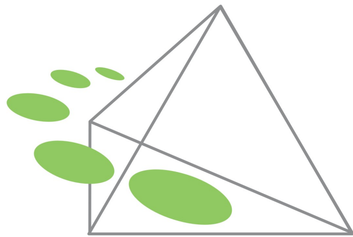
Design and Manufacture of Integrated Nanosystems 2011



CENTER FOR SCALABLE AND INTEGRATED NANOMANUFACTURING

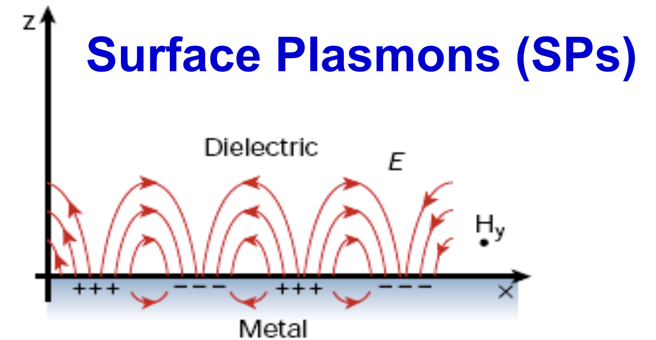
Plasmonic Optics Enables High Throughput Nano-manufacturing

Cheng Sun
Northwestern University

An NSF Nanoscale Science and Engineering Center

Surface Plasmons Promises Subwavelength Resolution

Surface Plasmons: Collective electron oscillations at optical frequencies



ω

Light $k_x = \frac{\omega}{c}$

$$k_x = \frac{\omega}{c}\sqrt{\frac{\varepsilon_m \cdot \varepsilon_d}{\varepsilon_m + \varepsilon_d}}$$

Surface Plasmons

Frequency

Deep sub-λ feature

Plasmon Optics:

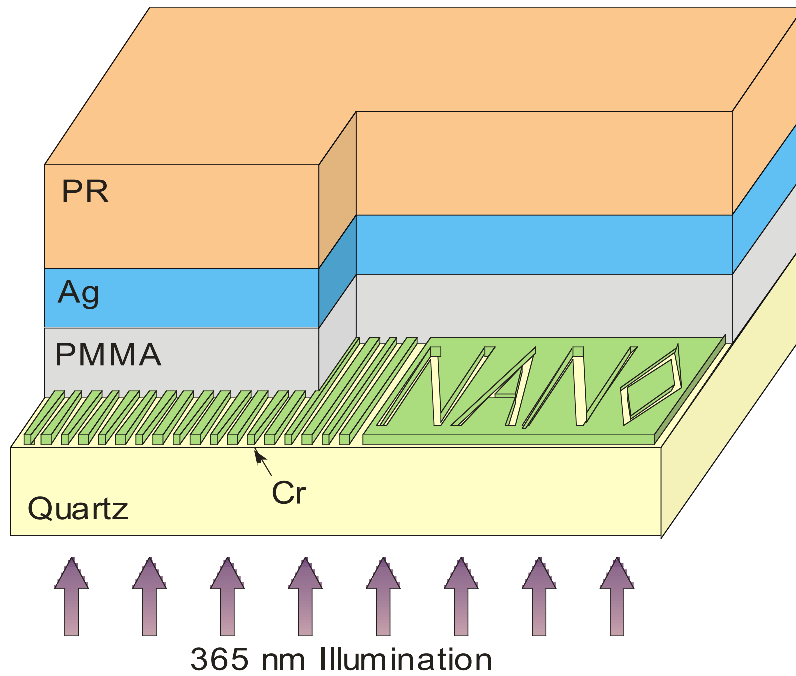
Optical frequency, X-ray wavelength !

Wave Vector

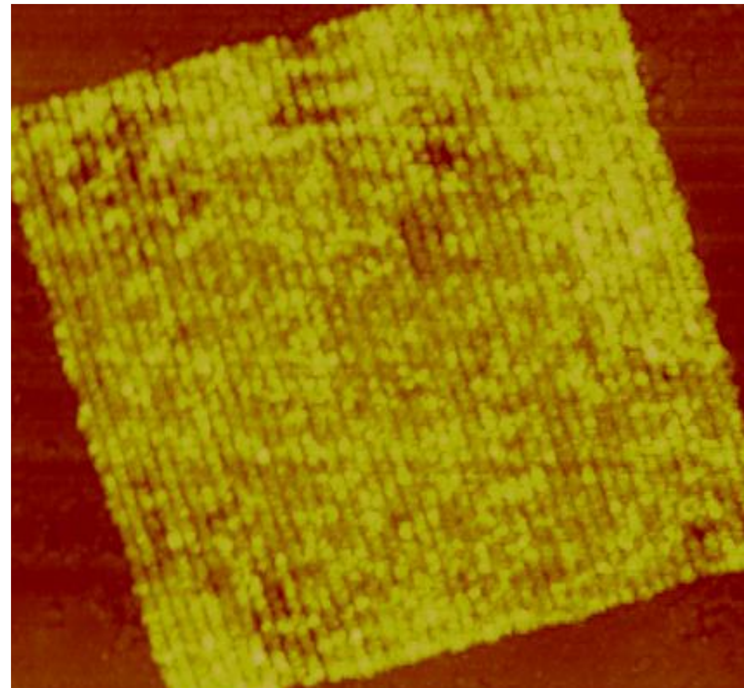
k_x

[H. Raether, Surface Plasmons, Springer-Verlag, 1988]

Plasmonic Superlensing at 60 nm



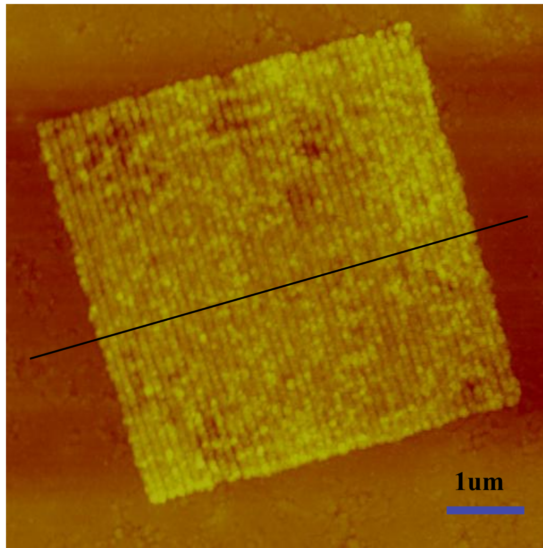
60 nm wire array image

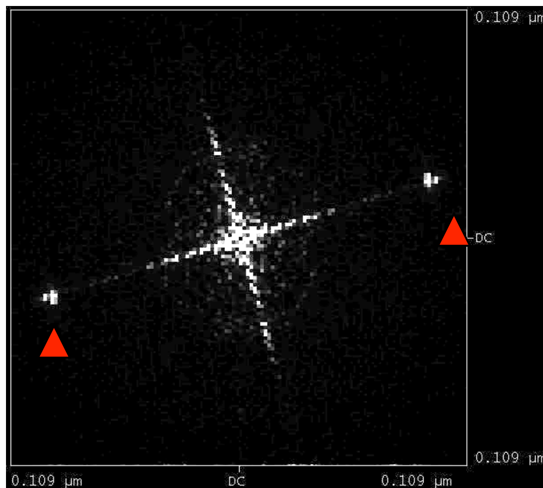


[Fang, Science, 2005]

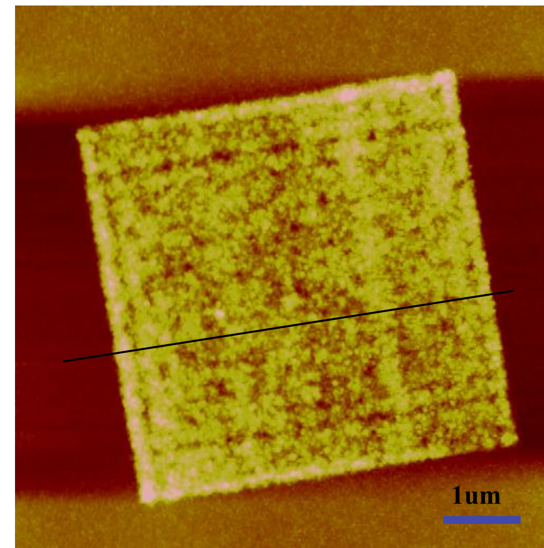
Imaging Results (Fourier Space)

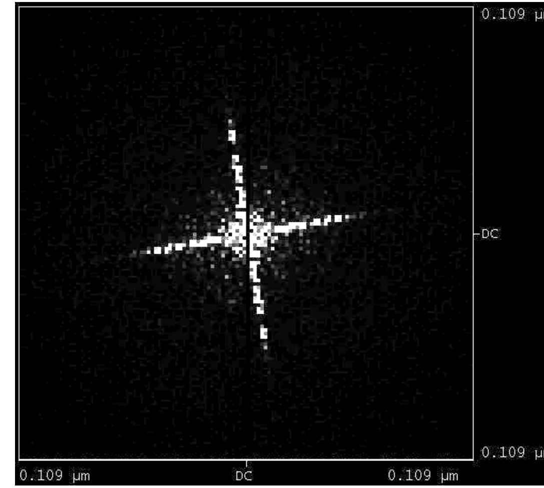
Superlens Nano-lithography





Control – w/o Superlens

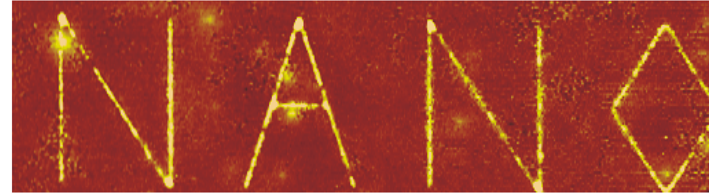


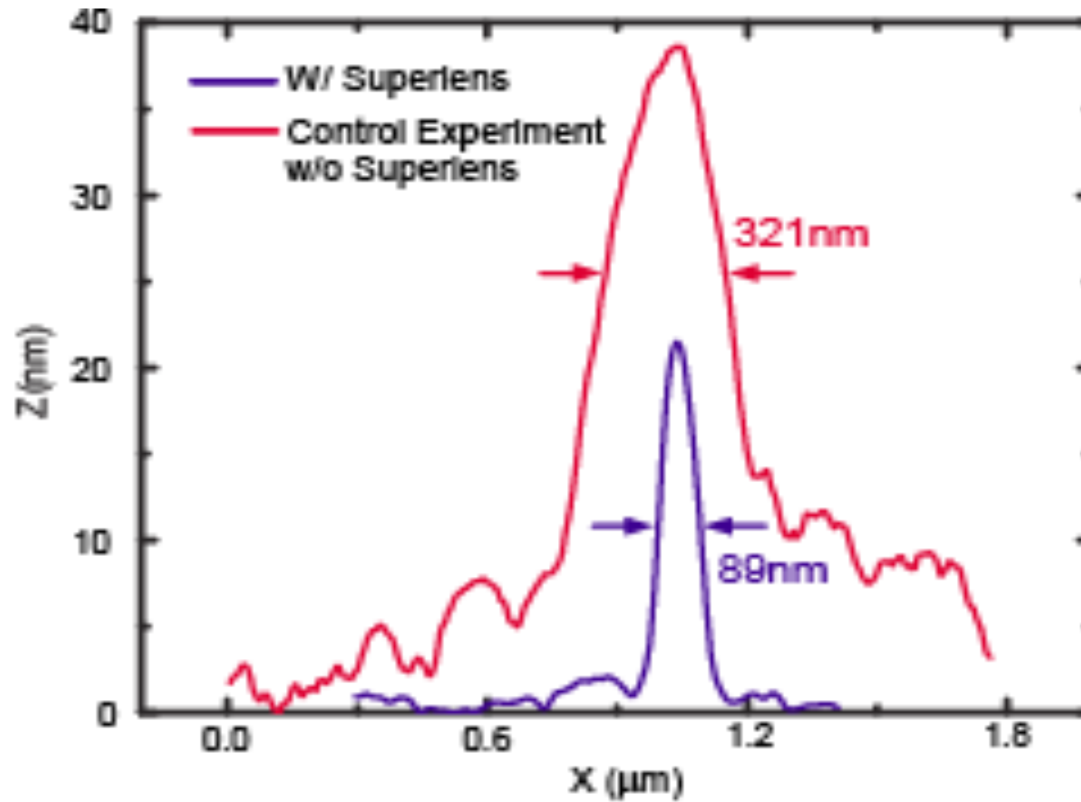


Superlensing of Arbitrary Object

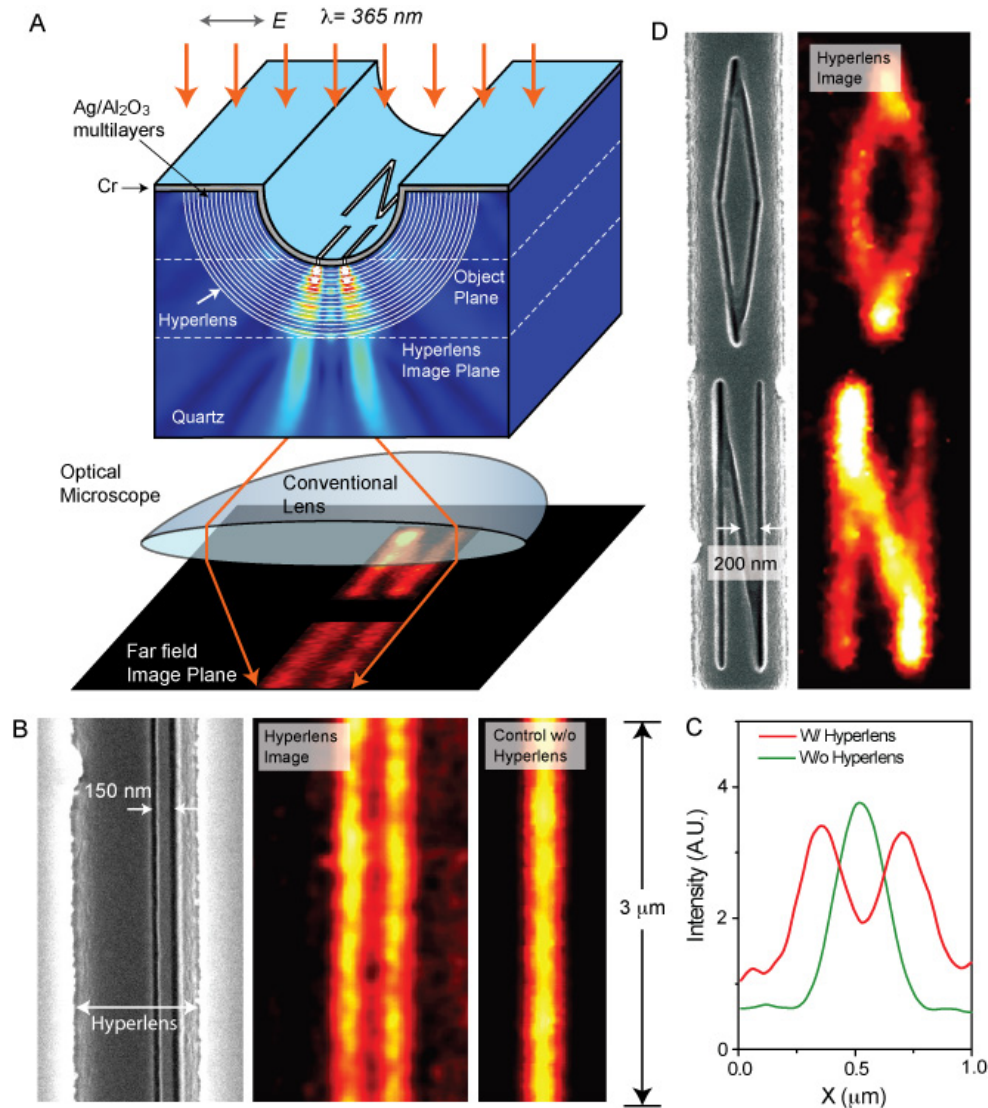
Object made by FIB

Superlens Nano-lithography





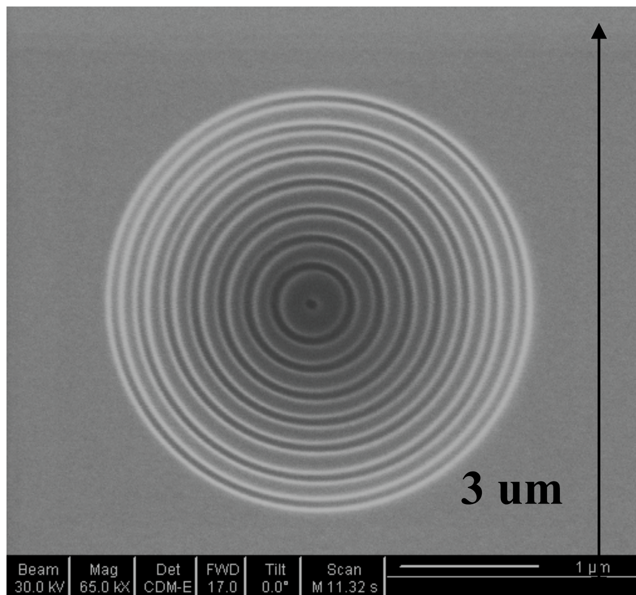
Optical Hyperlens



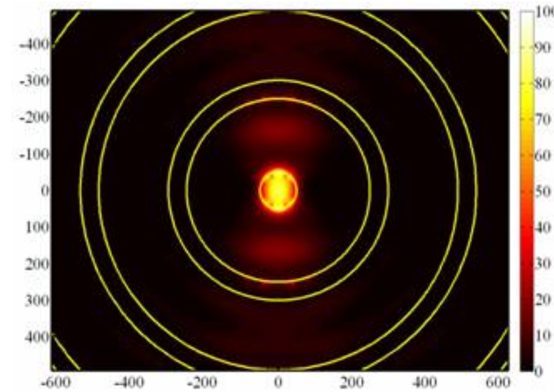
[Liu, Science, 2007]

Plasmonic Focusing Lens Design

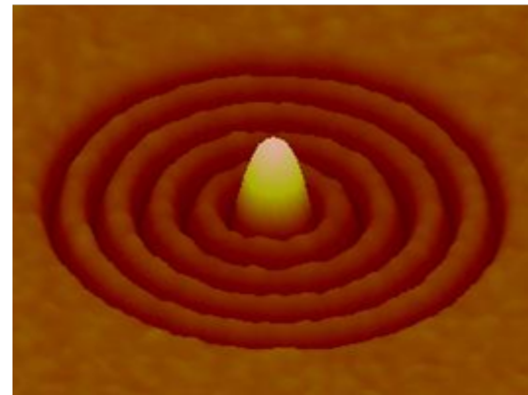
Plasmonic Focusing Lens



Simulation



Experiment



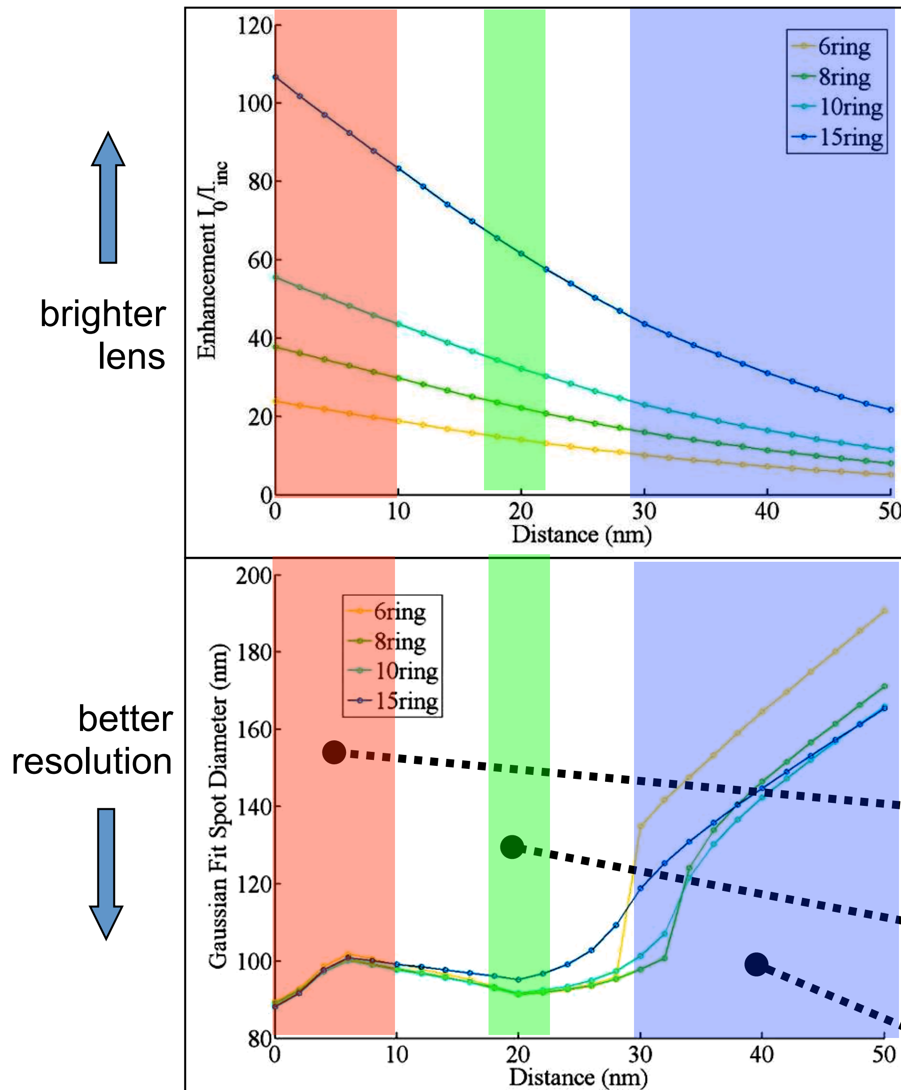
- 100 nm focus
- High Intensity at focus point

Intensity Enhancement: ~ 30

[Thio, et. al., Opt. Lett., 2001]

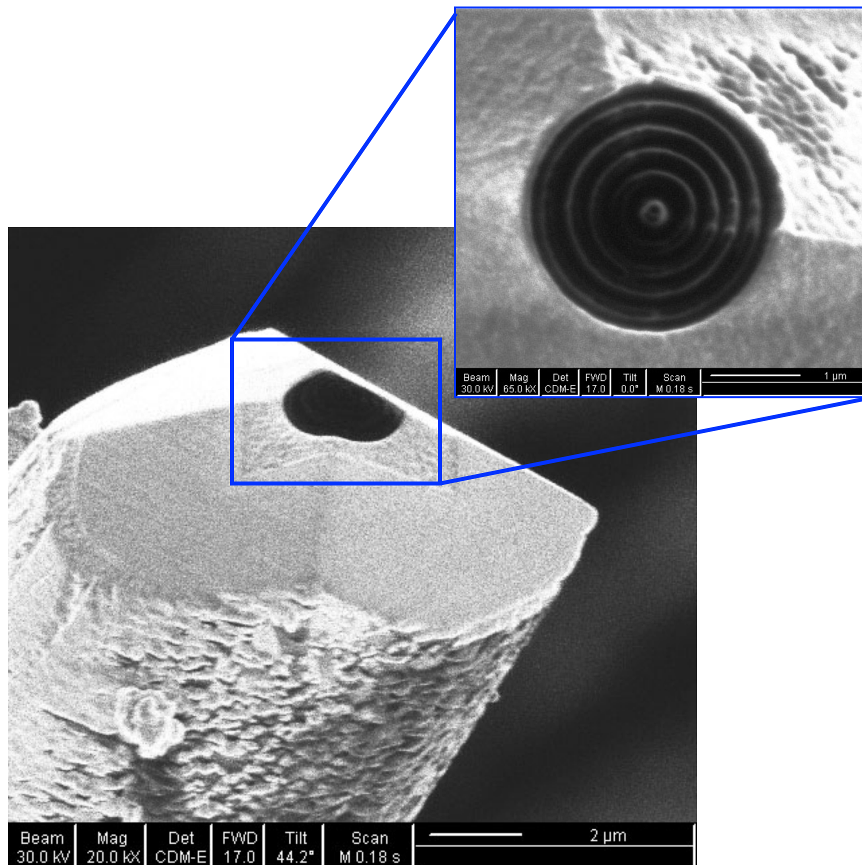
[Srituravanich, Nano Lett., 2004]

Challenges of Working Distance

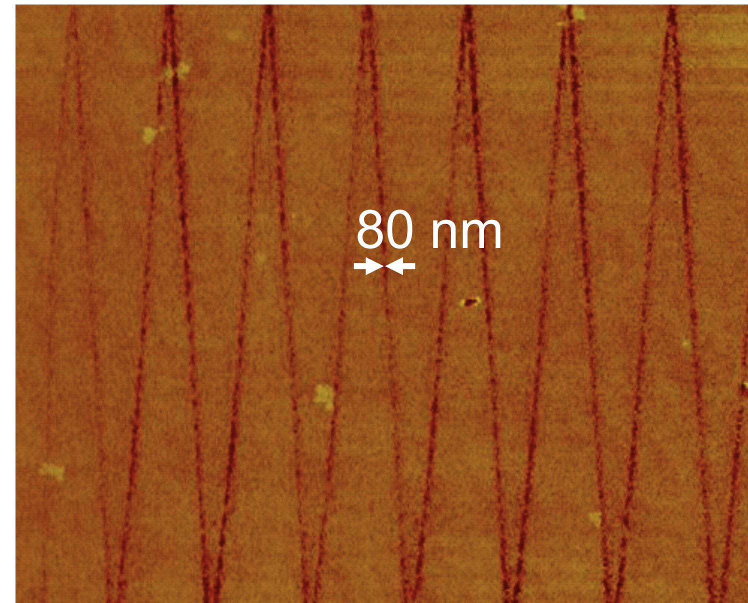


- Writing distance of the PL need to regulated with a few nanometers accuracy in order to achieve good reliability and capability.
  - SP waves decays exponentially w.r.t. distance.
  - Exists a critical gap where smaller gap will cause excessive interface damages during high speed scanning.

Nanolithography by Scanning Plasmonic Lens



80 nm lines by scanning of the plasmonic lens

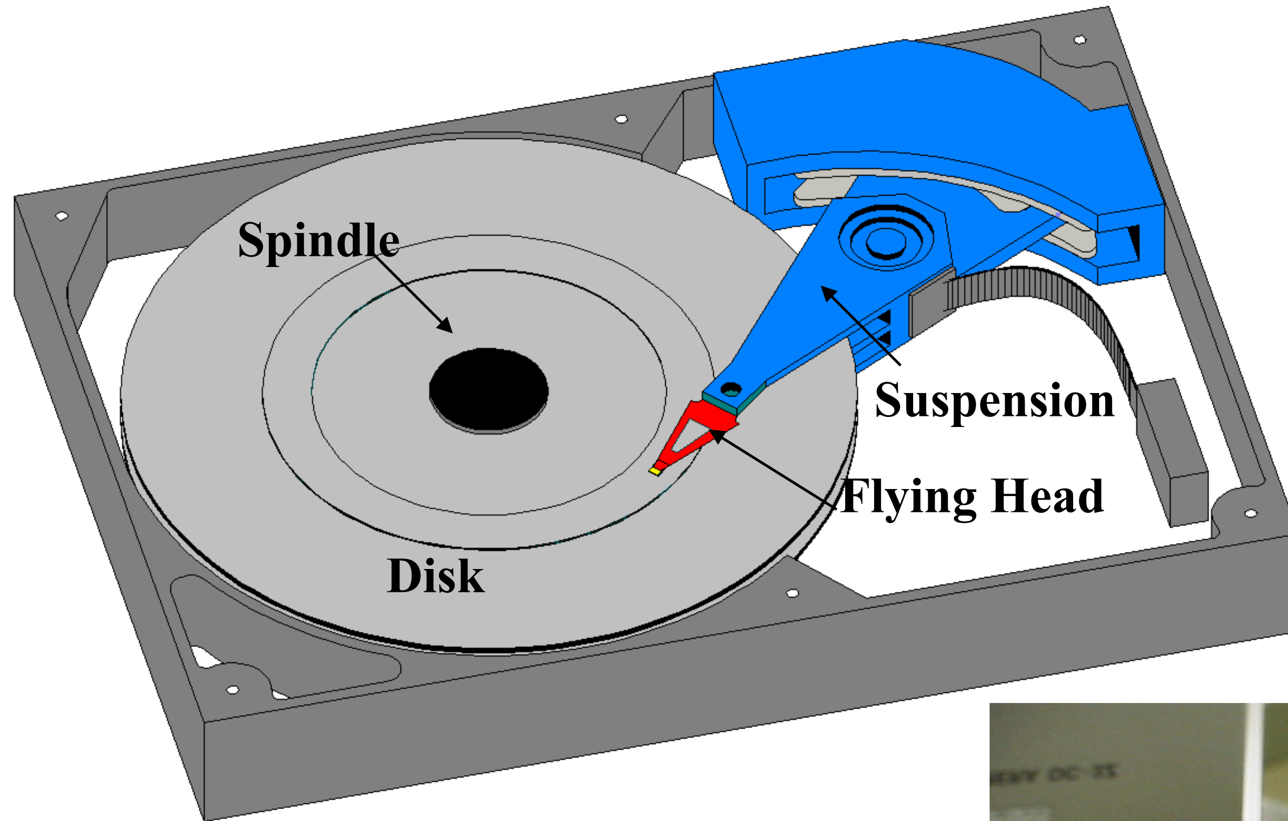


Laser power ~0.25 mW at 40 µm/s scanning rate

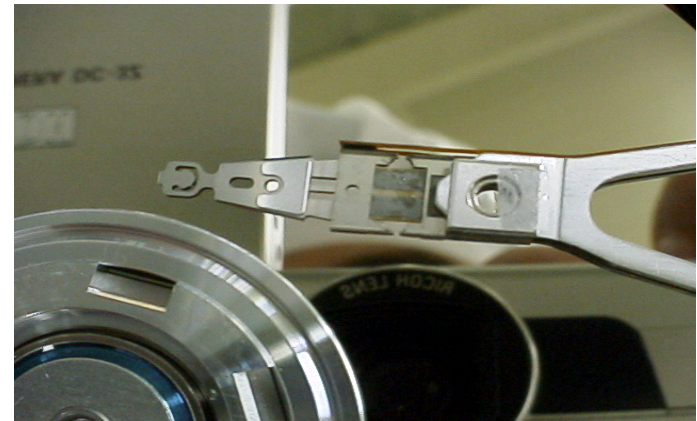
80 nm lithographic resolution has been demonstrated but at very low scan speed!

[Wang, Nano Lett, 2009]

Flying Plasmonic Lens at Nearfield for High Throughput Nanolithgraphy



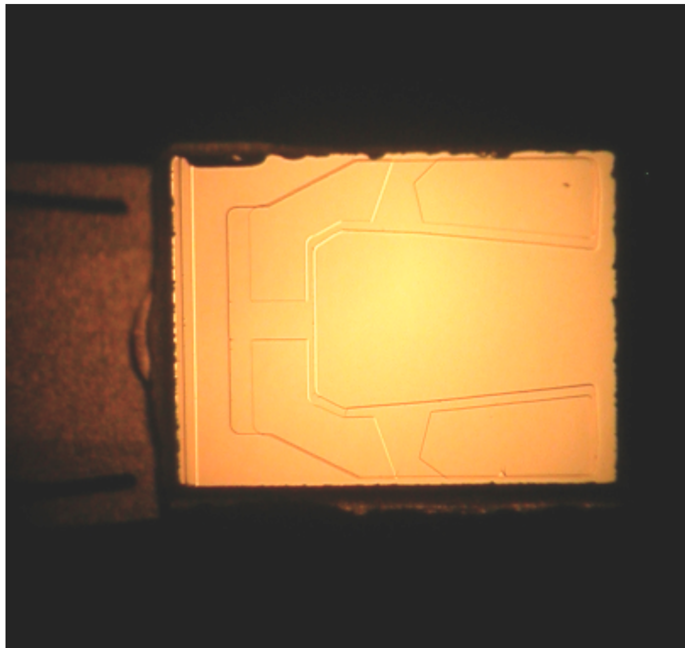
High disk flying head running at
10 Meter/second with gap ~ 20 nm!



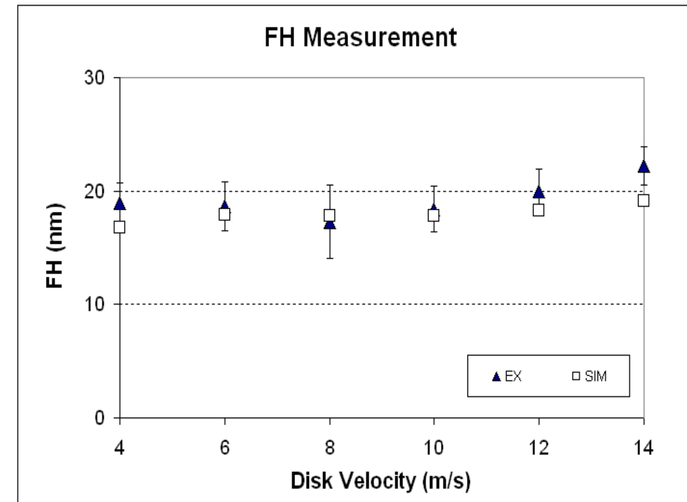
High Speed Flying Head design

Challenges:

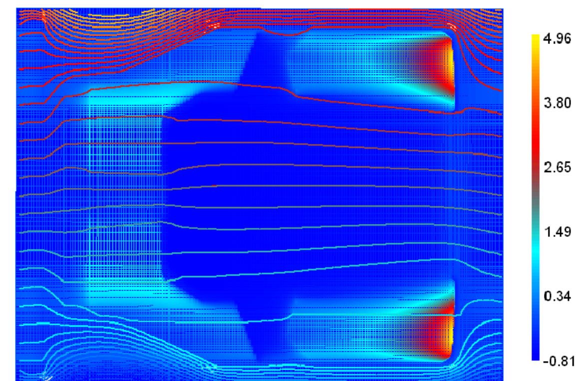
- Transparent Slider fabrication
- Flying dynamics to maintain parallelism
- Process reliability



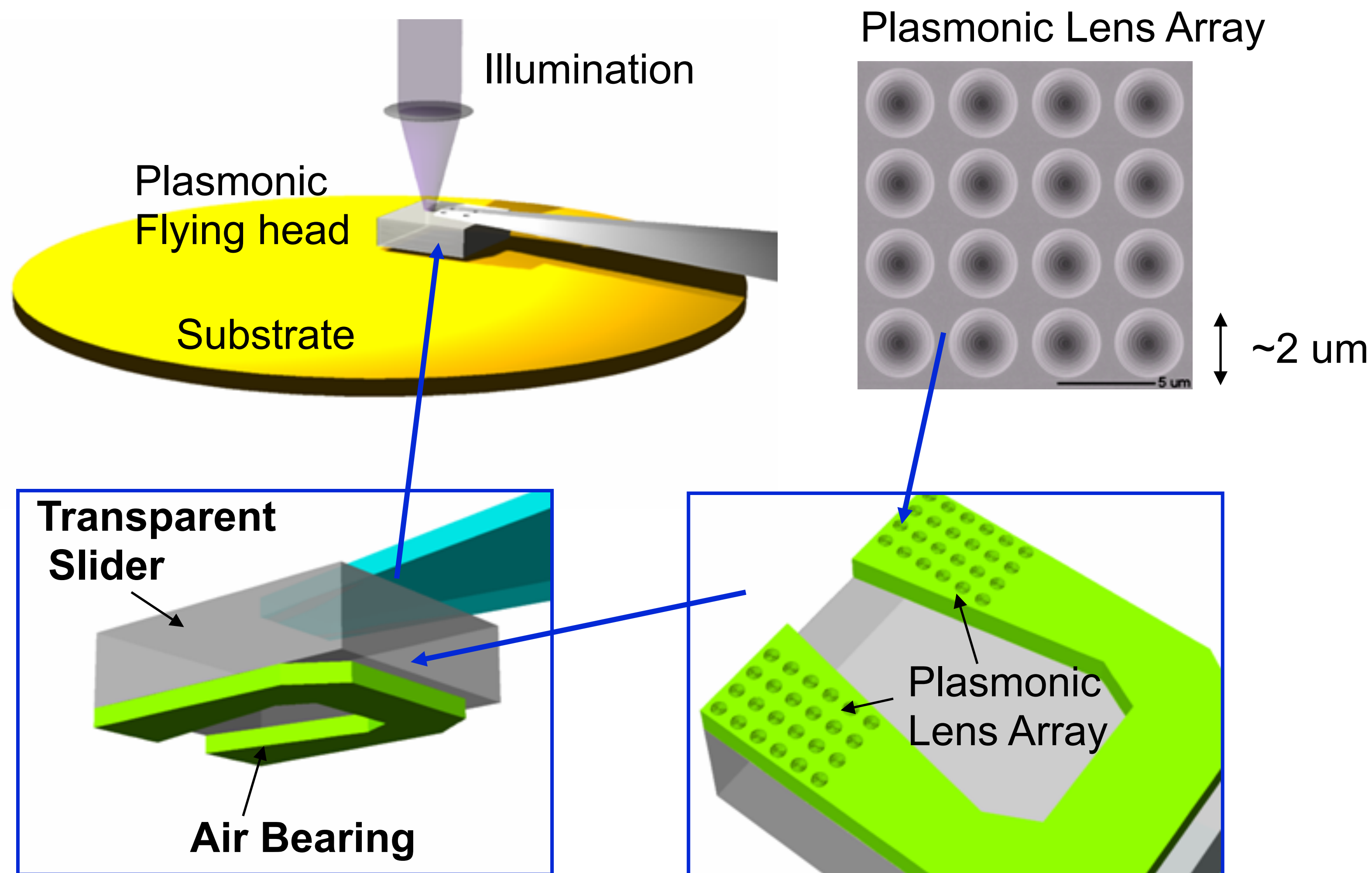
Flying High Simulation



Simulated air bearing pressure profile.

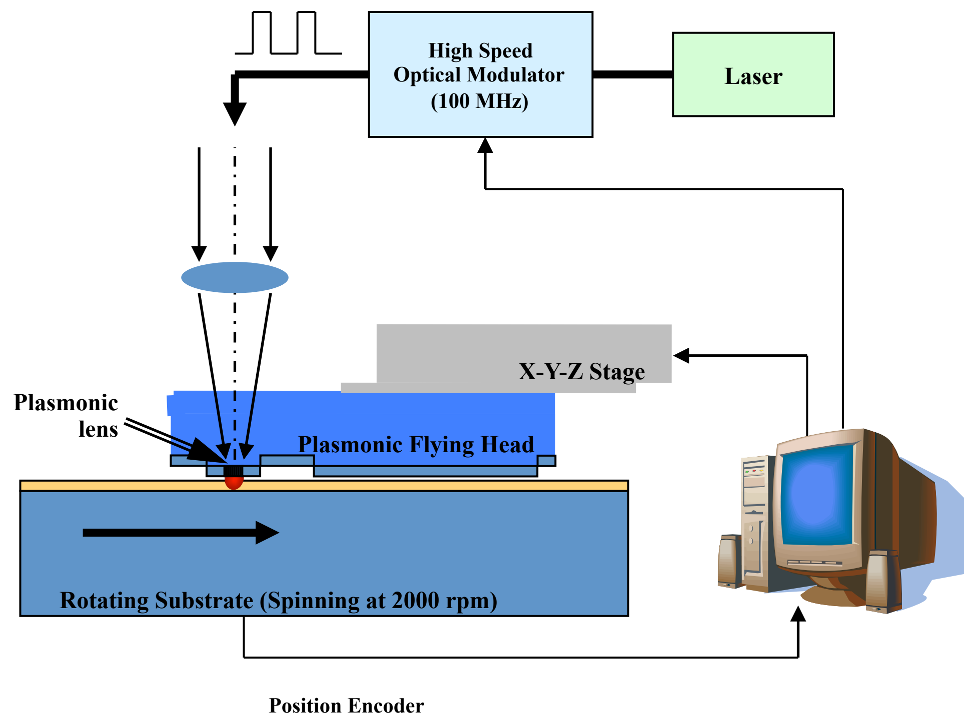


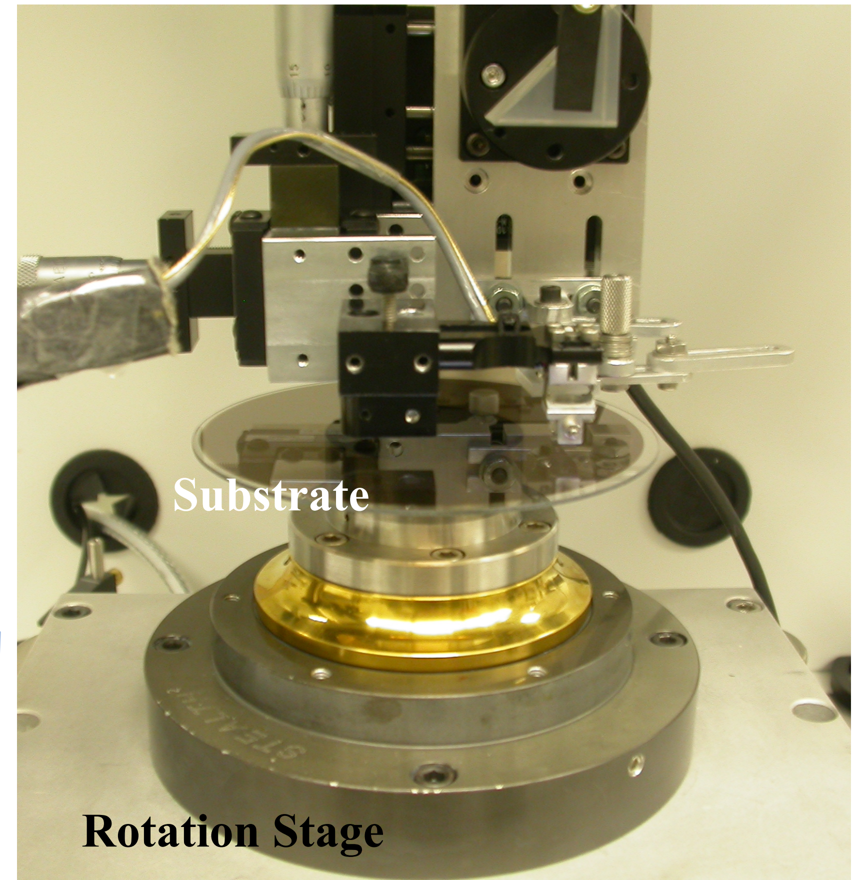
High-throughput Plasmonic Lithography



>60 Wafers per hour using 10,000 lenses at 22 nm hp

High Speed Plasmonic Nanolithography Machine





Plasmonic NanoLithography (PNL)

- By integrating nano-optics structure, plasmonic lens (**PL**), to air bearing slider, we demonstrated high speed direct pattern writing onto thermal-type Inorganic PhotoResist (**IPR**).

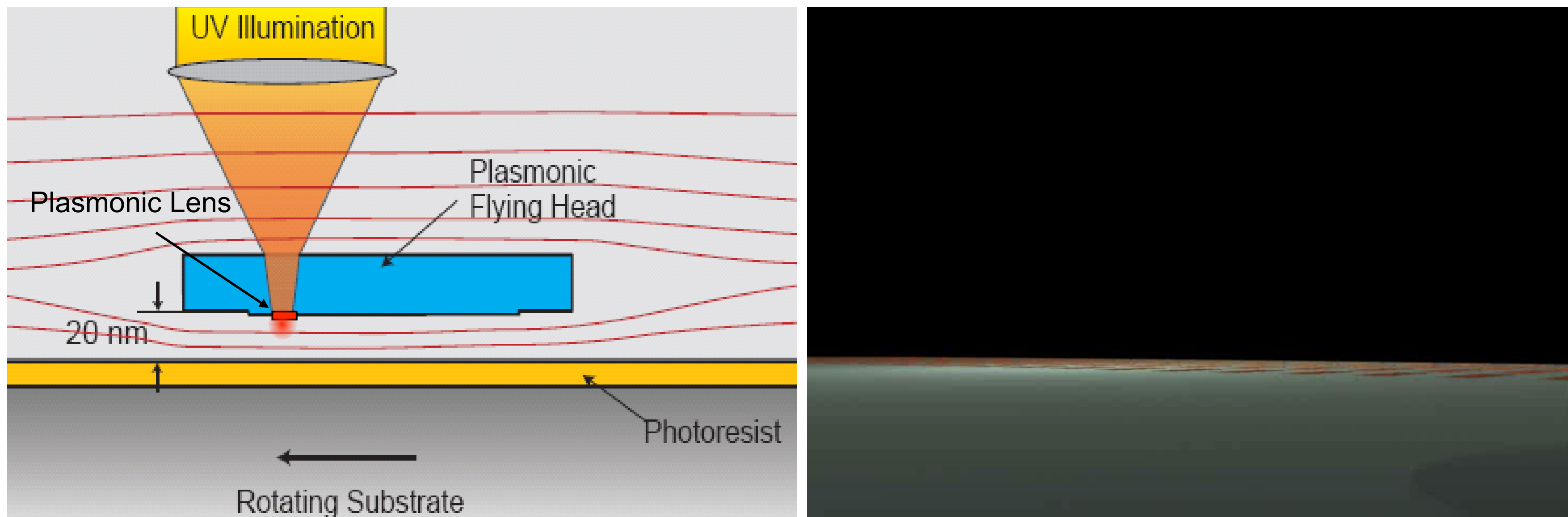
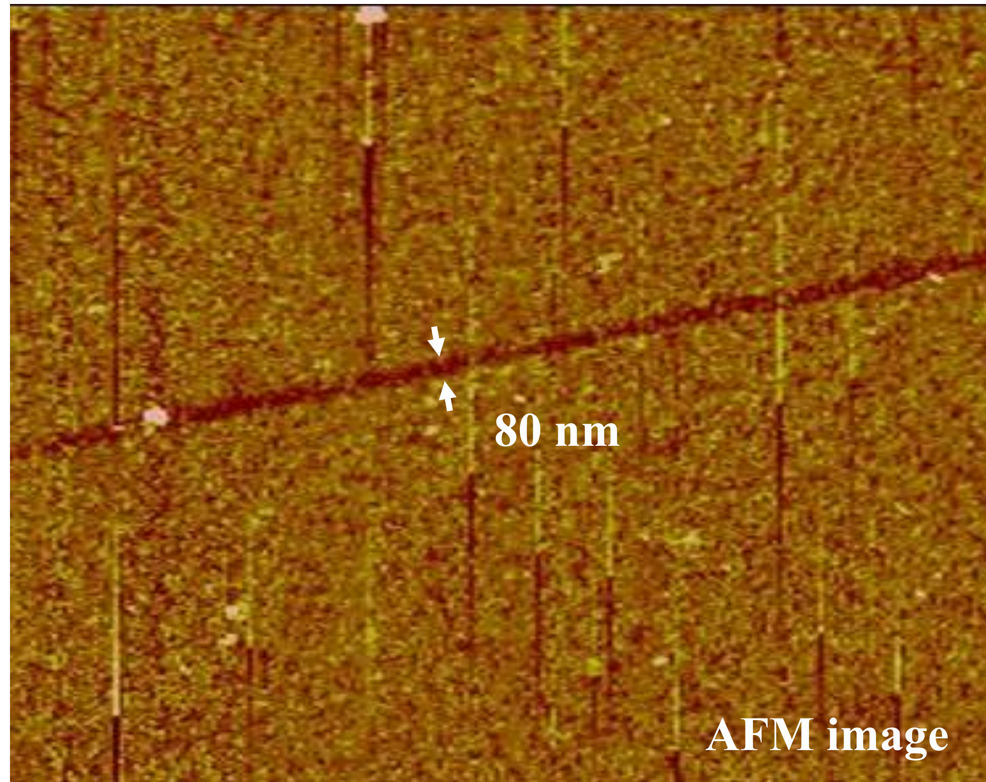


Illustration of Plasmonic NanoLithography

Plasmonic Nano-lithography at 10 Meter/second

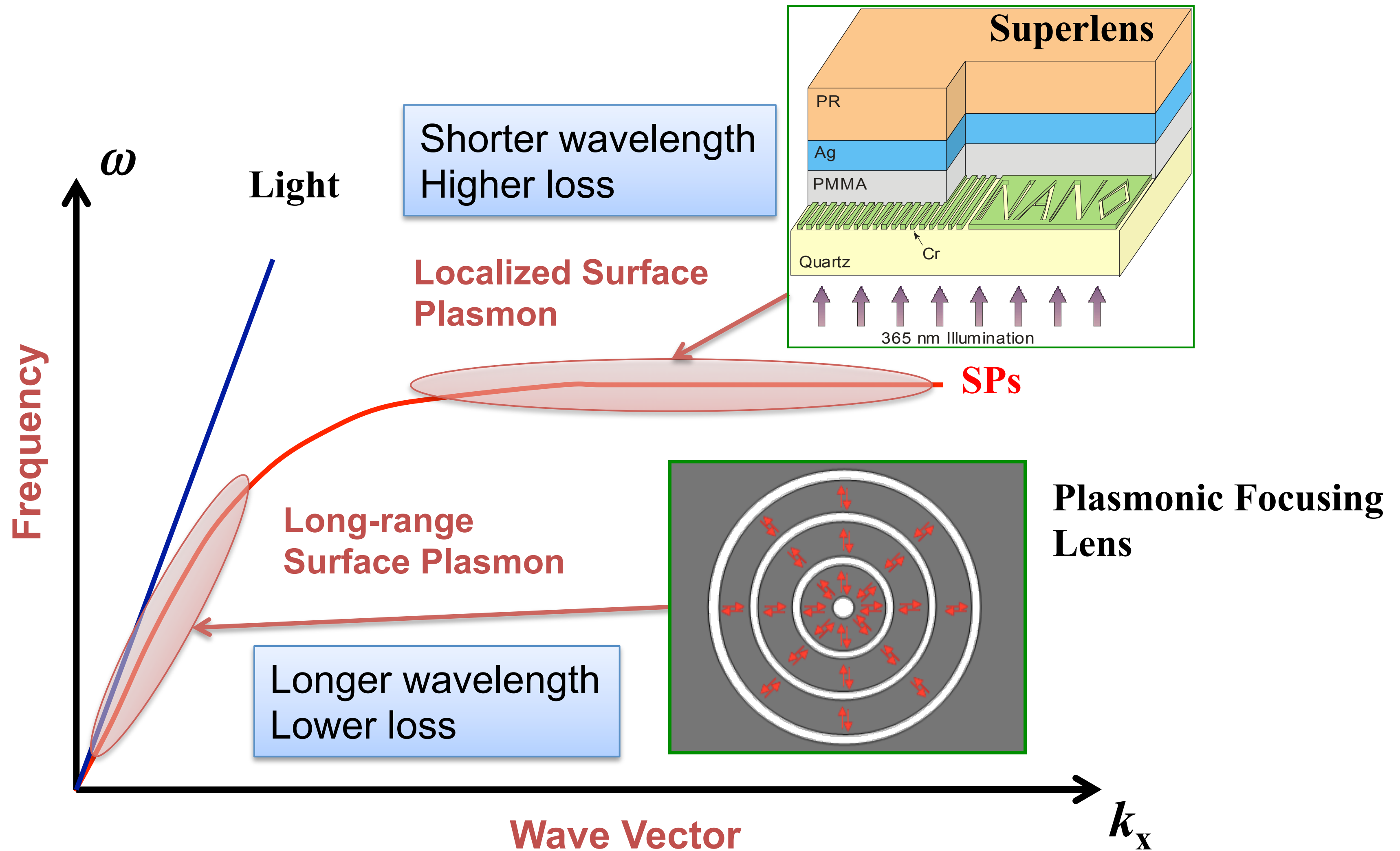
For high-throughput maskless lithography



Spindle Speed: 2000 rpm (10 m/s)
Laser power: 150 ~ 200 mW @ 365nm

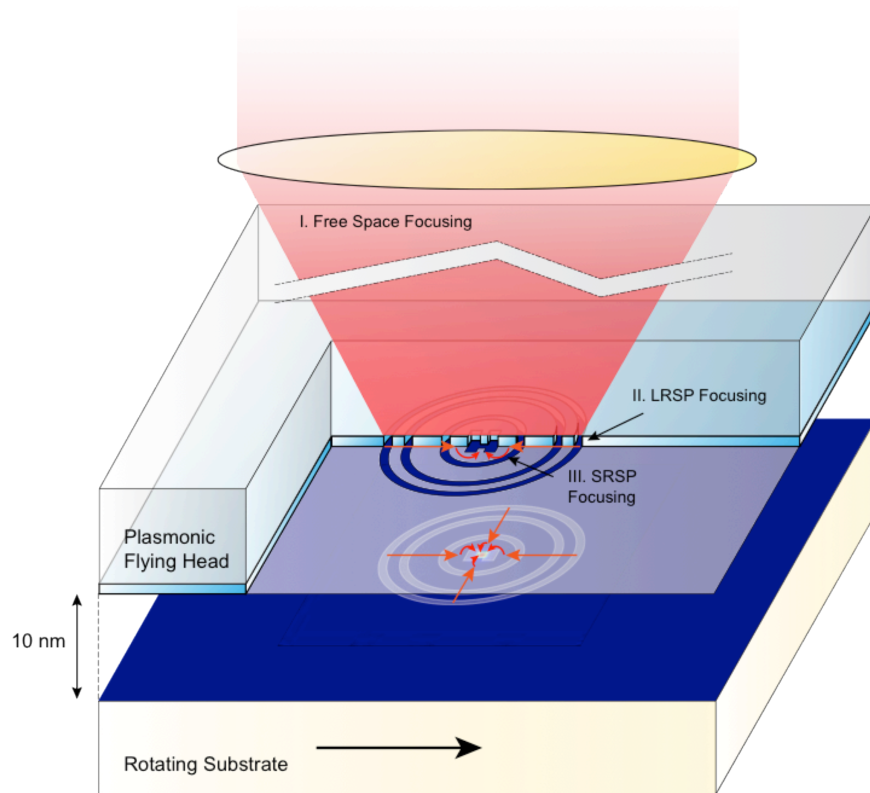
[Nature Nanotechnology, 2008]

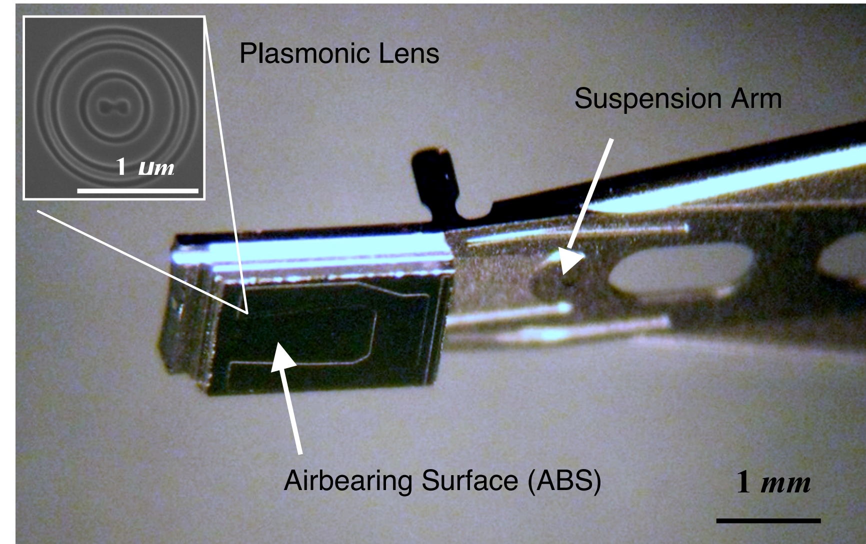
Optical Superlens vs. Plasmonic Focusing Lens



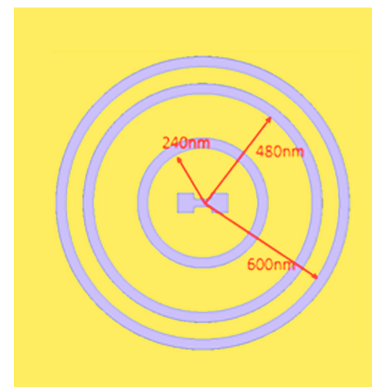
[H. Raether, Surface Plasmons, Springer-Verlag, 1988]

A Hybrid Plasmonic Focusing Lens Design

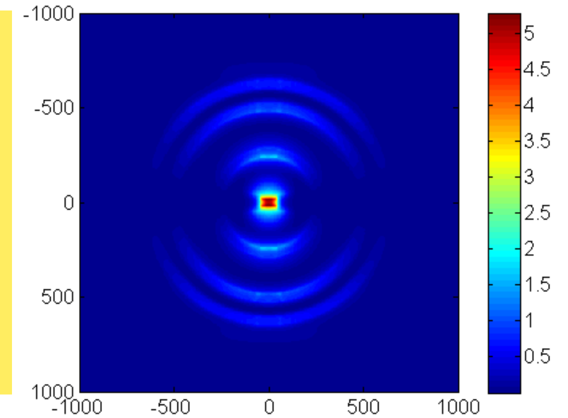




Hybrid Lens Design

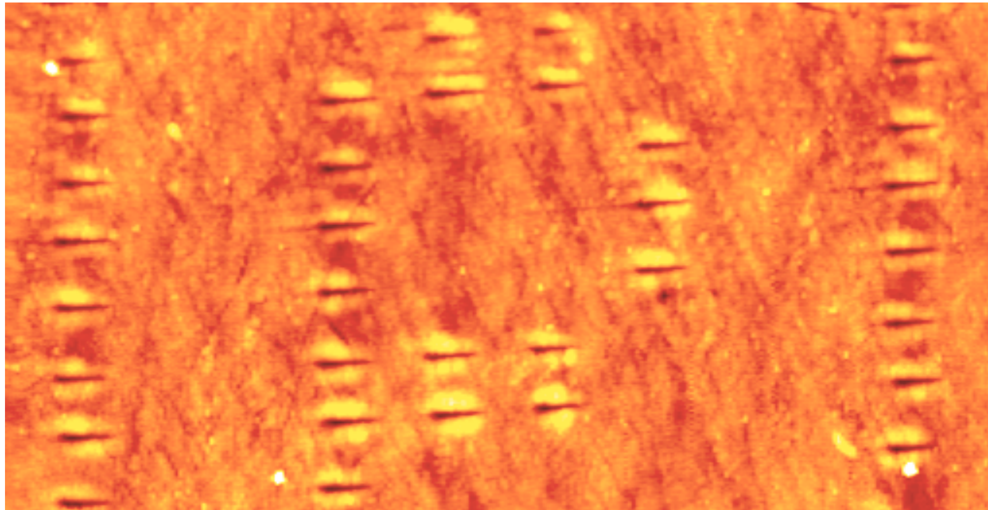


Numerical Simulation

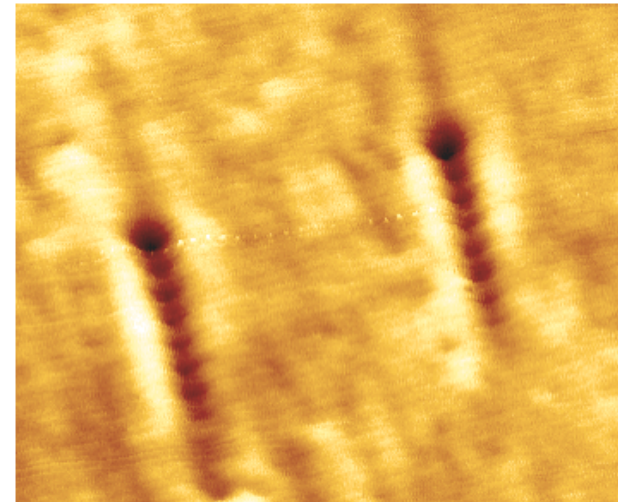


22 nm Half-Pitch Nano-lithography (~λ/16)

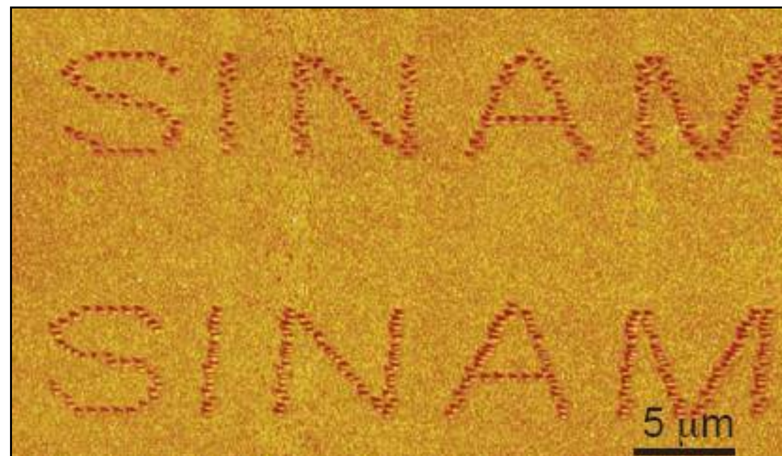
Line pattern at 30nm FWHM



22nm half-pitch features



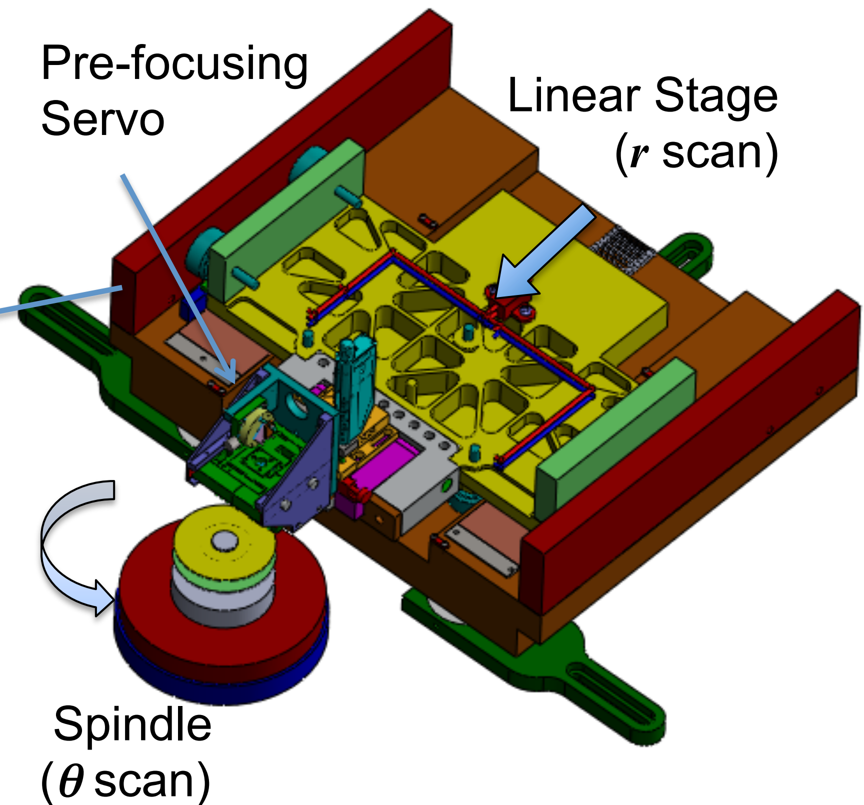
Arbitrary Pattern Writing



Tool Development: Working in Progress

UV Laser
& Optics

Nano-positioning Assembly



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