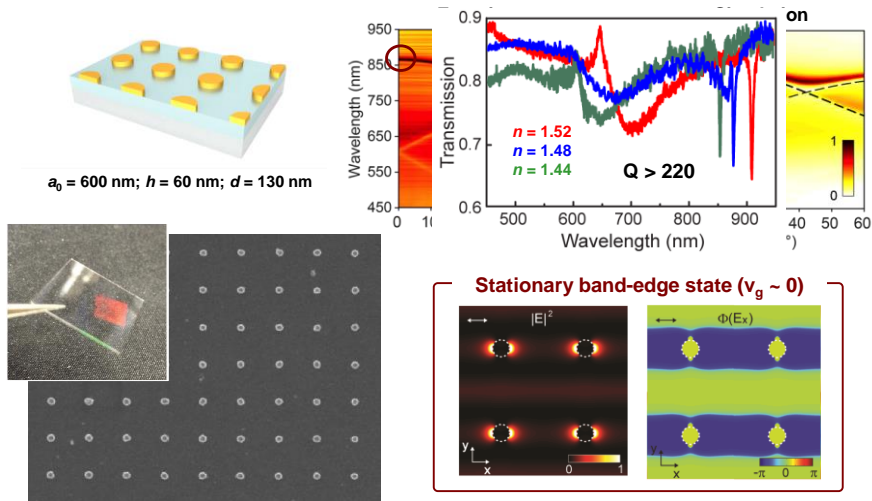
Fabrication of Nanoparticle Arrays on Different Substrates



H. Gao, J. Henzie, and T.W. Odom, *Nano Lett* 6, 2104 (2006)
 J. Henzie, M.H. Lee, and T.W. Odom, *Nature Nanotech.* 2, 549 (2007)

A. Yang, T. B. Hoang, M. Dridi, C. Deeb, M. H. Mikkelsen G.C. Schatz, T.W. Odom, *Nature Communications* 6, 6939 (2015)

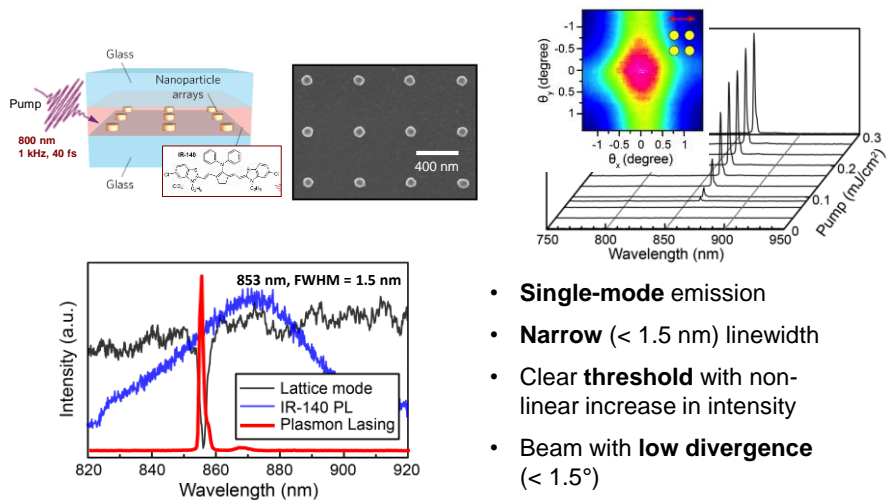
Band-edge Optical Modes as Cavities in the Visible



W. Zhou, M. Dridi, J.Y. Suh, C.H. Kim, D.T. Co, M.R. Wasielewski, G.C. Schatz, and T.W. Odom, *Nature Nanotech.* 8, 506 (2013)
 A. Yang, T. B. Hoang, M. Dridi, C. Deeb, M. H. Mikkelsen G.C. Schatz, T.W. Odom, *Nature Communications* 6, 6939 (2015)

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Lattice Plasmon Nanolasers

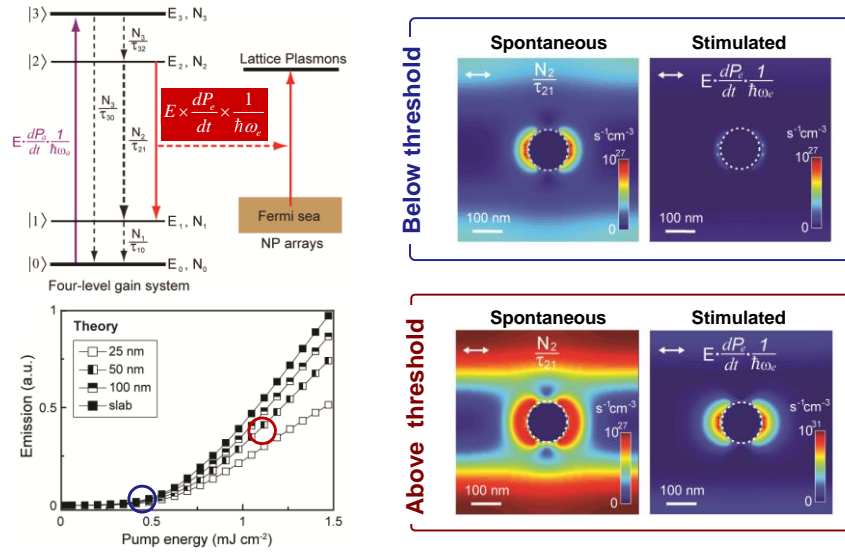


- **Single-mode** emission
- **Narrow** (< 1.5 nm) linewidth
- Clear **threshold** with non-linear increase in intensity
- Beam with **low divergence** (< 1.5°)
- Mechanism?

W. Zhou, M. Dridi, J.Y. Suh, C.H. Kim, D.T. Co, M.R. Wasielewski, G.C. Schatz, and T.W. Odom, *Nature Nanotech.* 8, 506 (2013)
 A. Yang, T. B. Hoang, M. Dridi, C. Deeb, M. H. Mikkelsen G.C. Schatz, T.W. Odom, *Nature Communications* 6, 6939 (2015)

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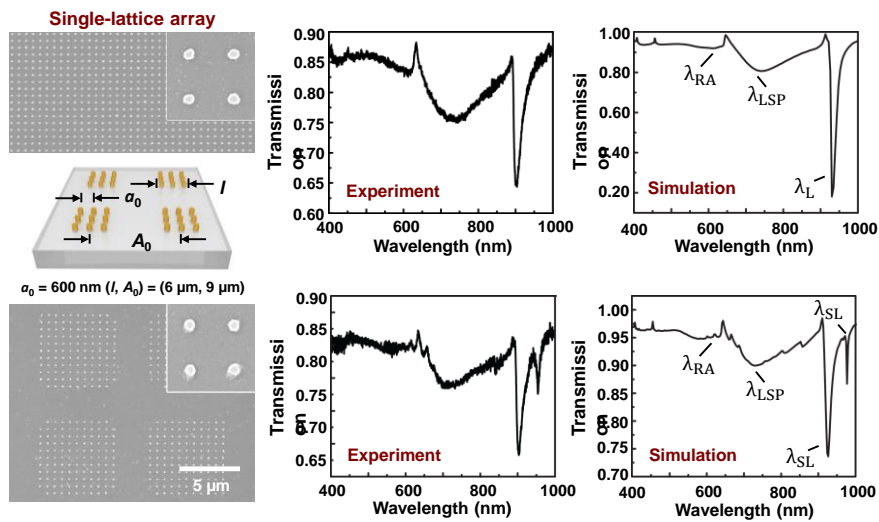
Semi-quantum Simulations



W. Zhou, M. Dridi, J.Y. Suh, C.H. Kim, D.T. Co, M.R. Wasielewski, G.C. Schatz, and T.W. Odom, *Nature Nanotech.* 8, 506 (2013)

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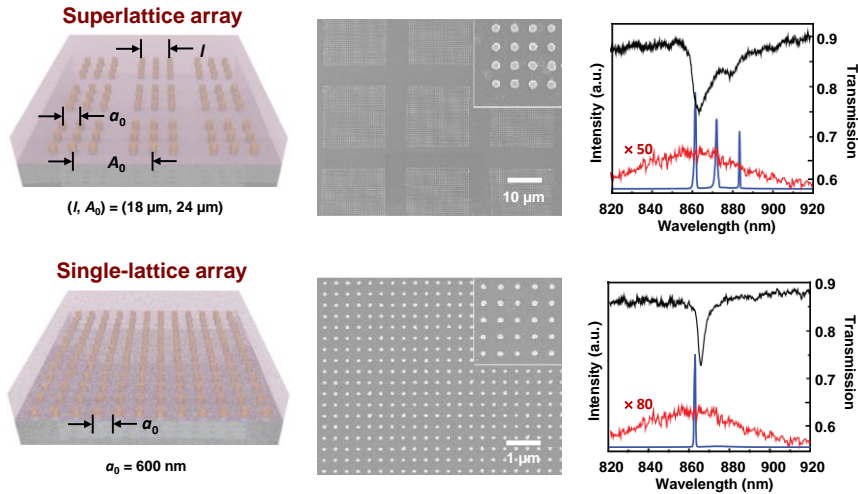
Superlattice (Multi-scale) Plasmons



D. Wang, A. Yang, A.J. Hryn, G.C. Schatz, and T.W. Odom, *ACS Photonics* 2, 1789 (2015)

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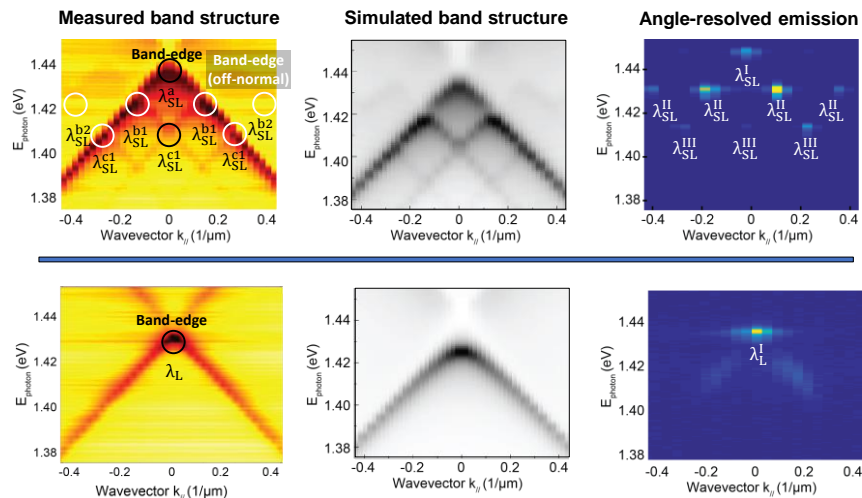
Can Superlattice Plasmons Lase?



D. Wang, W. Wang, A. Yang, Y. Hua, R. Schaller, G.C. Schatz, and T.W. Odom, *Nature Nanotech.* 12, 889 (2017)

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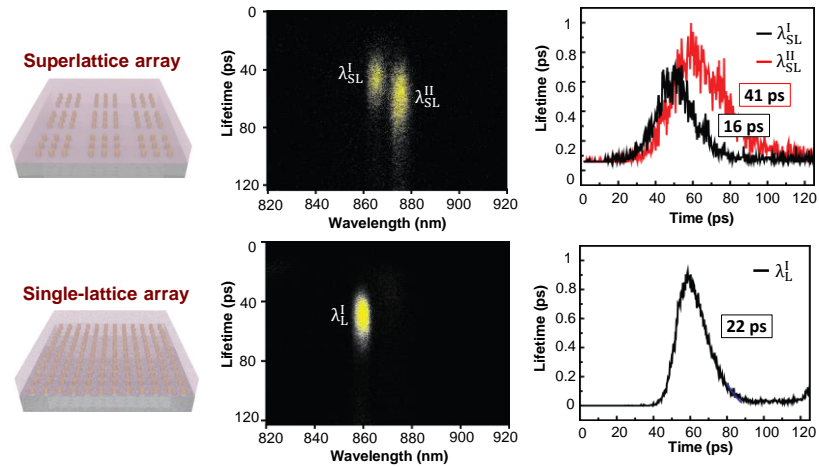
Multi-modal Lasing from Band-edges at Zero and Non-zero Wavevectors



D. Wang, W. Wang, A. Yang, Y. Hua, R. Schaller, G.C. Schatz, and T.W. Odom, *Nature Nanotech.* 12, 889 (2017)

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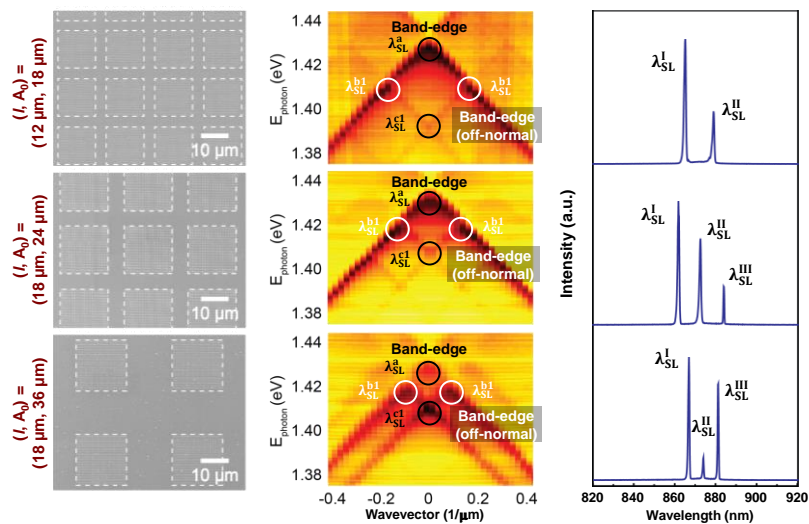
Different Lifetimes for Different Modes



D. Wang, W. Wang, A. Yang, Y. Hua, R. Schaller, G.C. Schatz, and T.W. Odom, *Nature Nanotech.* 12, 889 (2017)

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Engineering Band-edge Modes by varying Patch Periodicity



D. Wang, W. Wang, A. Yang, Y. Hua, R. Schaller, G.C. Schatz, and T.W. Odom, *Nature Nanotech.* 12, 889 (2017)

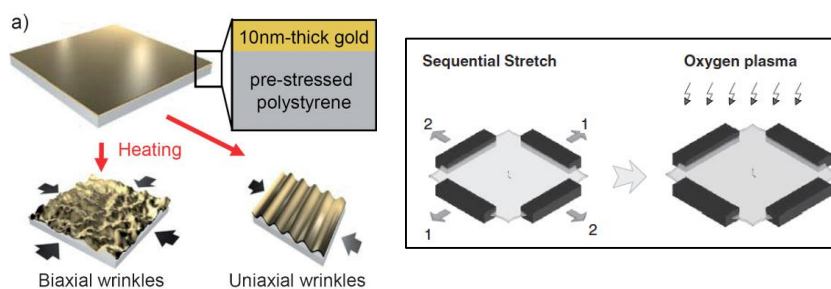
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Natural Wrinkles at all Scales



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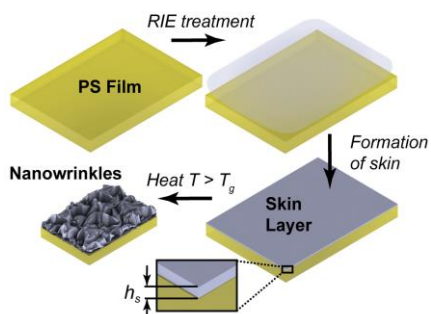
Microscale Wrinkles: status quo



- **Method 1: Deposit metal film onto a compressive substrate**
 - Drawbacks for **nano**: continuous metal film > 10 nm; large E_S/E_B ratio
- **Method 2: Chemically modify top of a pre-strained polymer**
 - Drawbacks for **nano**: h_S & E_S/E_B are difficult to control and measure

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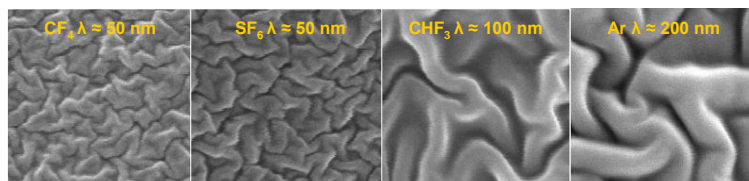
Nanowrinkles by Chemical Patterning



$$\frac{1}{\mu} h_c \frac{\partial E_S}{\partial E_B} \propto \theta^{1/3}$$

$$A \propto \lambda \varepsilon^{1/2}$$

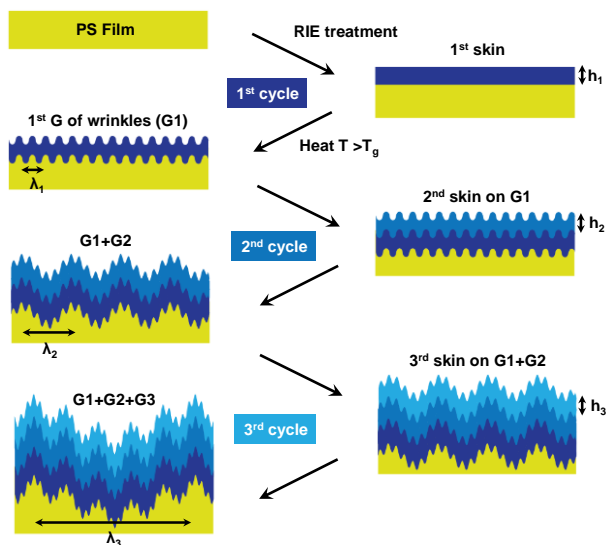
Wavelength proportional to skin thickness



M.D. Huntington, C.J. Engel, A.J. Hryn, and T.W. Odom, *ACS Appl. Mater. Interfaces* 5, 6438 (2013)

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Multi-scale Nanowrinkles

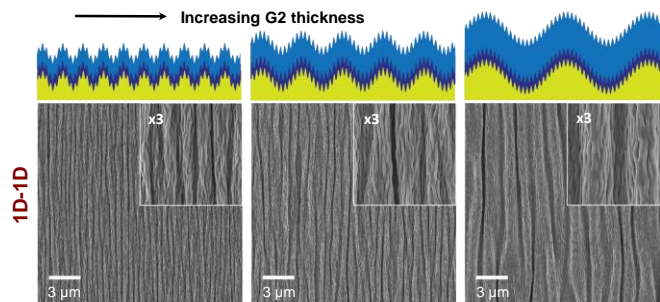


W.K. Lee, C.J. Engel, M.D. Huntington, T.W. Odom, *Nano Lett.* 15, 5624 (2015)

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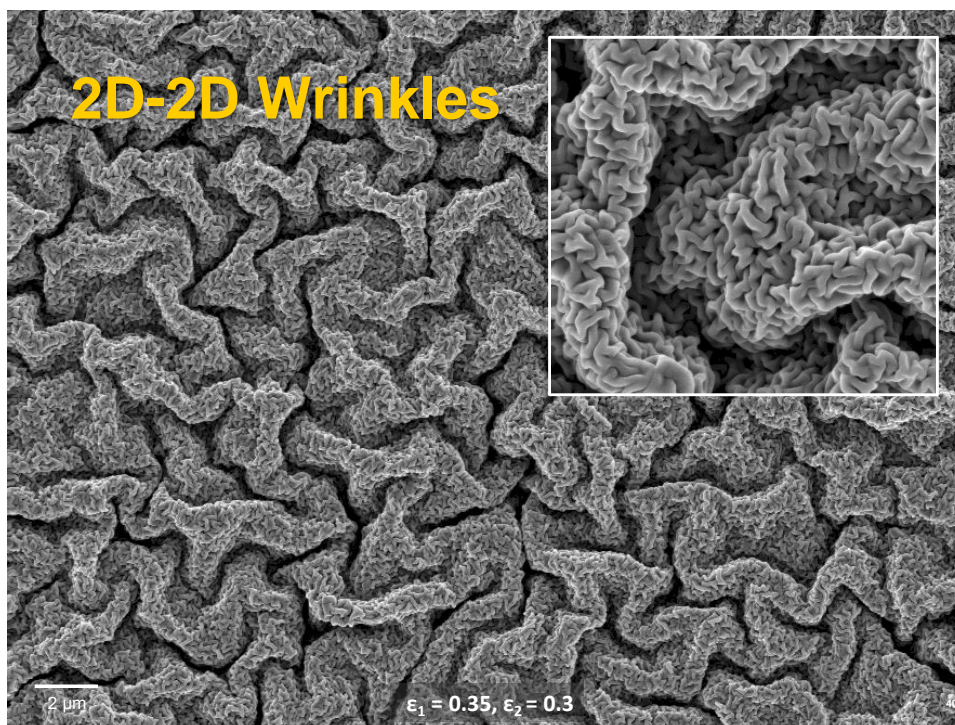


Independent Control of Multi-scale Wrinkle Wavelengths

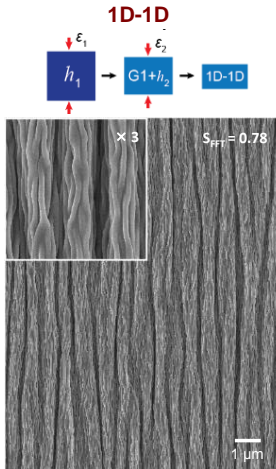


W.K. Lee, C.J. Engel, M.D. Huntington, T.W. Odom, *Nano Lett.* 15, 5624 (2015)

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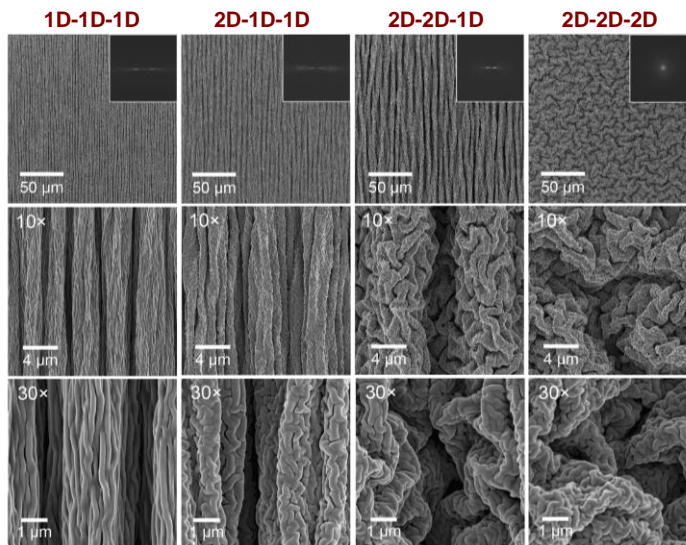
Control of Generation and Multi-scale Wrinkle Wavelengths



W.K. Lee, C.J. Engel, M.D. Huntington, T.W. Odom, *Nano Lett.* 15, 5624 (2015)

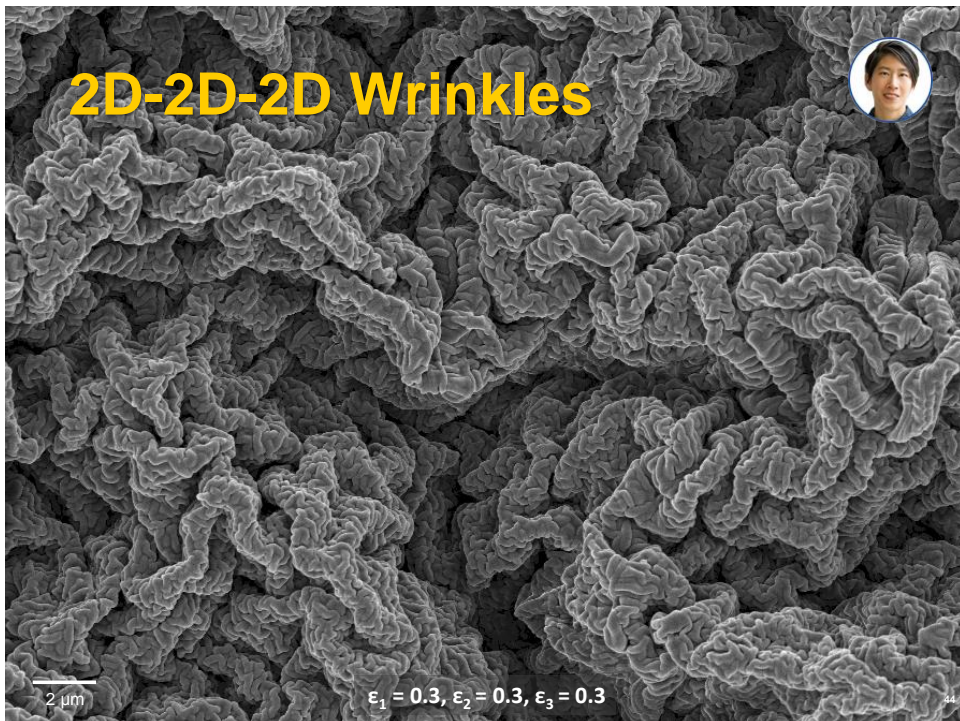
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Three Generations of Wrinkles

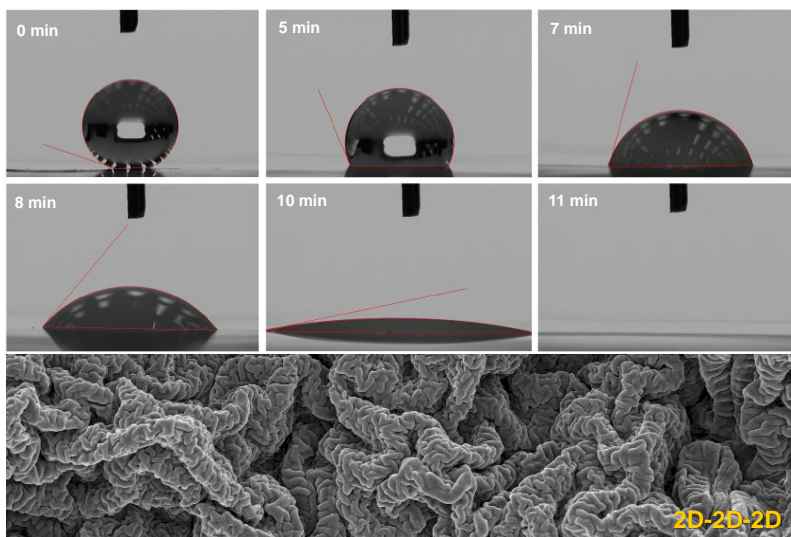


W.K. Lee, C.J. Engel, M.D. Huntington, T.W. Odom, *Nano Lett.* 15, 5624 (2015)

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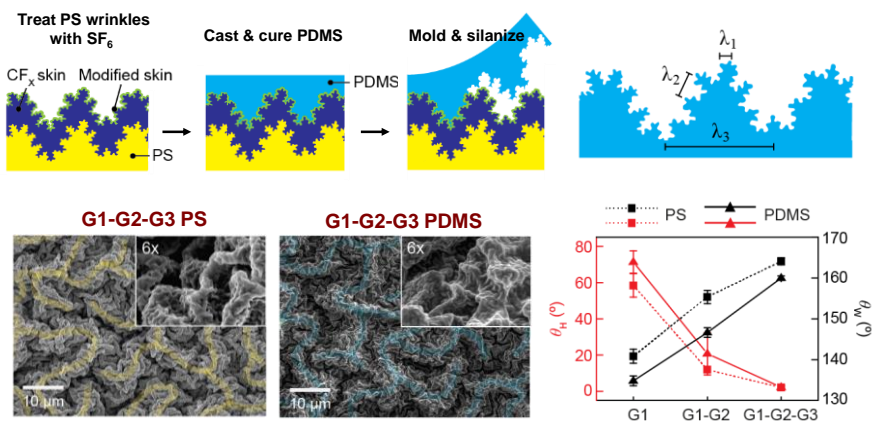
Superhydrophobic to Superhydrophilic



W.K. Lee, C.J. Engel, M.D. Huntington, T.W. Odom, *Nano Lett.* 15, 5624 (2015)

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Monolithic Multi-scale Wrinkles: 3D stretchable surfaces

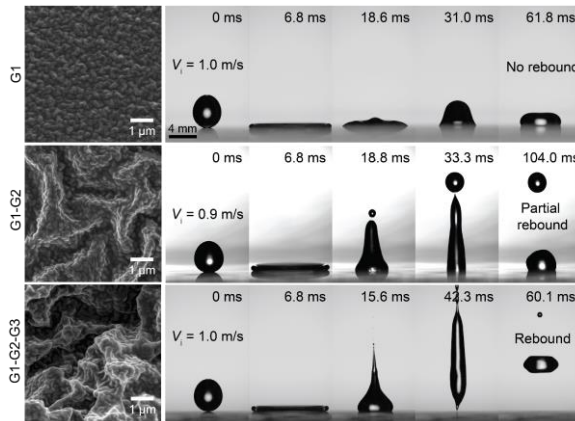


W.K. Lee, W-B. Jung, S.R. Nagel, T.W. Odom, *Nano Lett.* 16, 3774 (2016)

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Multi-scale G1-G2-G3 PDMS Patterns Necessary for Complete Rebound

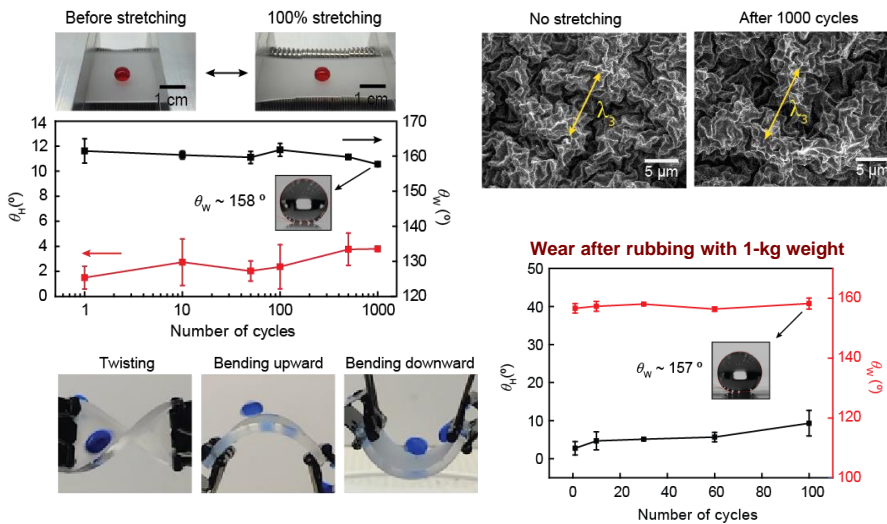


W.K. Lee, W-B. Jung, S.R. Nagel, T.W. Odom, *Nano Lett.* 16, 3774 (2016)

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Durability of G1-G2-G3 PDMS Wrinkles

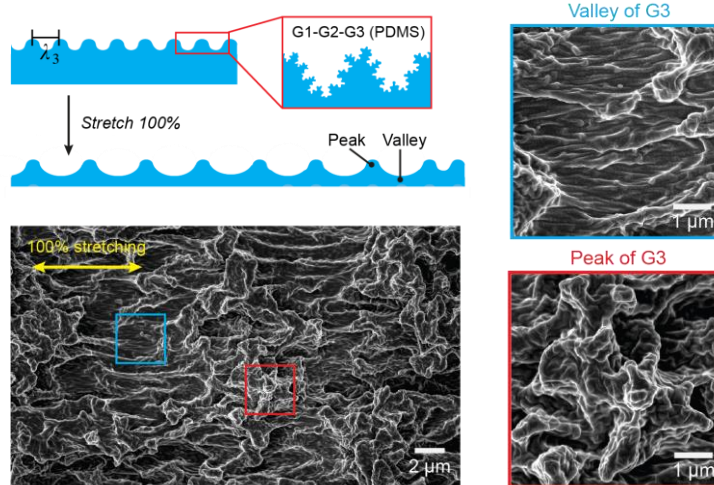


W.K. Lee, W-B. Jung, S.R. Nagel, T.W. Odom, *Nano Lett.* 16, 3774 (2016)

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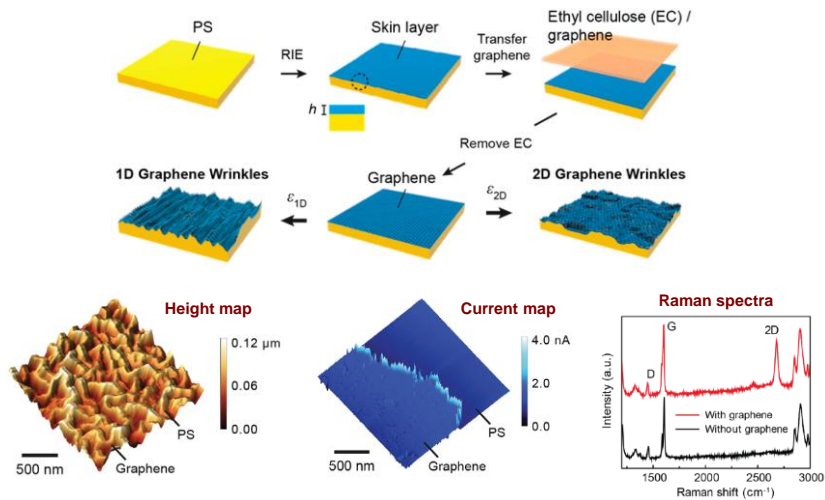
Partial Preservation of Nanoscale Features under Stretching



W.K. Lee, W-B. Jung, S.R. Nagel, T.W. Odom, *Nano Lett.* 16, 3774 (2016)

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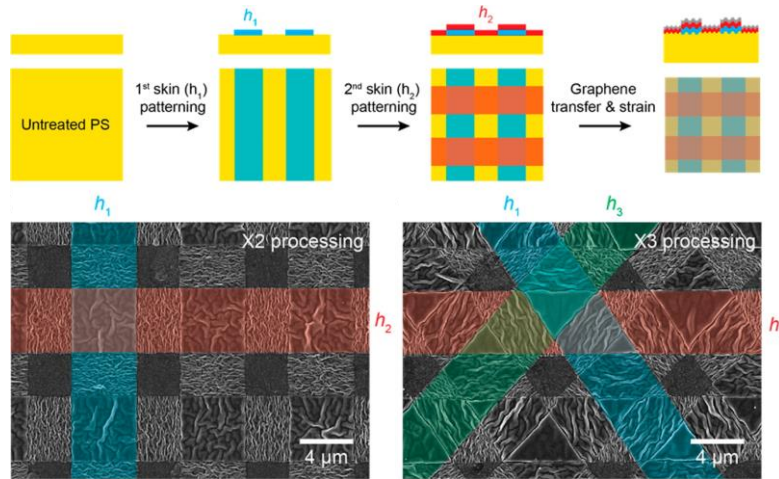
Multi-scale Patterning of Graphene: Conformal wrinkling



W. K. Lee, J. Kang, K-S. Chen, C. J. Engel, W-B. Jung, D. Rhee, M.C. Hersam, and T.W. Odom, *Nano Lett.* 16, 7121 (2016)

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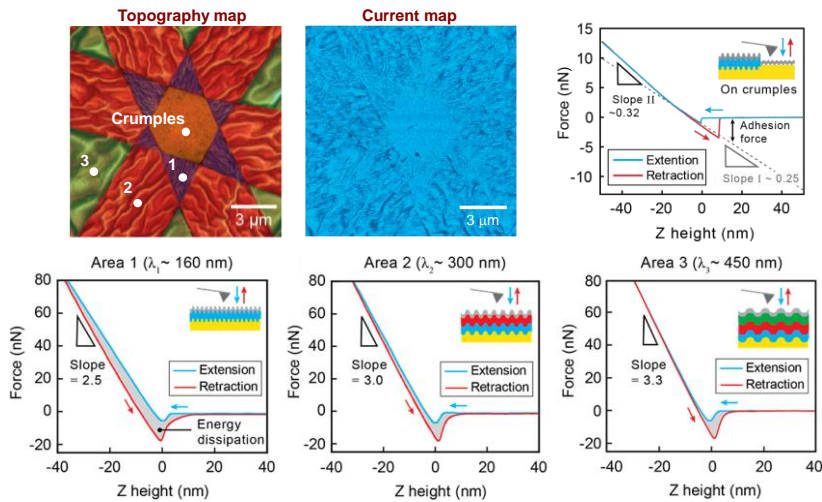
Multi-scale Graphene Wrinkles: Patterning adjacent regions of skin layers



W. K. Lee, J. Kang, K-S. Chen, C. J. Engel, W-B. Jung, D. Rhee, M.C. Hersam, and T.W. Odom, *Nano Lett.* 16, 7121 (2016)

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Same Electrical / Different Mechanical Properties on Patterned Graphene



W. K. Lee, J. Kang, K-S. Chen, C. J. Engel, W-B. Jung, D. Rhee, M.C. Hersam, and T.W. Odom, *Nano Lett.* 16, 7121 (2016)

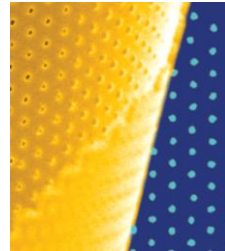
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Summary and **Exciting** Prospects



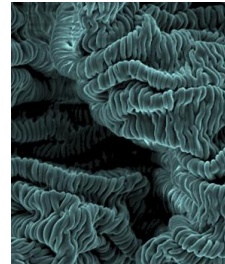
- **Multi-scale hard nanomaterials**

- Tunable, switchable nanolasing
- Multi-modal nanolasing
- **Reconfigurable** plasmon lattices
- **Evolutionary design** of metasurfaces



- **Multi-scale soft nanomaterials**

- Hierarchical polymer nanomaterials
- Stretchable superhydrophobicity
- Multi-functional substrates
- **Functional** optoelectronic metasurfaces



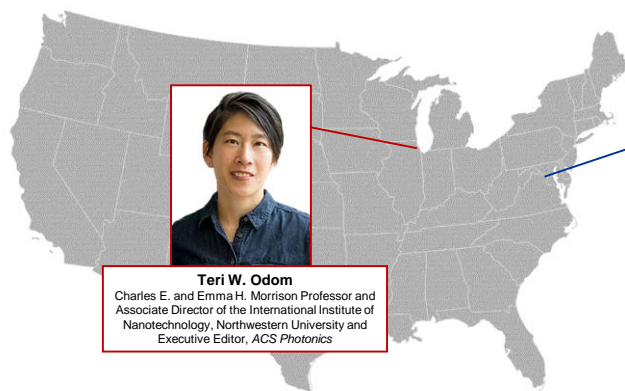
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The Odom Group





"Nano 2.0: Multi-scale Nanomaterials" In Celebration of National Nanotechnology Day!



Teri W. Odom
Charles E. and Emma H. Morrison Professor and Associate Director of the International Institute of Nanotechnology, Northwestern University and Executive Editor, *ACS Photonics*



Laura Fernandez
Managing Editor, *ACS Nano* and *Nano Letters*

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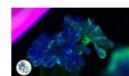
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Patricia Simpson, Director of Academic Advising and Career Services for the School of Chemical Sciences, University of Illinois

Thursday, October 19, 2017



Avoiding the Next Chemical Catastrophe: Strategies for Chemical Threat Reduction

Andrew Nelson, Postdoctoral Appointee, International Biological and Chemical Threat Reduction Program, Sandia National Laboratories

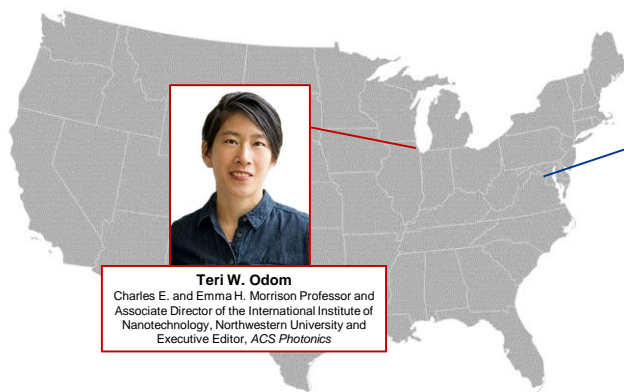
Ralph Stuart, Chemical Hygiene Officer, Keene State College and Chair, Safety Advisory Panel, ACS Committee on Chemical Safety

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