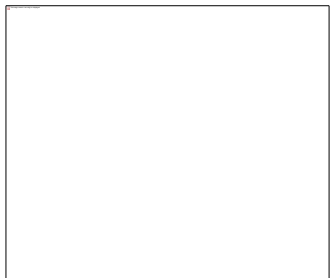


# Laser-Enabled Directed Nanomanufacturing

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Laser Thermal Laboratory  
Department of Mechanical Engineering  
University of California, Berkeley

U.S.-Korea Nanotechnology Forum  
October 15, 2013

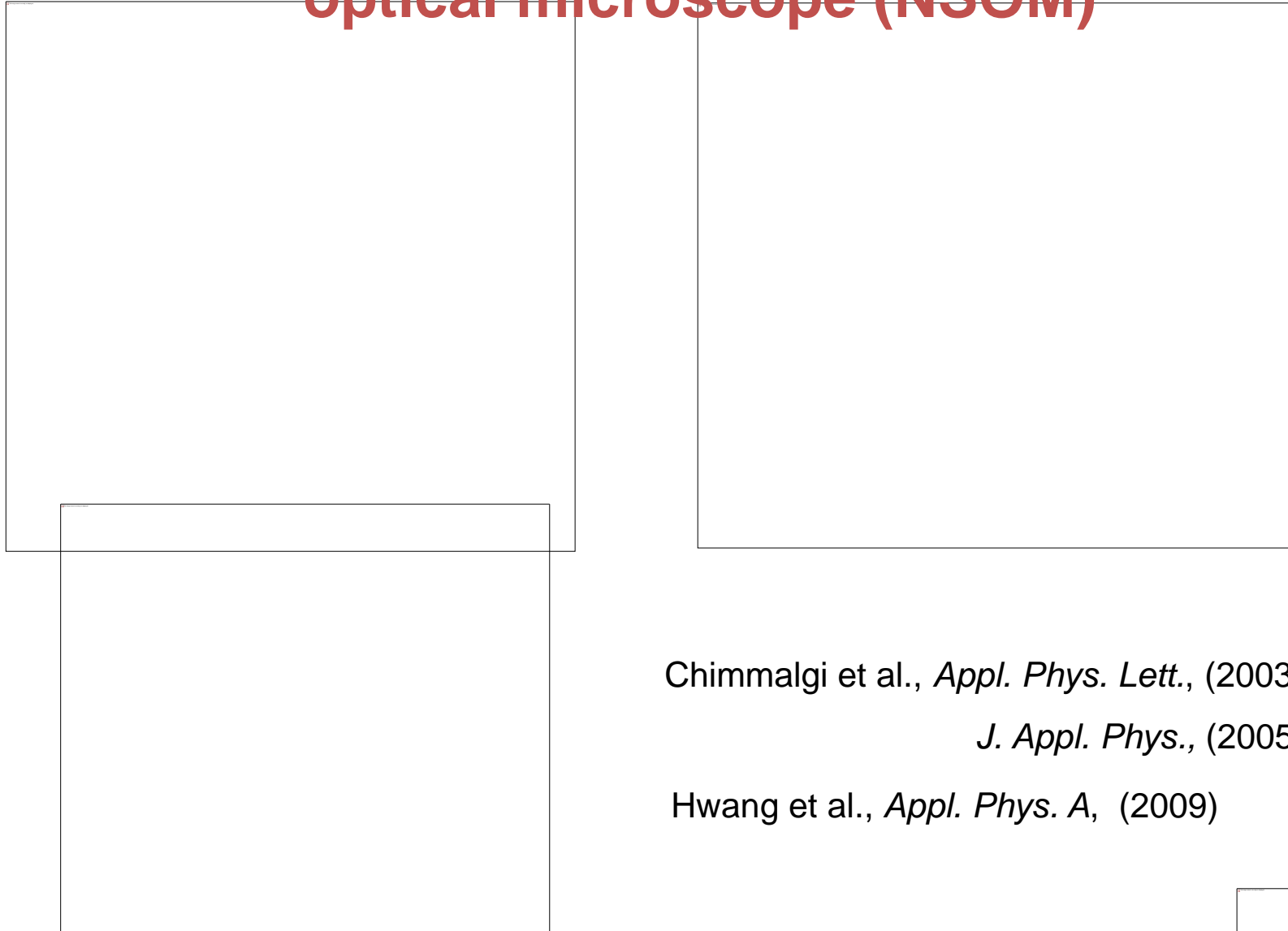


# Topics

- Laser nano/micromanufacturing
  - Laser Chemical Vapor Deposition
  - Directed growth of nanomaterials
- Laser-assisted electronic materials processing and device fabrication
  - Flexible electronics
- Laser interactions with biological materials
  - Surface patterning for cell growth
  - Fibrous material scaffolding



# Nanomachined patterns by femtosecond laser coupled to apertureless near field scanning optical microscope (NSOM)



Chimmalgi et al., *Appl. Phys. Lett.*, (2003)

*J. Appl. Phys.*, (2005)

Hwang et al., *Appl. Phys. A*, (2009)



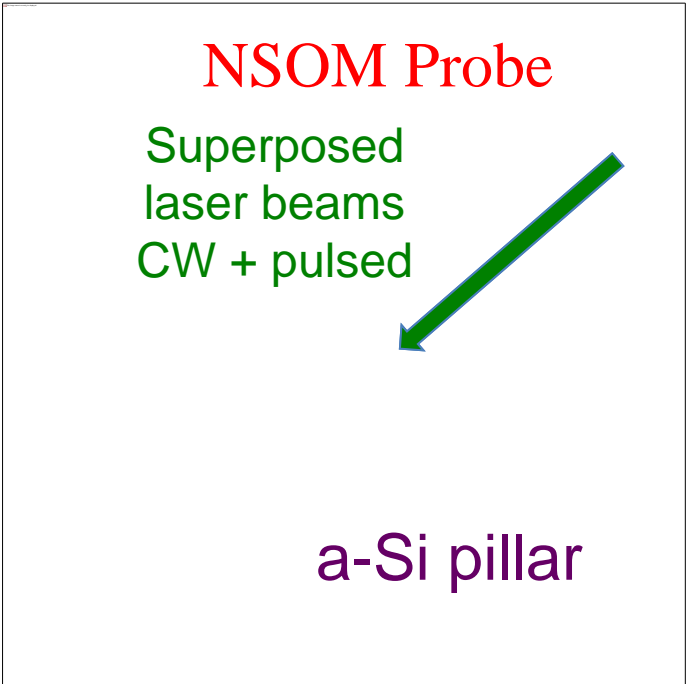
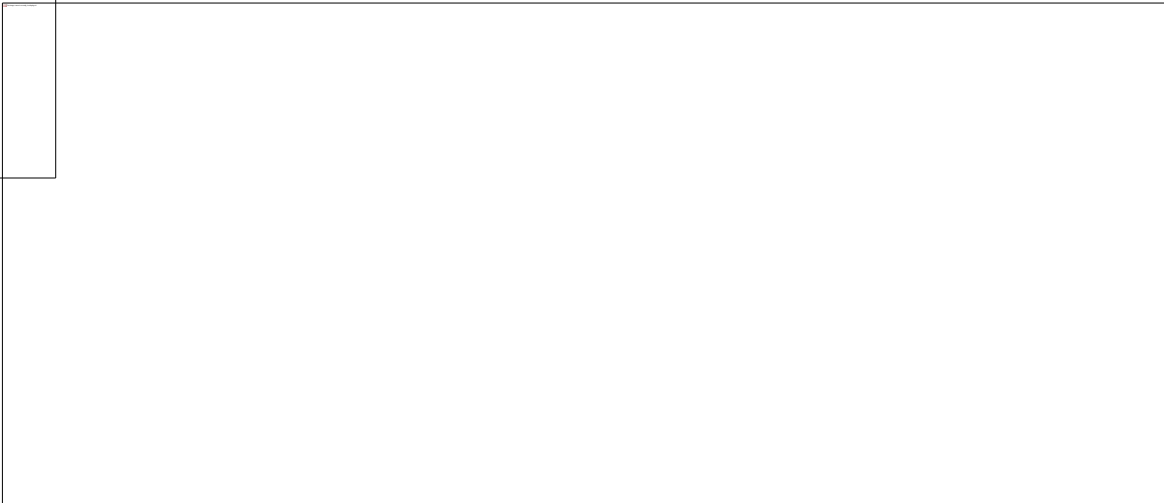
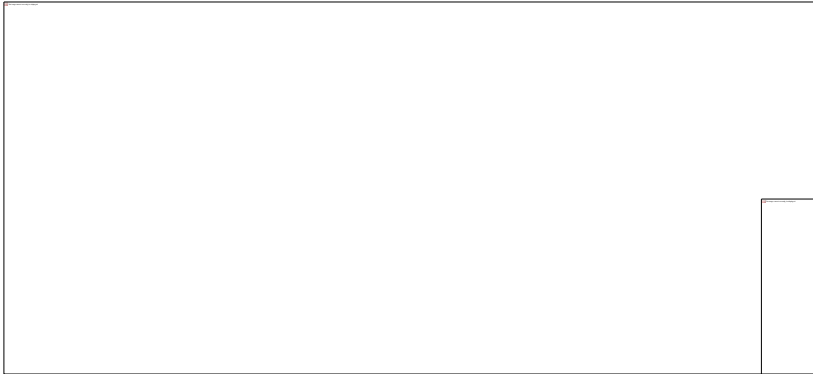
# Nano-crystallization by apertureless NSOM



Chimmalgi, *Nano Lett.* (2005)



# In-situ TEM Imaging and NSOM Processing

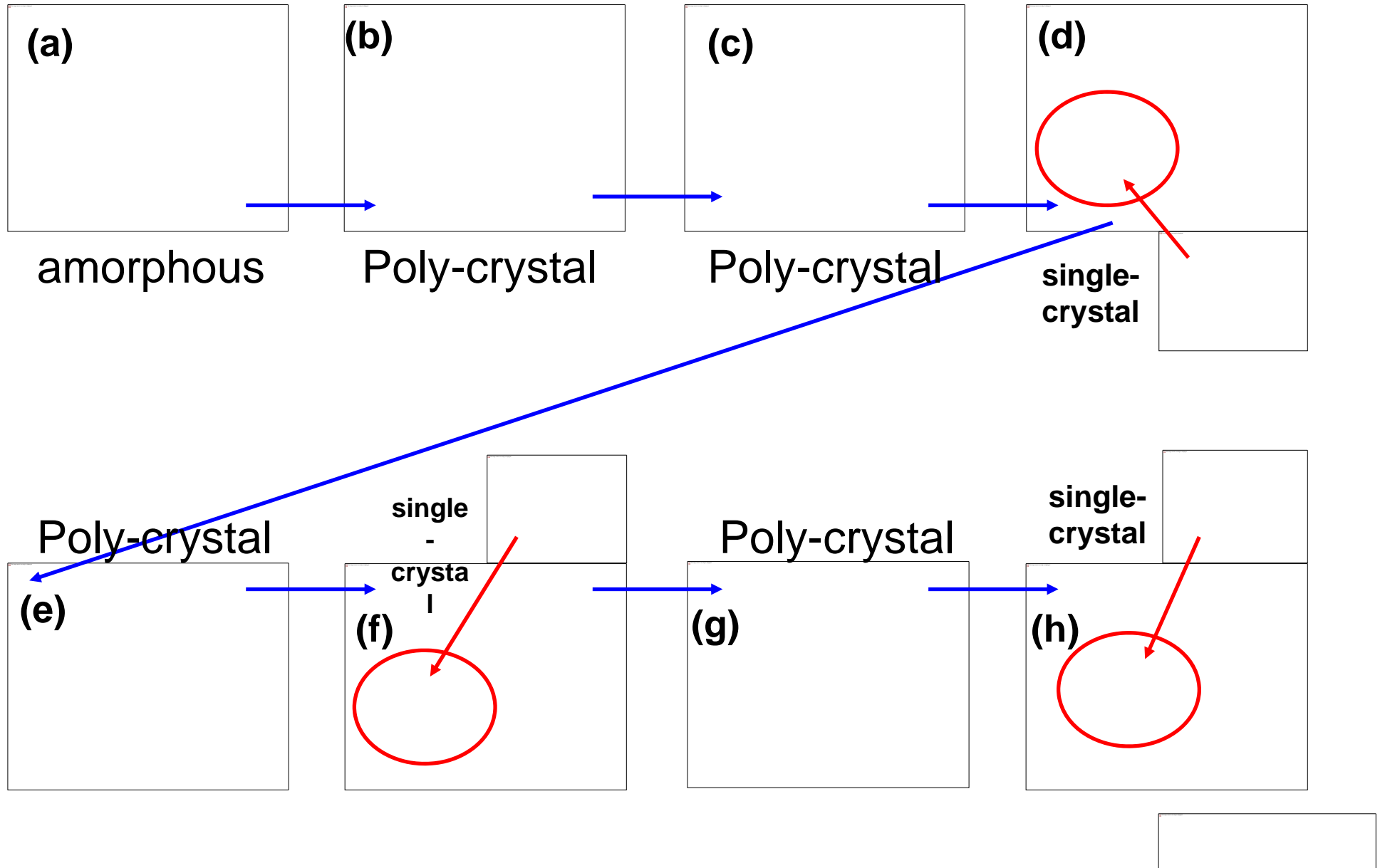


Transformation of an a-Si dot  
to a single Si nanocrystal on a  
non-participating substrate

Xiang et al., *Nano Lett.* (2012)

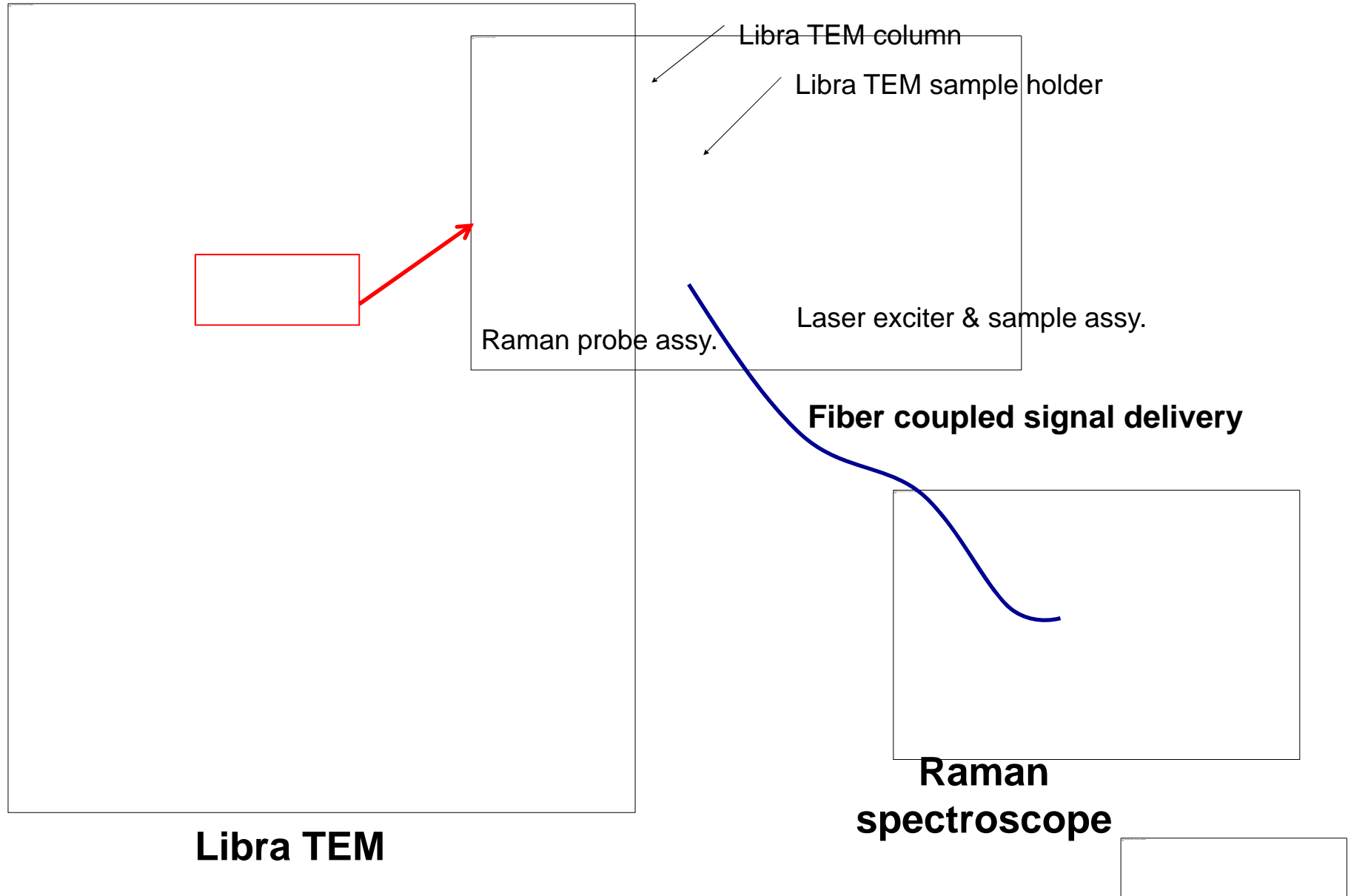


# Alternating Crystal Structure





# Laser In-situ TEM Diagnostics & Processing





# Laser-based Selective Nanowire growth

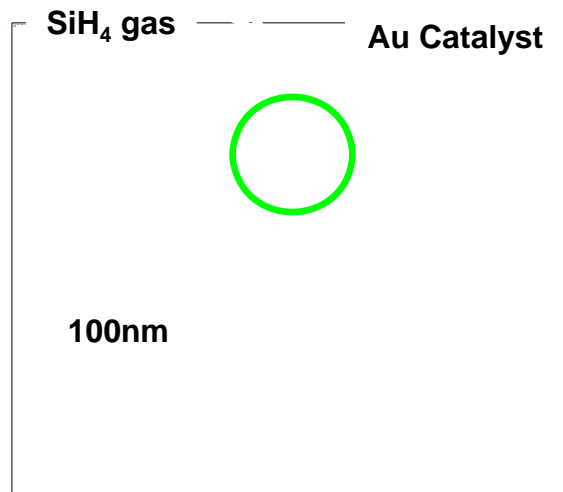
metal nanoparticle catalyzed silicon nanowire growth under VLS mechanism

VLS (Vapor-Liquid-Solid) Si nanowire growth

## Laser Illumination



Localized heating of catalysts  
& NW growth within laser spot

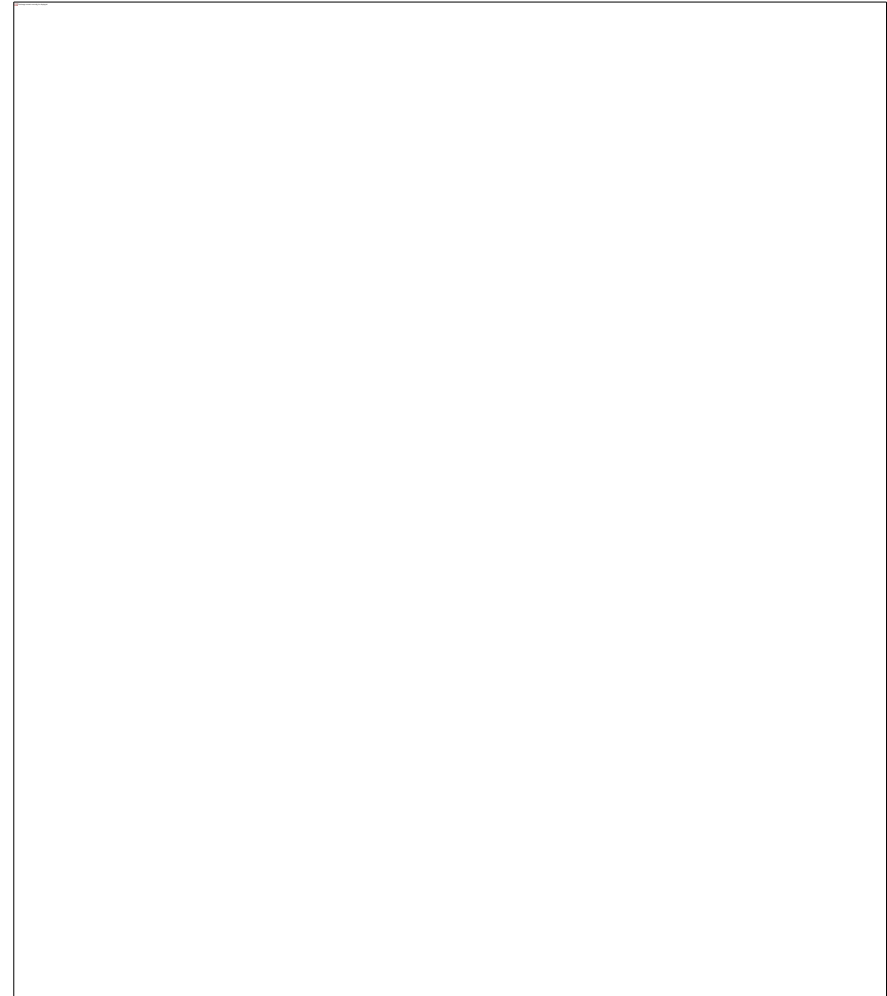


Laser-assisted localized Si nanowire growth setup



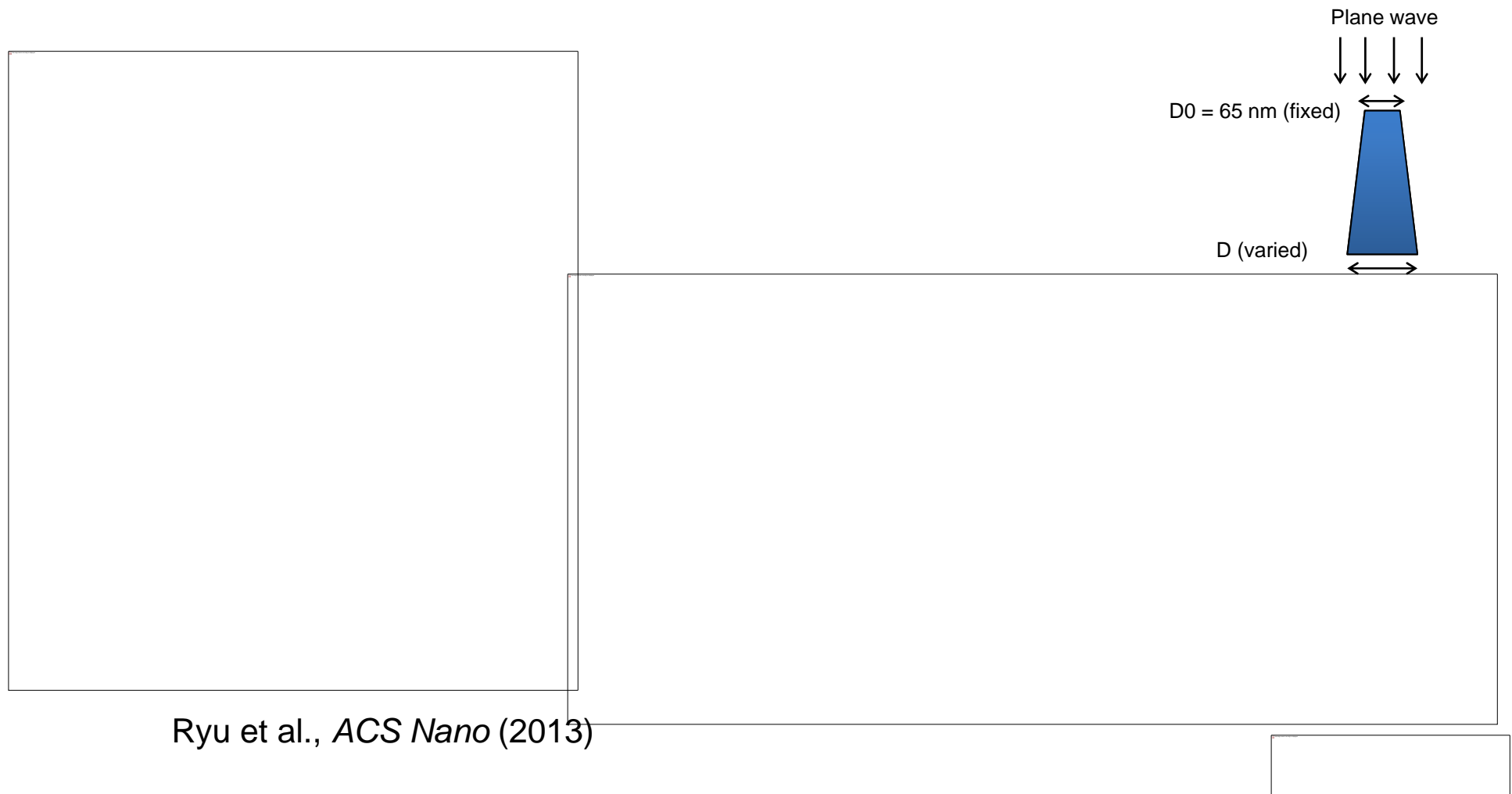


# Temperature and time dependent growth of GeNWs

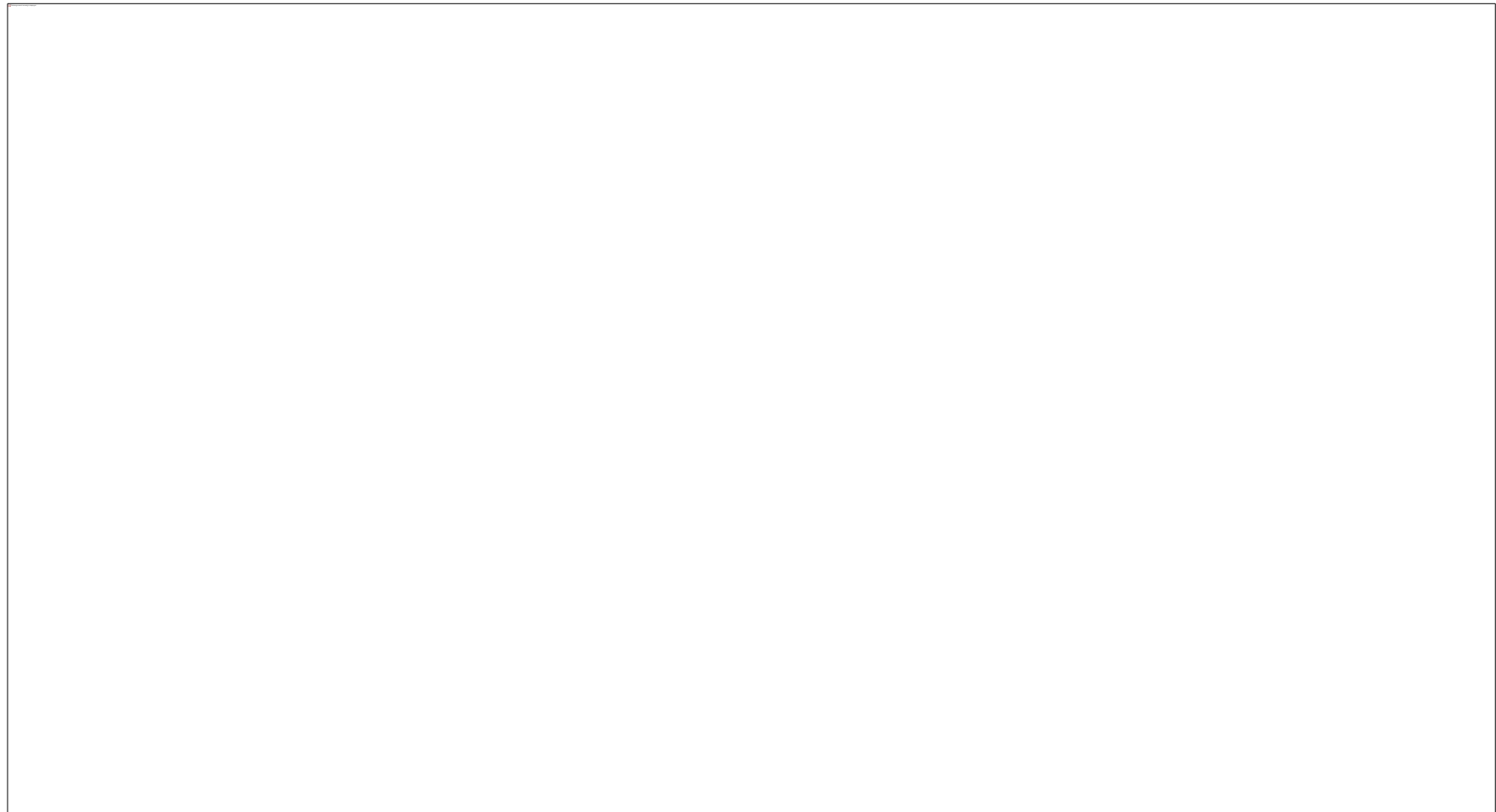


# On-demand Vertical GeNW Integration on Si(111)

## Location/shape controlled GeNW on a single Si(111) in vertical integration architecture



# Defect Free Epitaxial Growth of GeNWs on Si (111)



**Cross sectional HRTEM images of the vertically oriented GeNW on Si (111)**



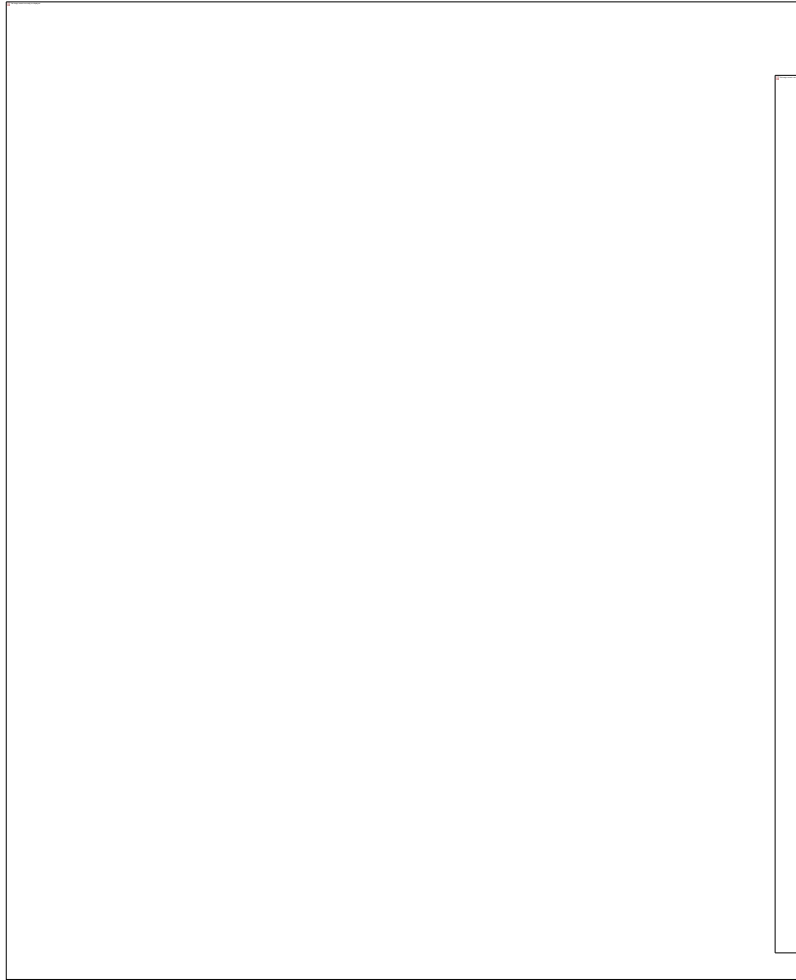
# Laser hydrothermal Growth of ZnO nanowires



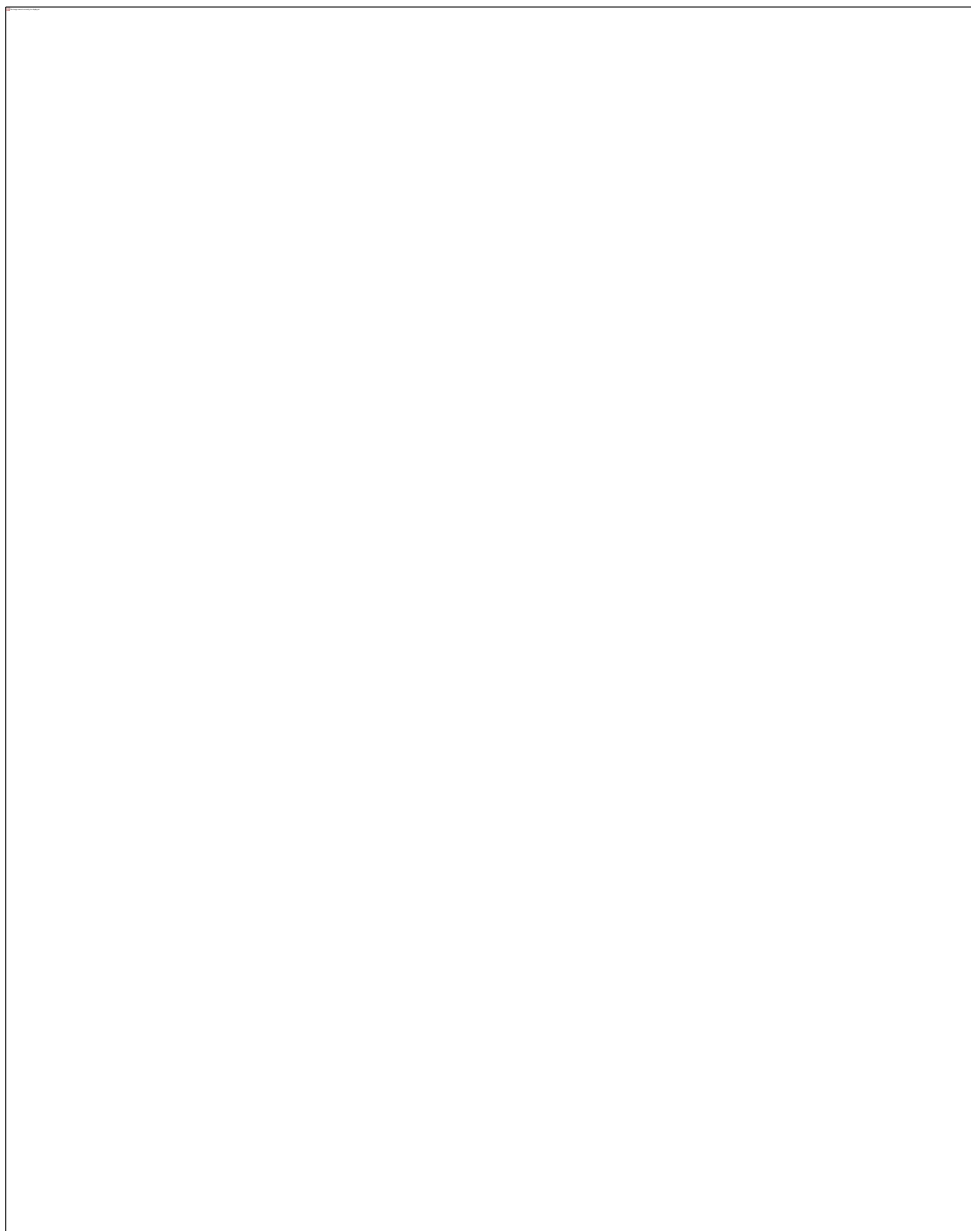
In et al., *Small* (2013)



# Growth visualization and control



# Graphene patterning and transferring

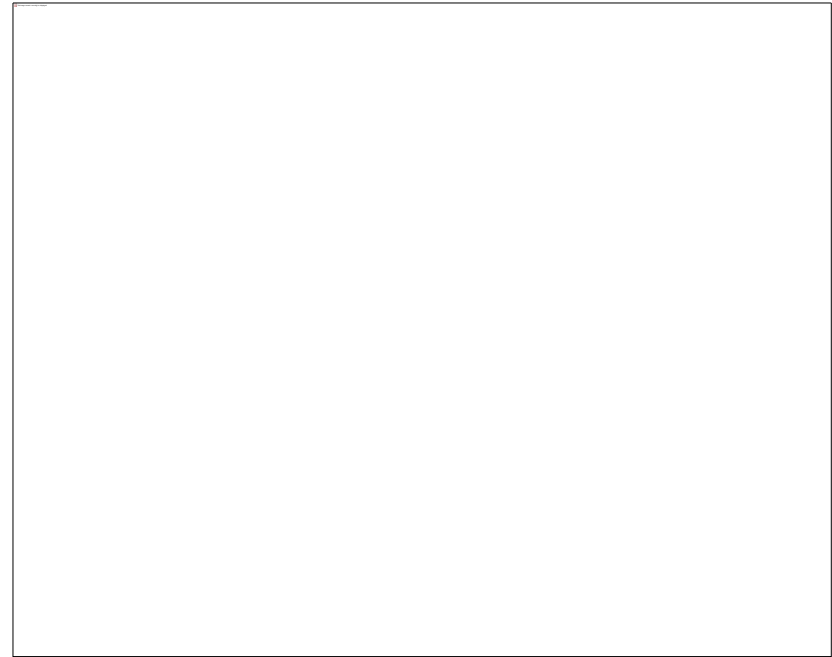


Yoo et al, Small (2013)

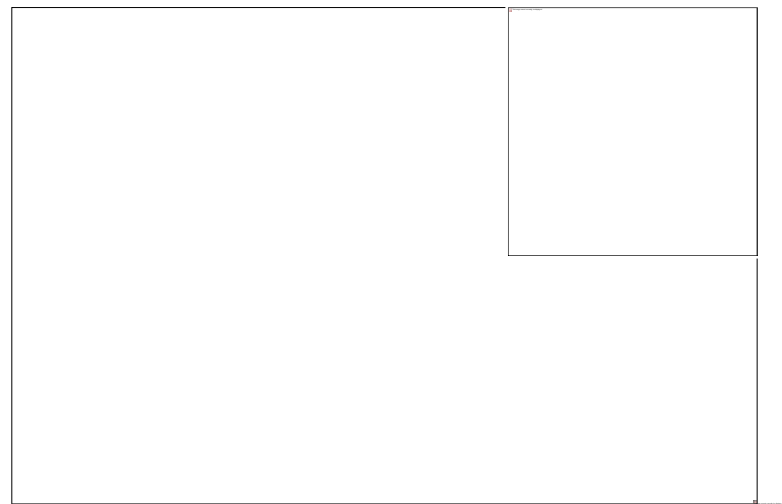
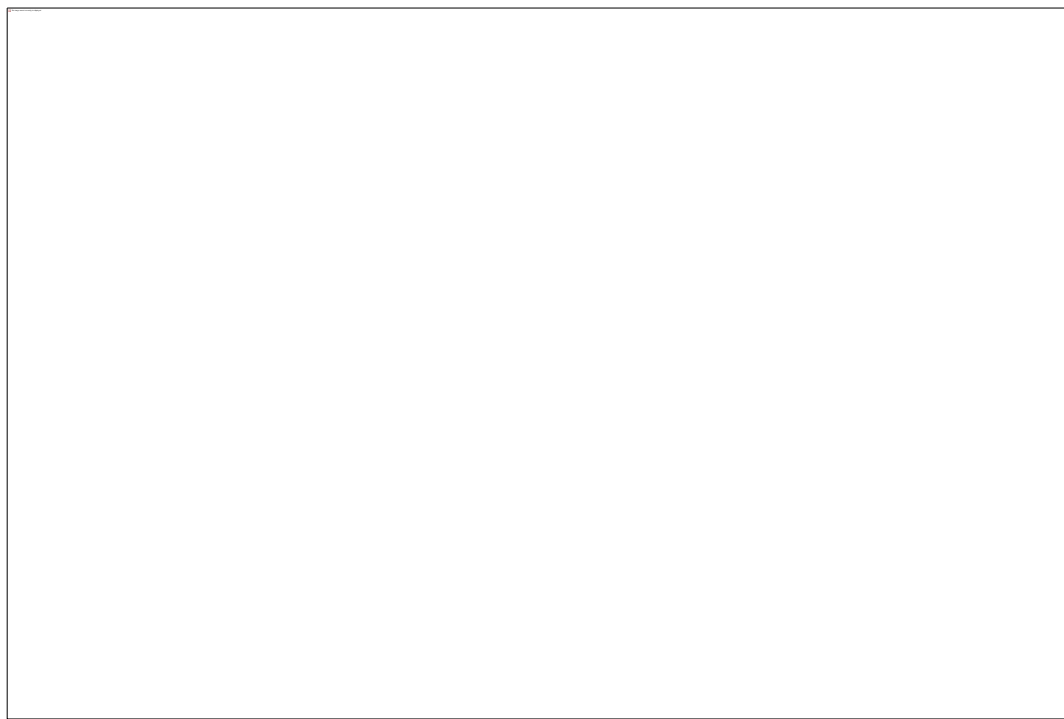
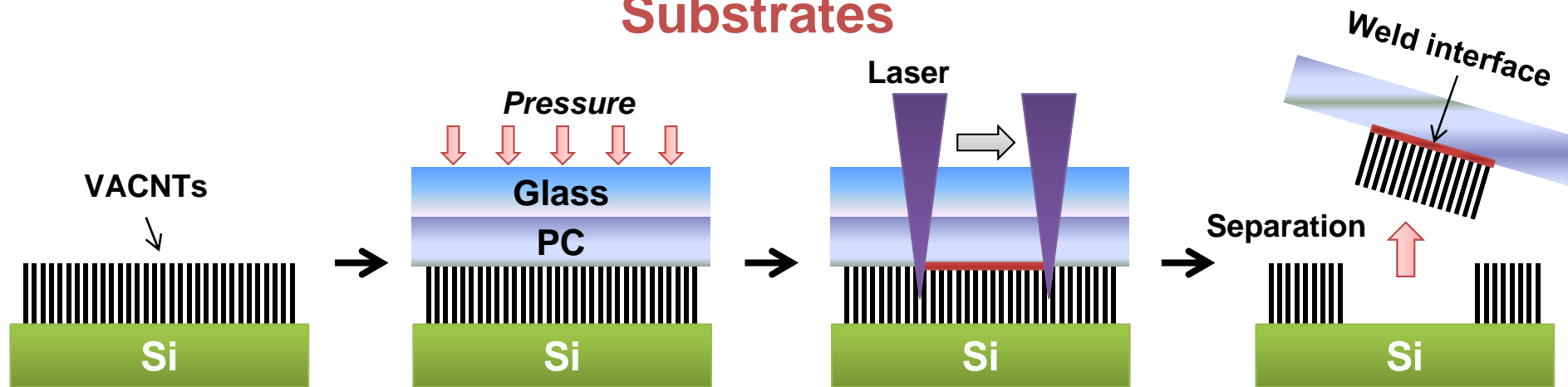




# Graphene devices



# Vertically Aligned Carbon Nanotube Transfer on Flexible Substrates



In et al., *ACS Nano* (2012)



# Beyond graphene

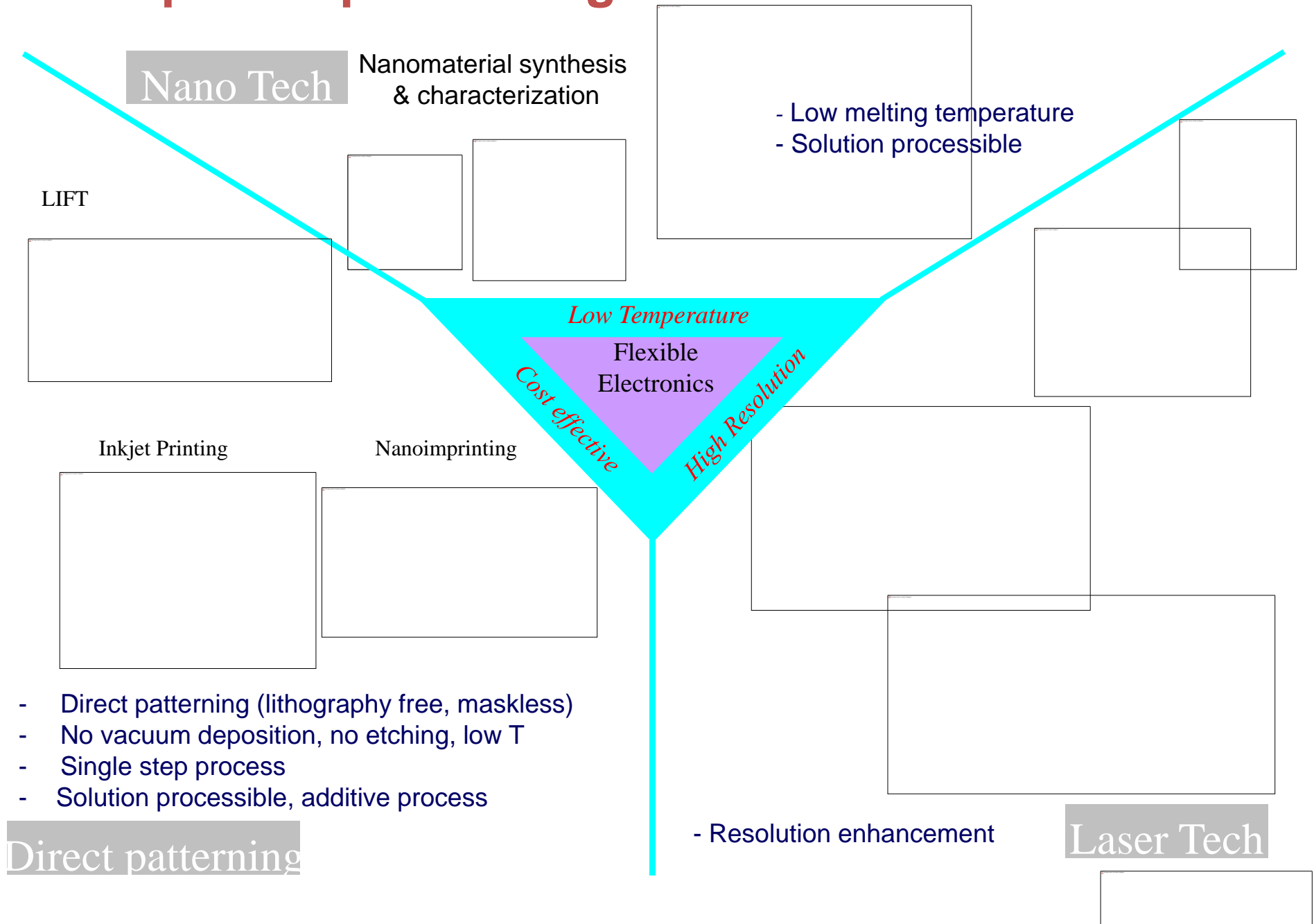
## Laser annealed MoS<sub>2</sub> transistors on plastic



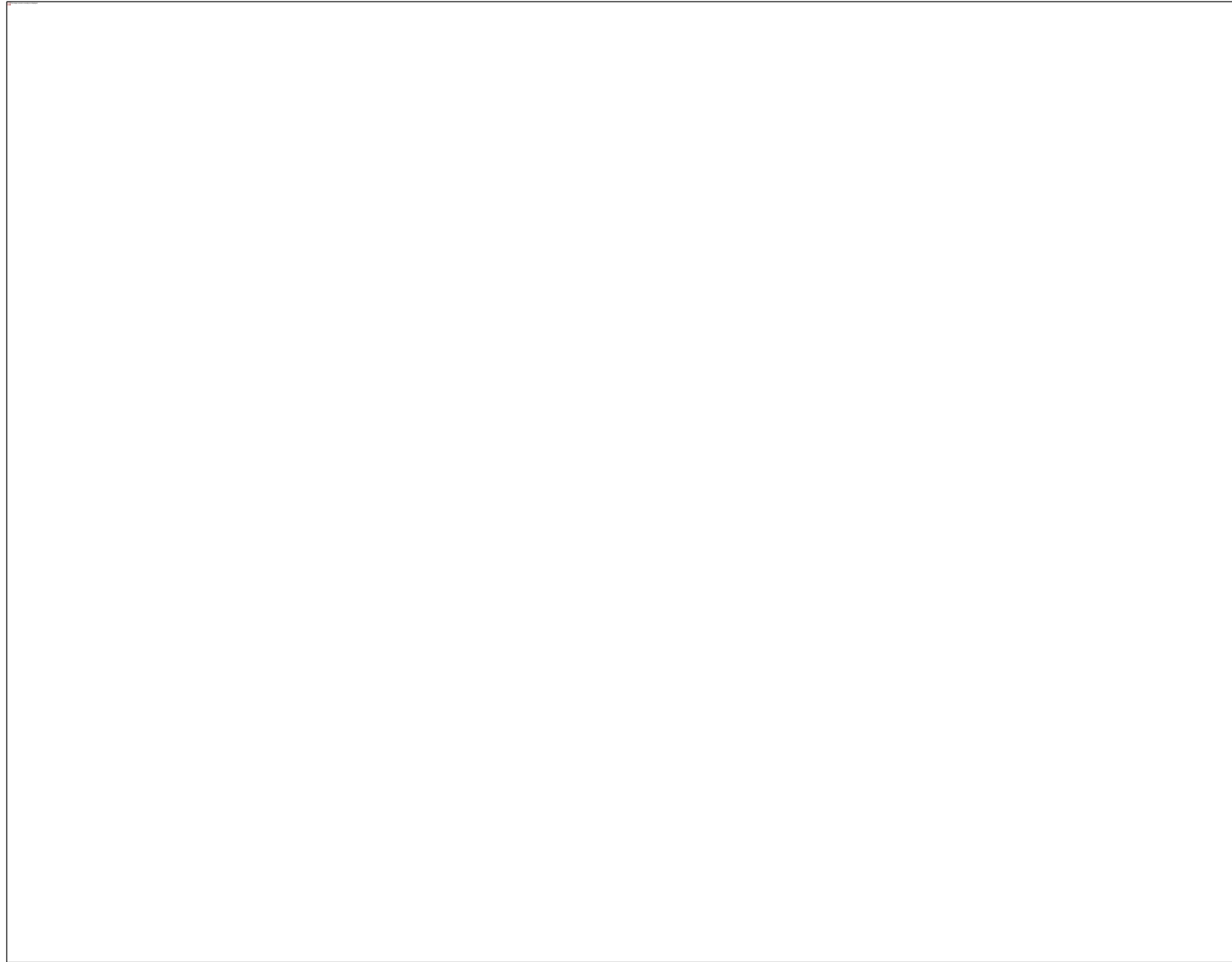
Choi, Kwon et al. IMID (2013)



# Nanoparticle processing for flexible electronics



# Digital Direct Metal Patterning (DDMP) Process on a Flexible Substrate



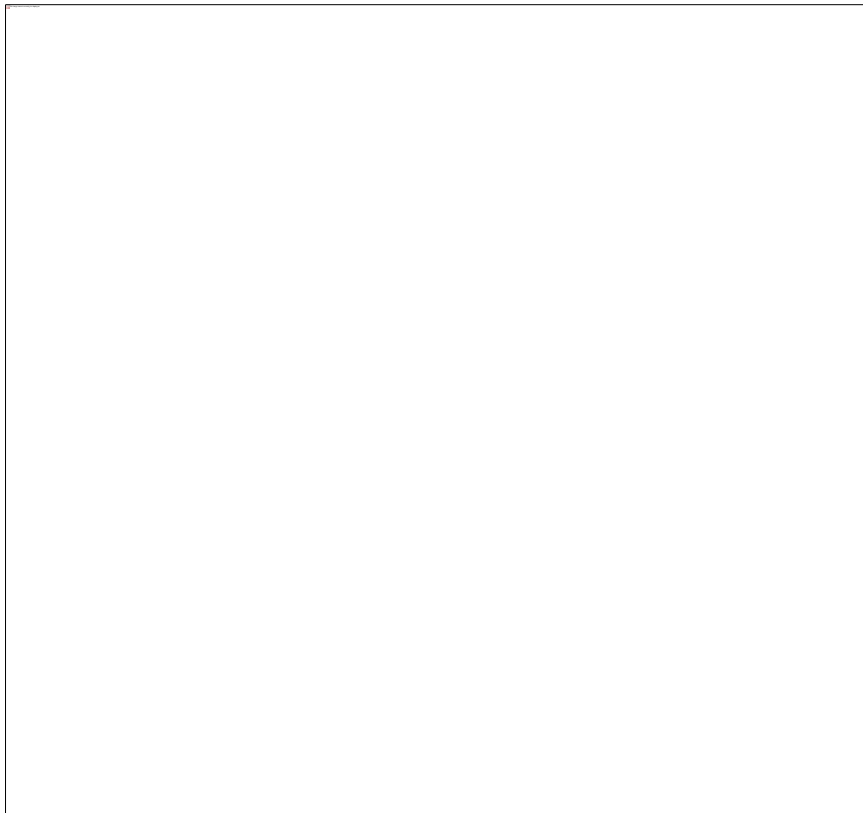
Yeo et al., *PLOS ONE*, (2012)



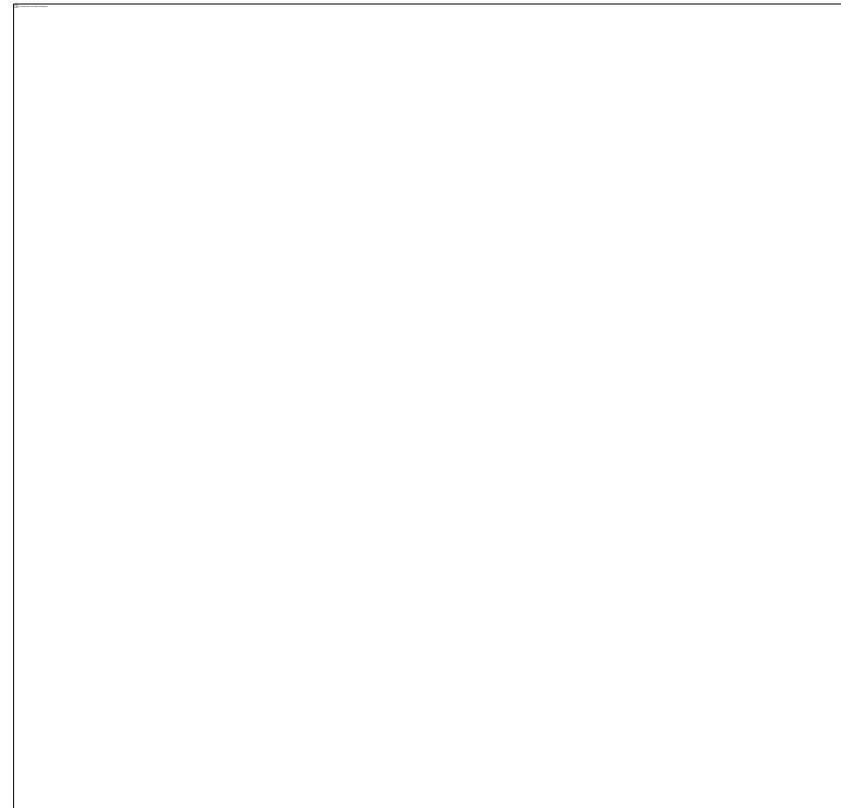
# Laser Sintering Examples

532nm wavelength, 70mW, CW laser, 4" wafer size, 2 m/s scanning speed

Room temperature, ambient pressure, Non-vacuum process, maskless process



High resolution metal features  
( total processing time: ~ 7 mins)  
(down to several microns)



16,000 OFETs on a PI substrate, 3 layered  
structures (PI substrate/ gate electrode / PVP/ source & drain  
electrodes)  
( total processing time: ~ 10 mins)



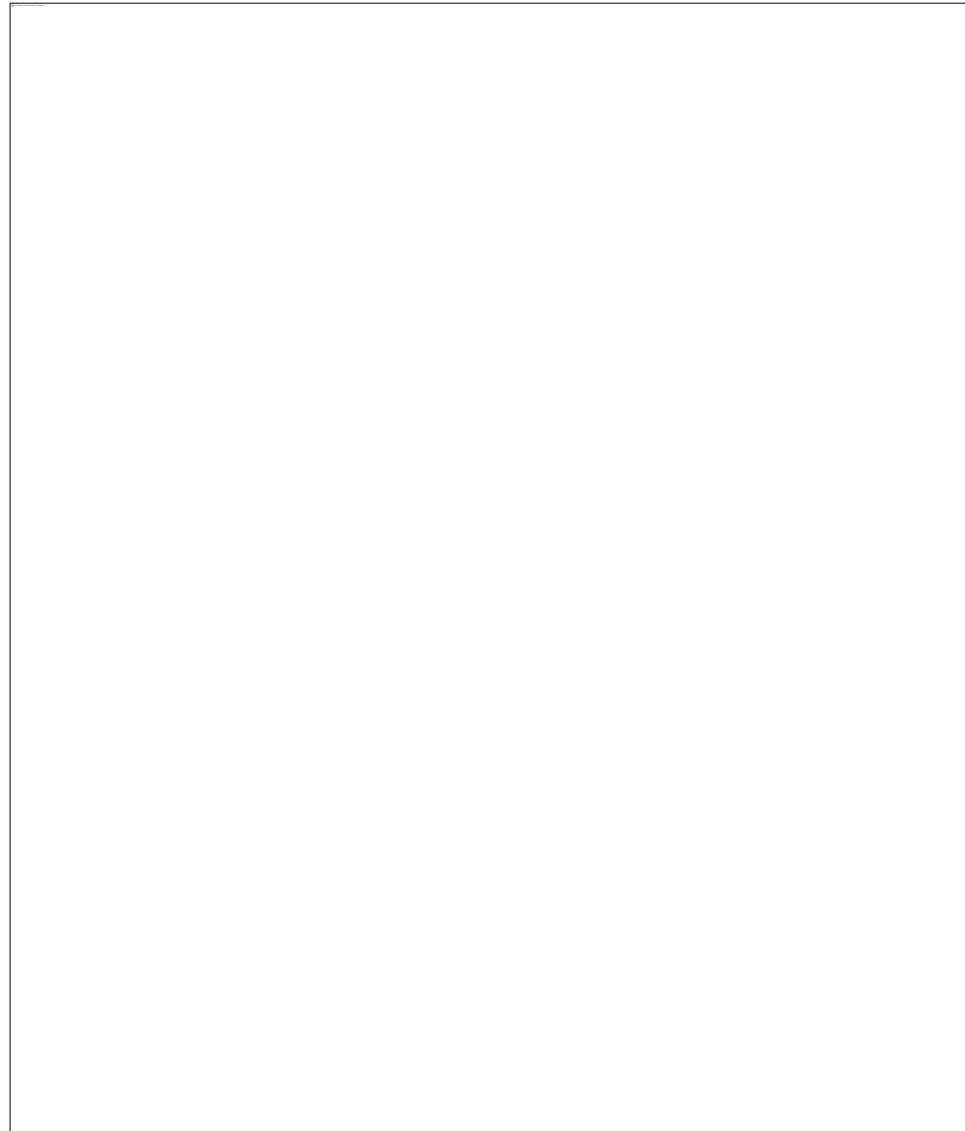
# Laser Enabled Wafer scale ZnO Nanoimprinting on Flexible Substrates

Master mold

PDMS stamp

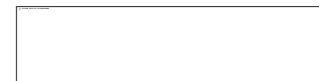
ZnO mesh

ZnO on  
polycarbonate



# Fiber scaffold fabrication via 2PP (two-photon polymerization)

Low N.A. objective





# Fiber scaffold fabrication



Jeon et al., *Biomed. Microdev.* (2011)



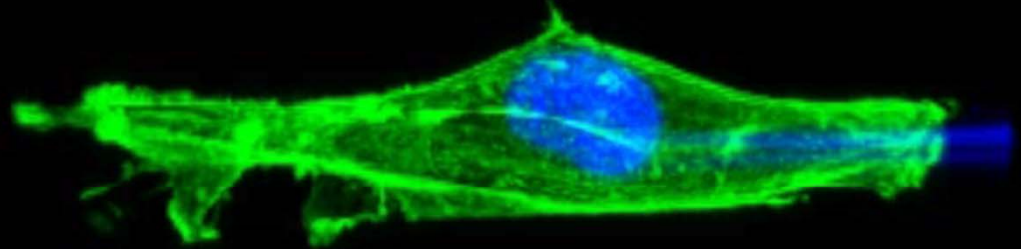
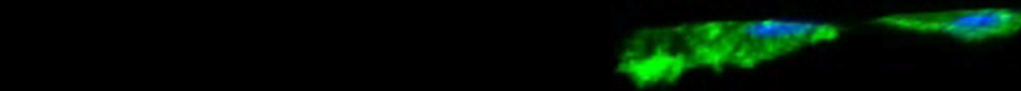
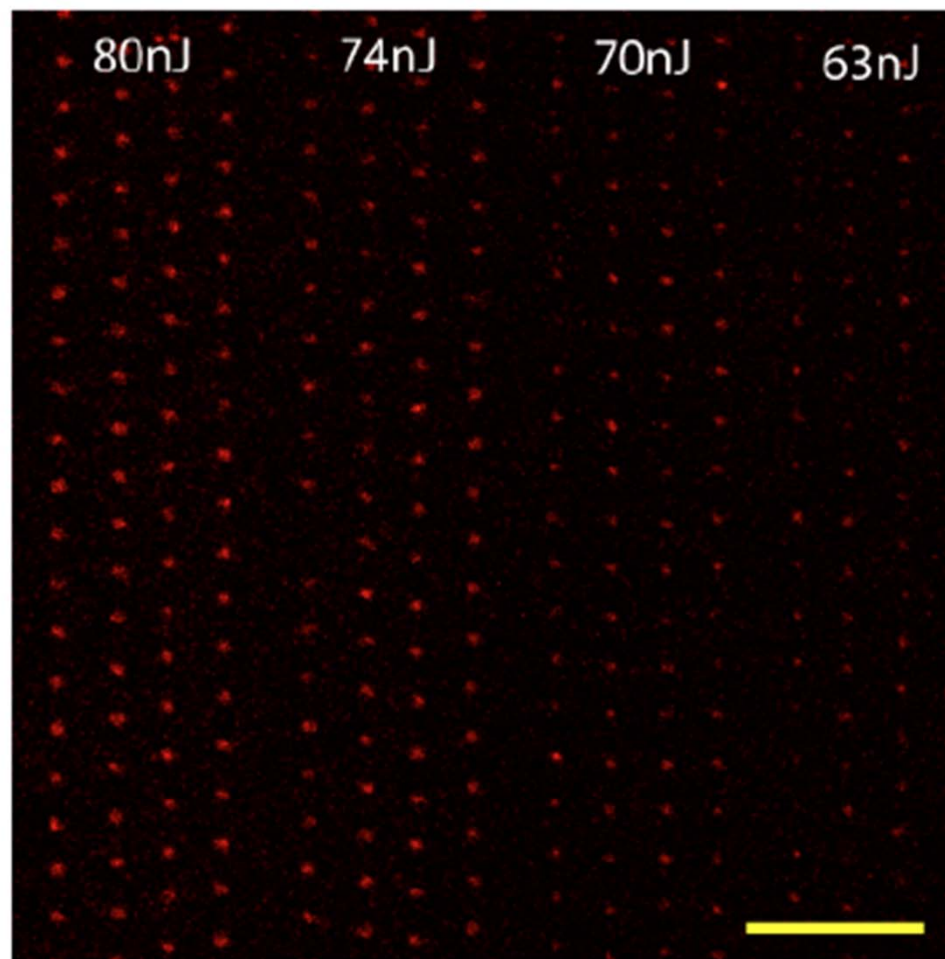
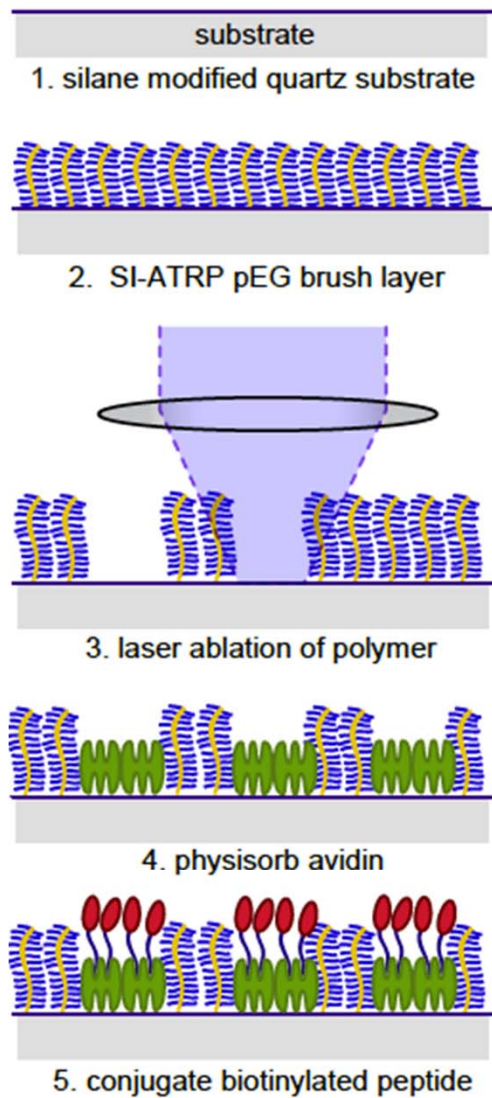


Figure 1

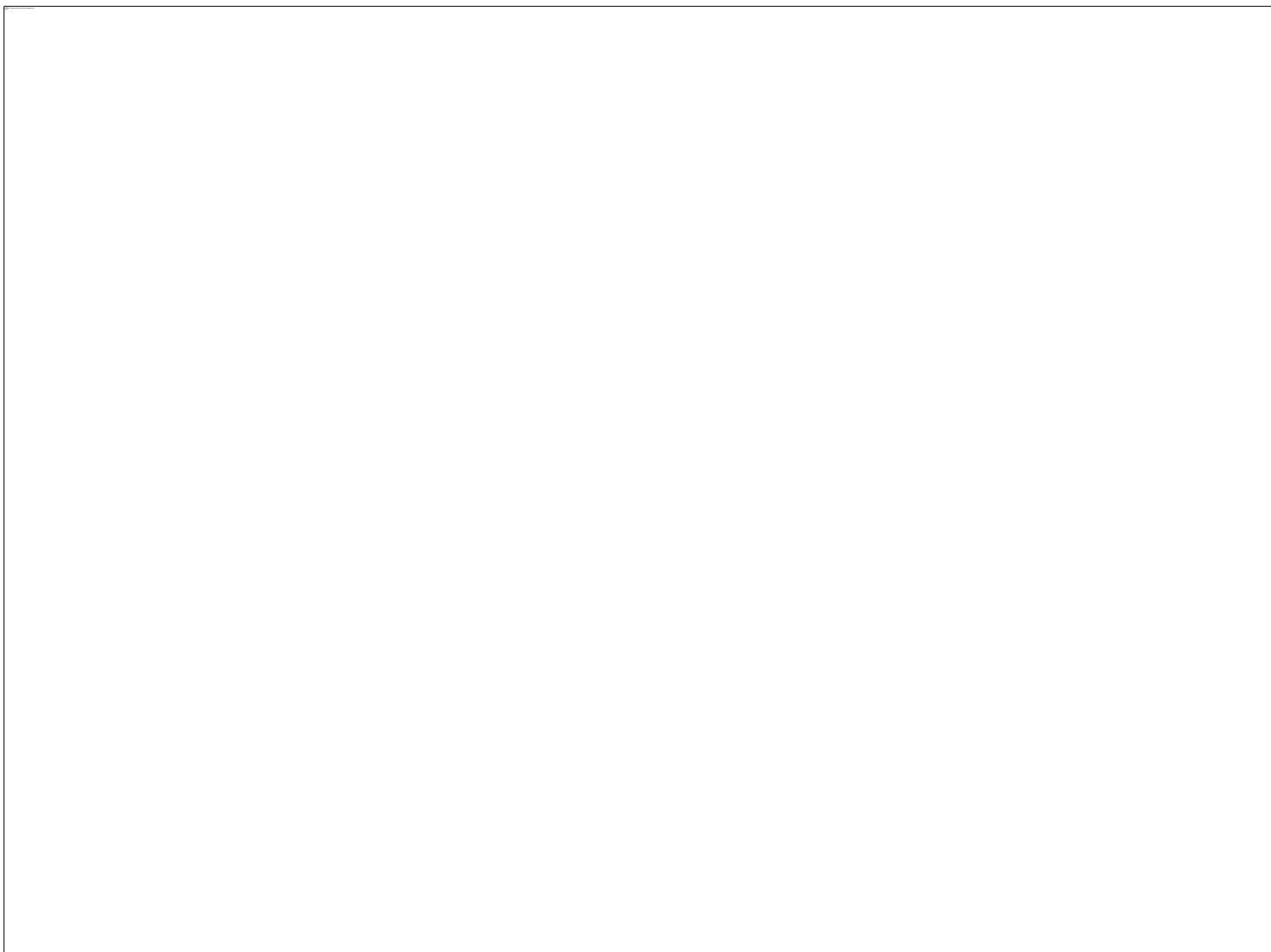
# Laser ablation nanofabrication



Jeon et al., JACS **133** (2011)

Jeon et al., 2011, submitted

## 2D pitch gradient pattern



# 2D pitch gradient pattern



## 3D 2PP nanofabrication examples



25 layer photonic crystal –  
periodicity of 400nm



Multi-scale biomimetic  
structure



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