Plasmon Printing

Using metal nanoparticle arrays for near field optical lithography

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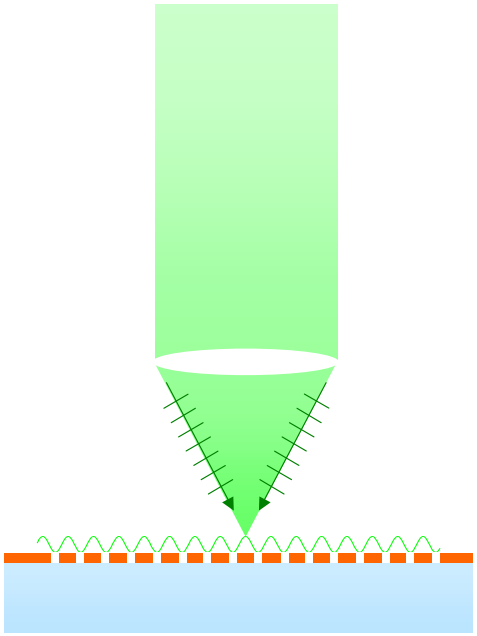
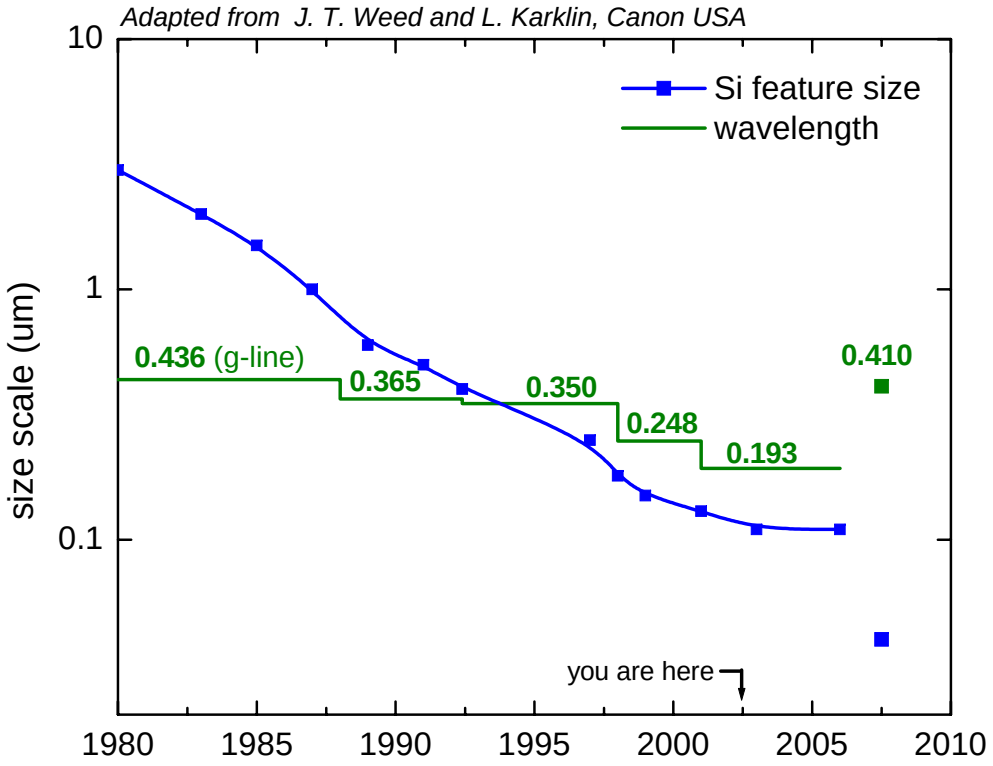
Projection lithography and the diffraction limit





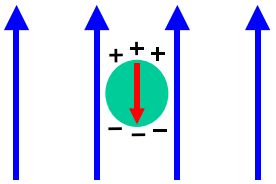
Projection lithography
smallest feature size **~λ**

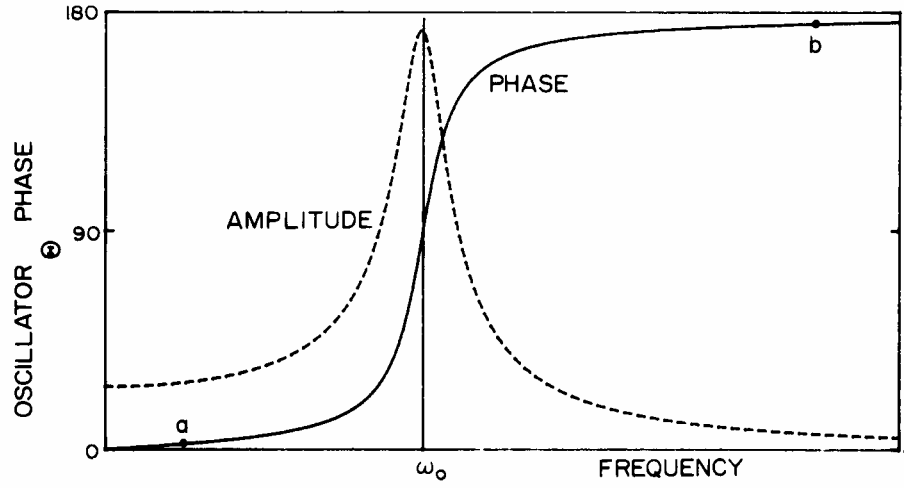
Plasmon printing
smallest feature size **~0.1 λ**

The surface plasmon resonance

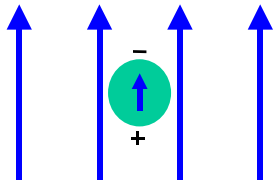
Absorption and scattering of light by small particles, Bohren & Huffman

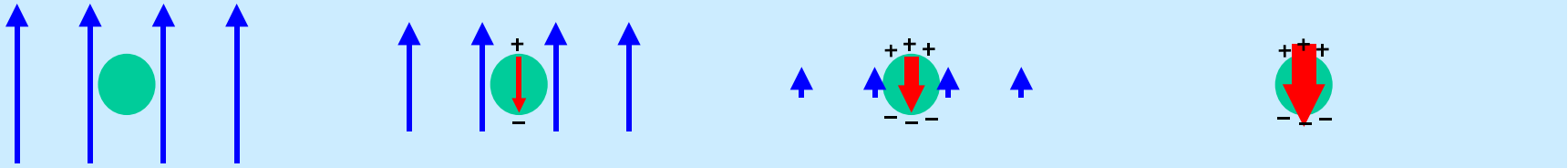
low frequency





high frequency

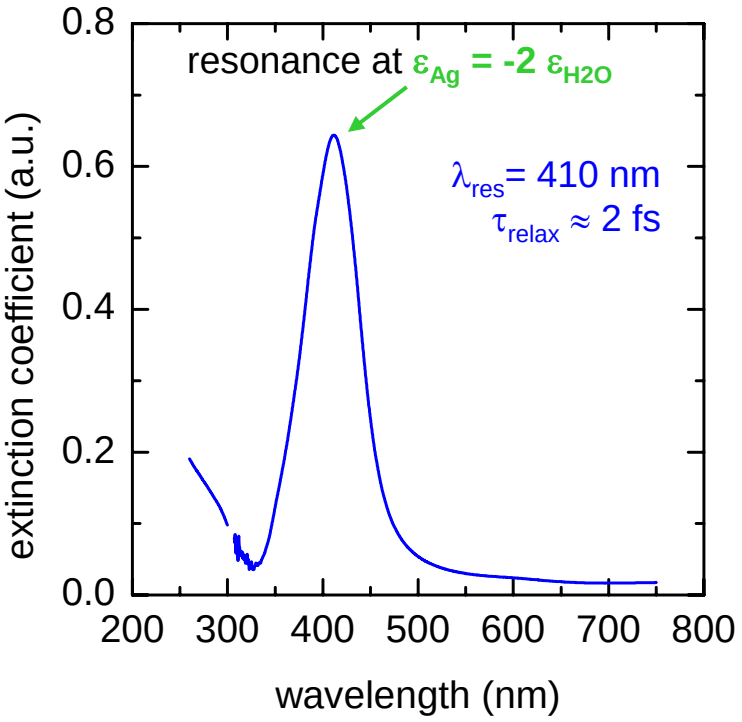




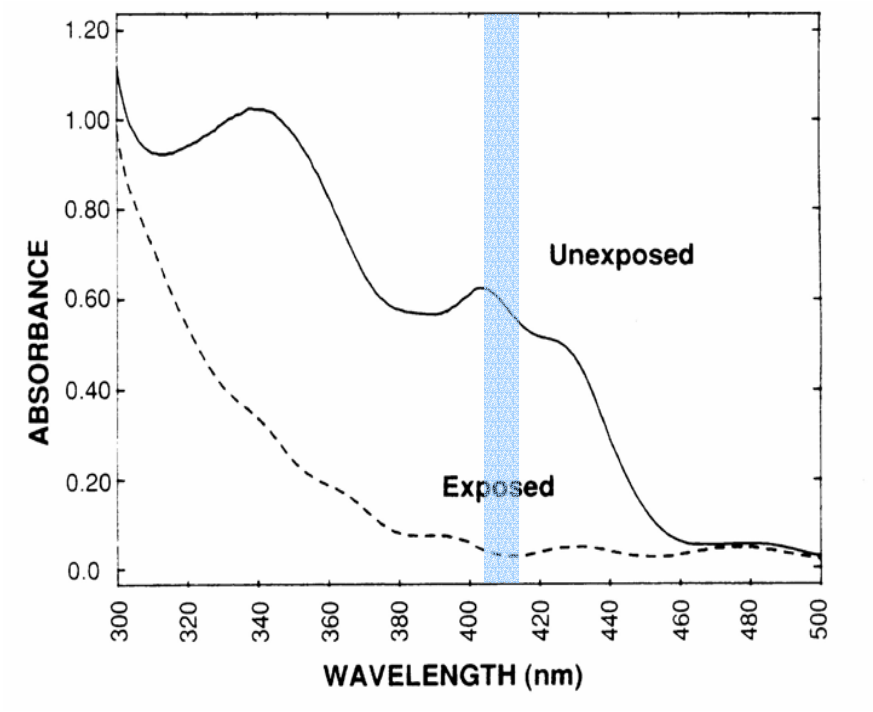
resonance: electron phase lag 90° $\Rightarrow$ field enhancement

Resonance in Ag nanoparticles

Ag (∅ 41 nm) in solution



AZ photoresist (g-line)

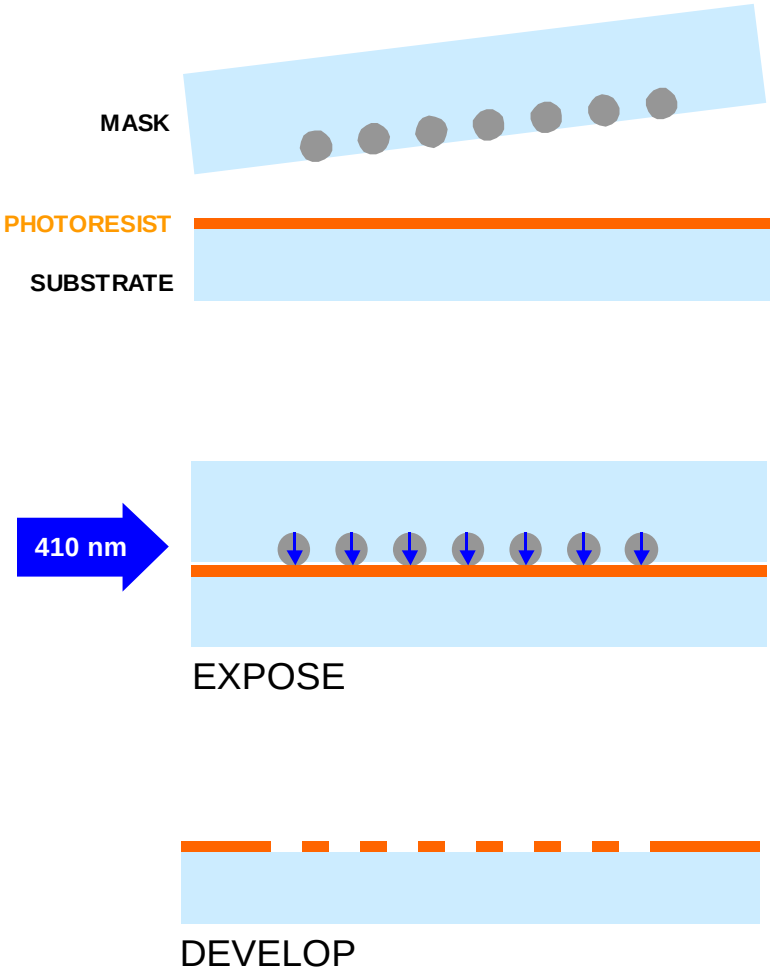


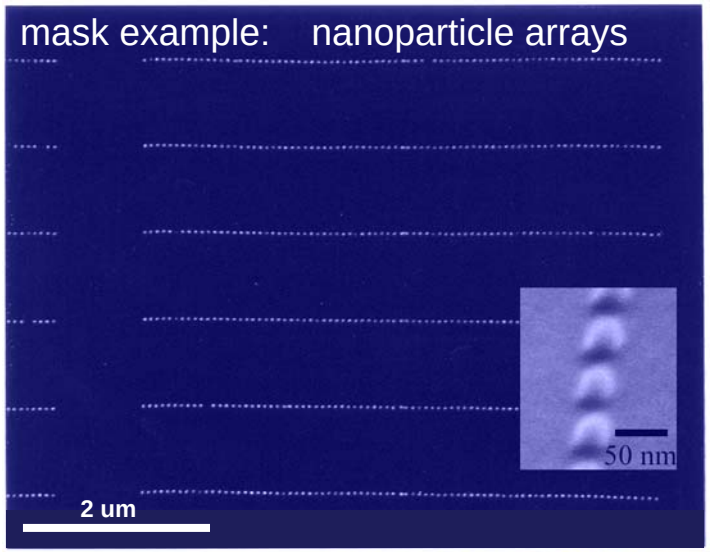
resonance wavelength: N_e, n_{matrix}, shape, size

resonance strength: τ_e ("internal" + surface scattering)

Ag: Strong resonance within sensitivity of standard g-line photoresist

Printing scheme

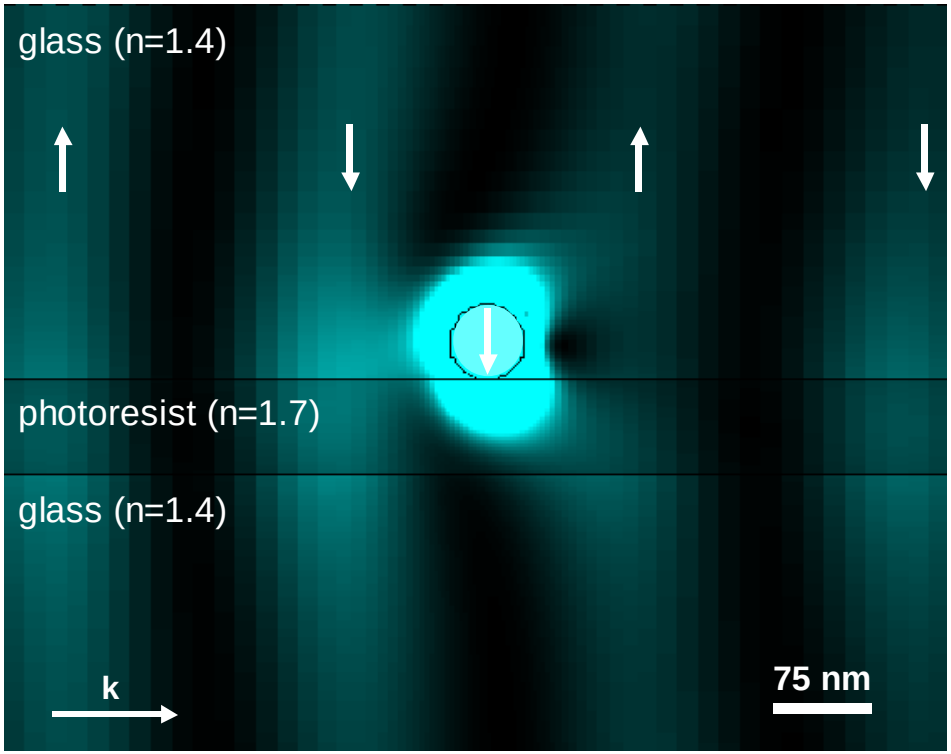




Mask fabricated with JPL, Pasadena, CA

- ✓ high resolution mask ($$)
- ✓ standard resist
- ✓ simple light source
- ✓ parallel, sub-wavelength

3D Finite Difference Time Domain calculations



Ag: Drude model

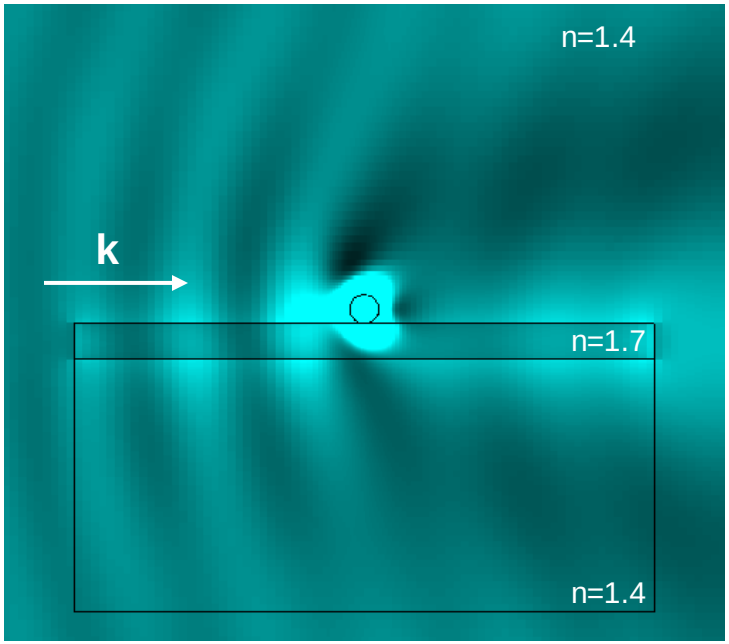
$$\varepsilon(\omega) = 1 - \frac{\omega_p^2}{\omega^2 - i\omega\gamma}$$

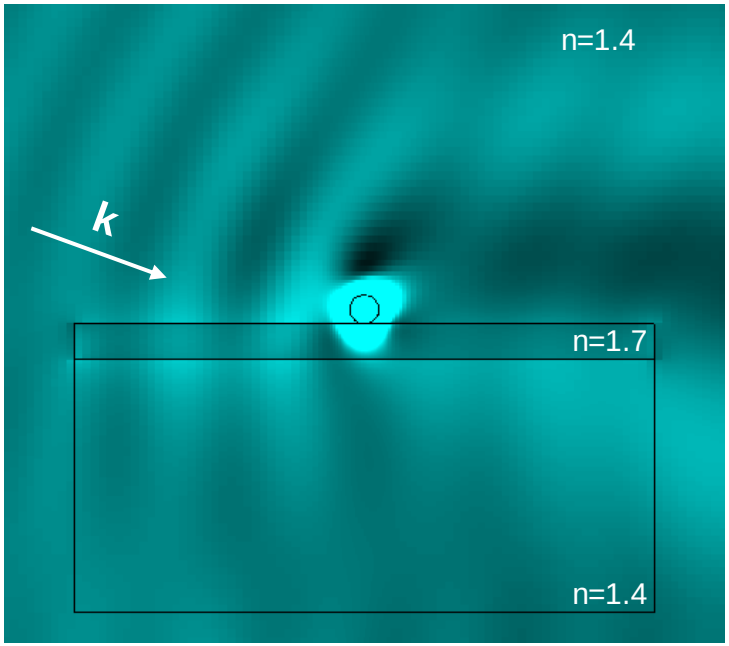
with $\gamma = \tau_e^{-1}$

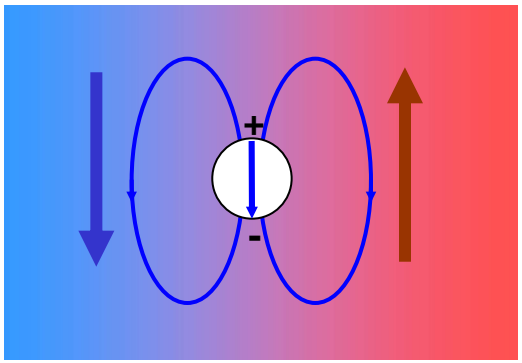
wavelength	439 nm
simulate	20 cycles
time step	750 / cycle

- Enhanced energy density directly below particle
- phase lag 90° $\Rightarrow$ resonant excitation

Time averaged energy density

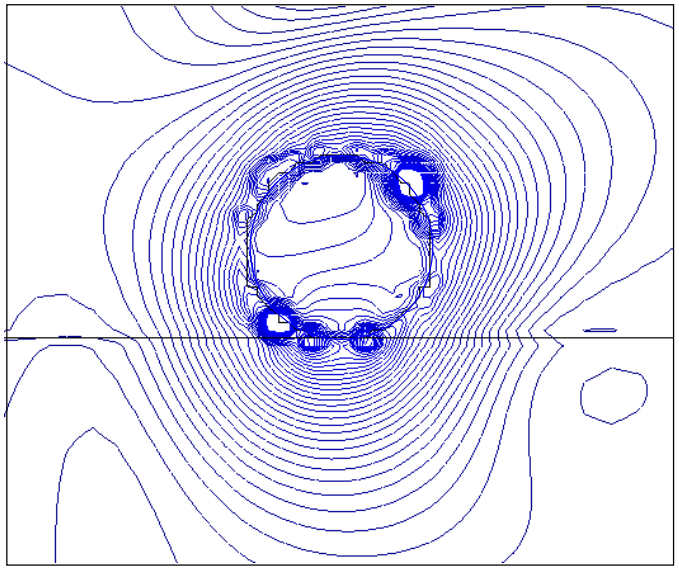




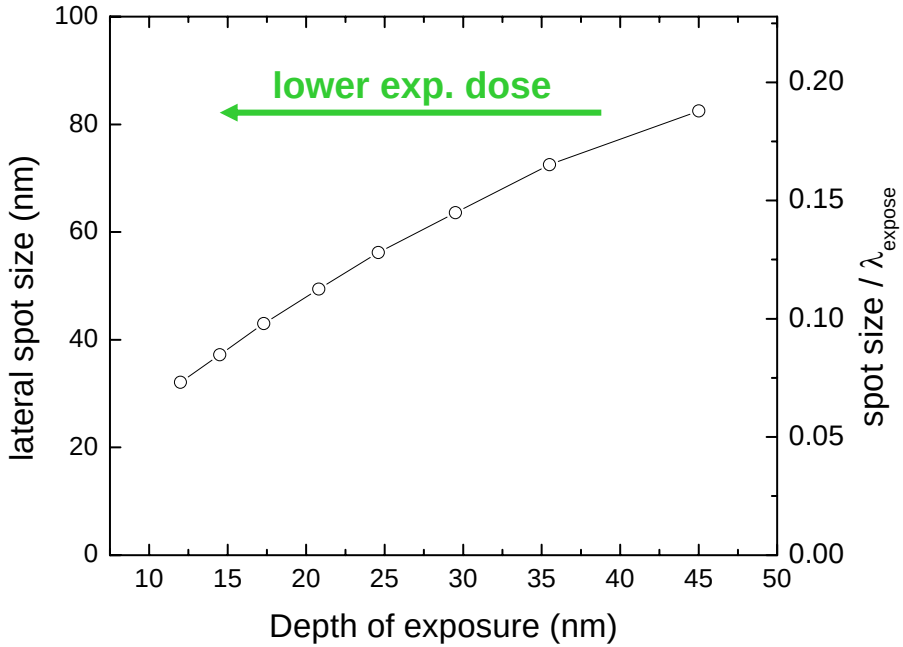


- enhanced exposure in photoresist layer
- interference fringes due to scattering
- phase lag $\Rightarrow$ spot anisotropy
- inclined illumination improves spot shape

Spot size vs. exposure dose

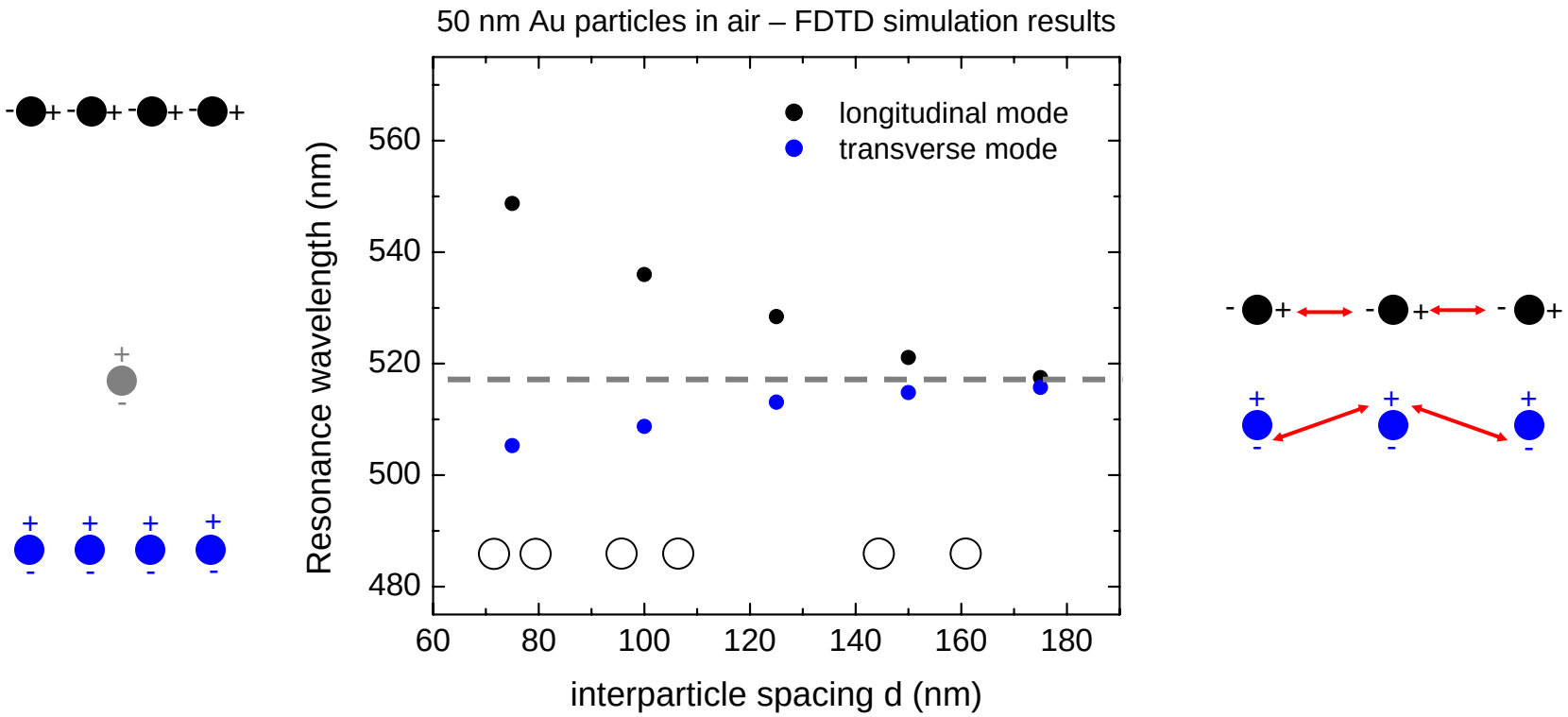


iso intensity lines 1 dB apart



- smallest features λ/15 (limited by simulation)
- trade-off: smaller width at the cost of lower depth
- **maximum** size determined by field enhancement

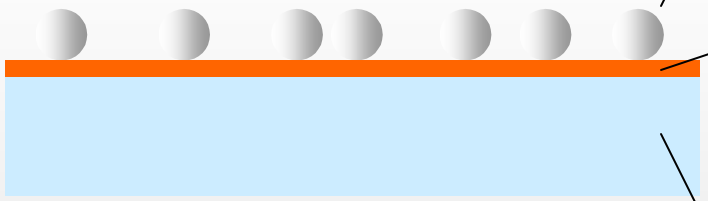
Particle-particle interactions



Closely spaced particles: collective modes and shifted resonances

Can be compensated by particle shape (e.g. 1:3 aspect $\Rightarrow$ 70 nm shift)

Initial experiments



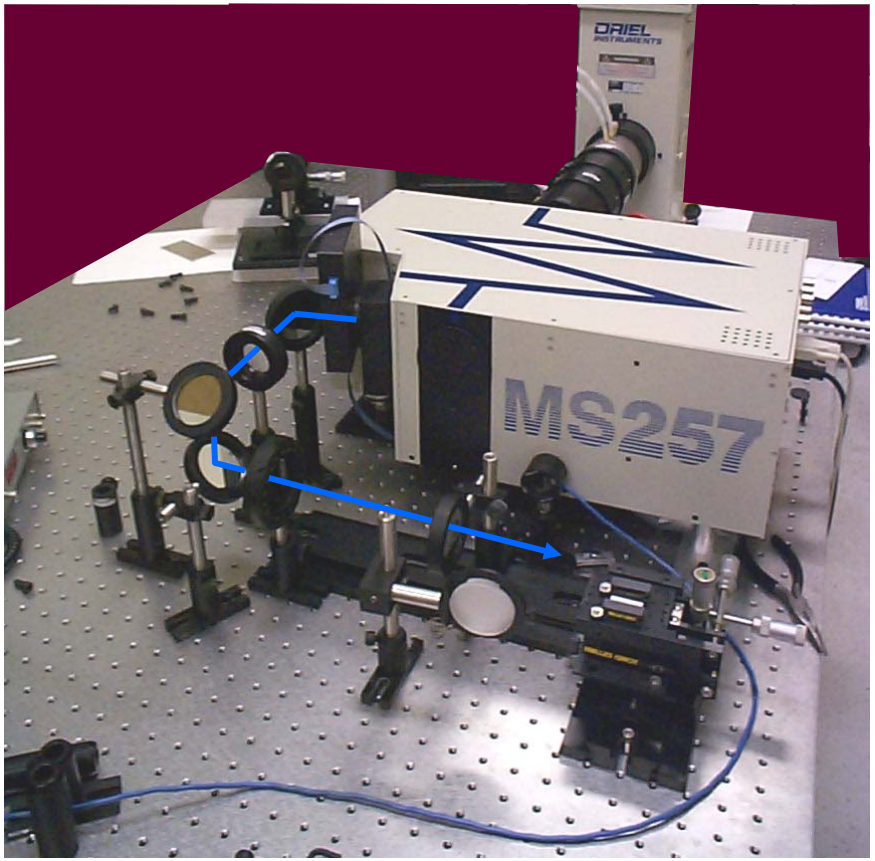
Nanoparticles
colloidal Ag (∅ 41 nm) in aqueous solution
deposit on resist (nebulize)

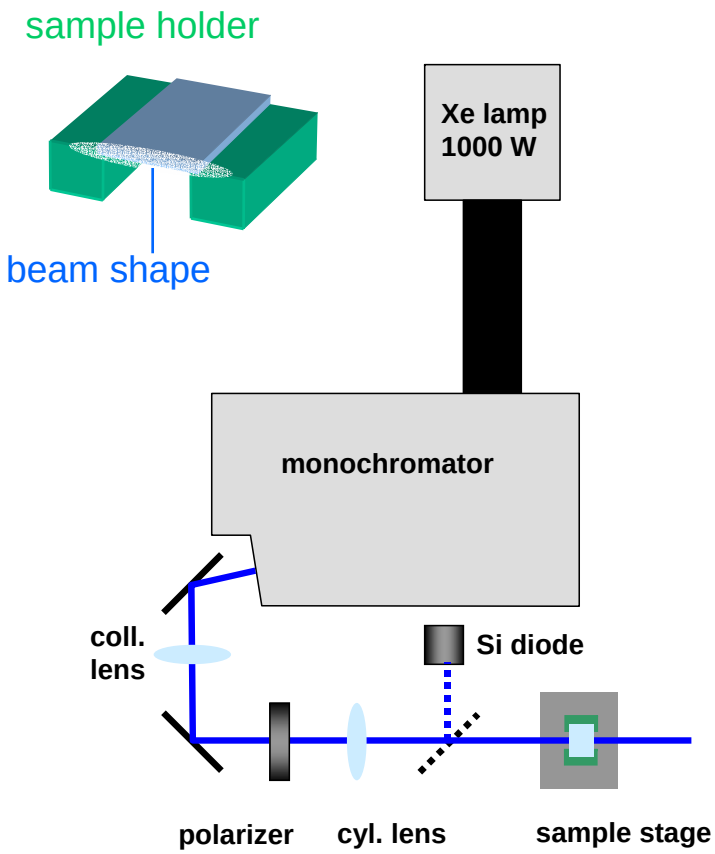
Resist
AZ1813 resist, diluted to 1:4 with EBR
spin 5000 rpm 60s ⇒ 75 nm thick layer
developing tested OK

Substrate
glass slide, roughness 5Å RMS

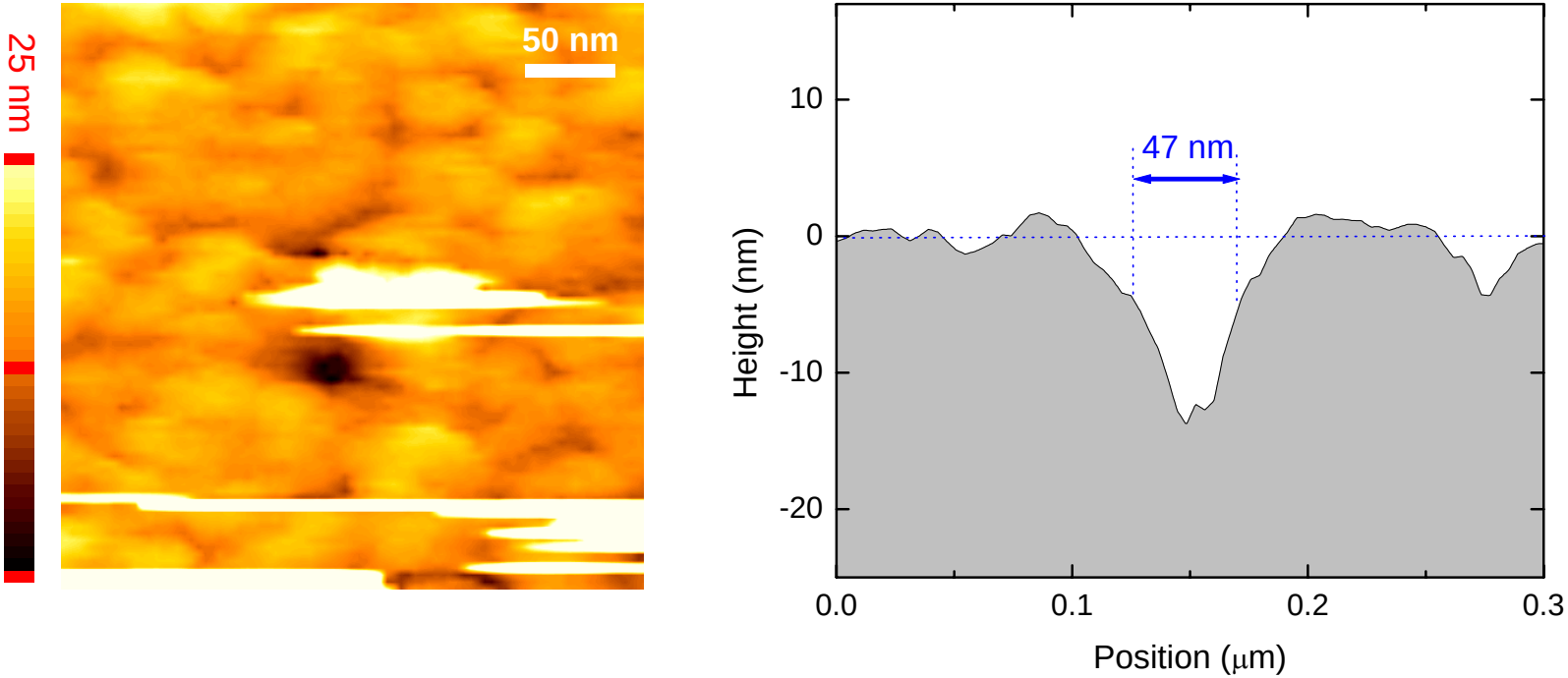
1. Expose — broad beam, Xe arc lamp at 410 nm
   intensity ~1 mW/cm^2 (TM)
   exposure 15 / 30 / 45 / 60 s
2. Develop — diluted 1:1 – dev. time ~20 s
3. Analyze — Use AFM to image printed features

Illumination setup





Contact mode AFM

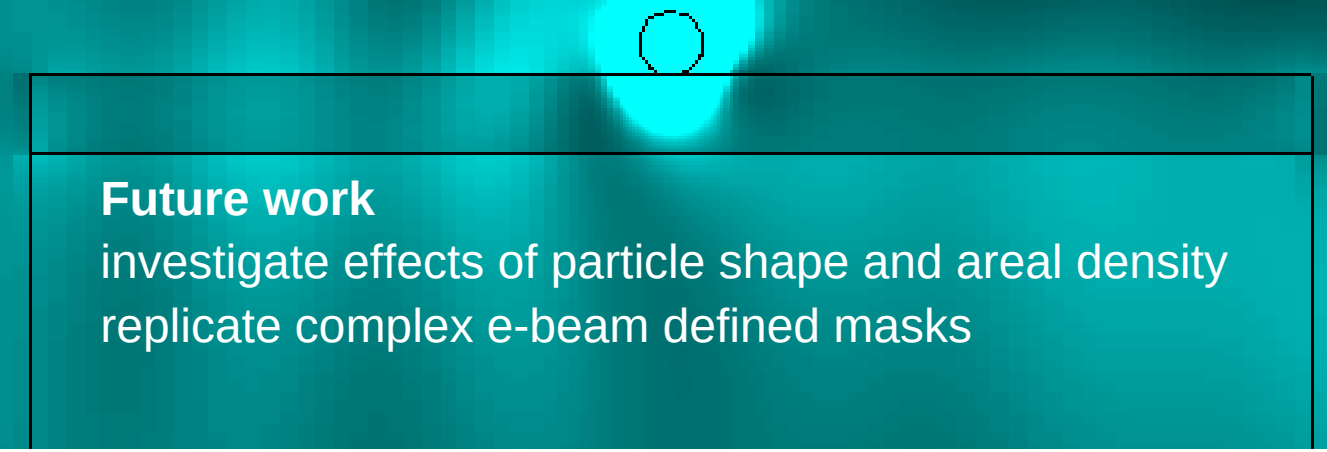


sample: Ag 40 nm AZ resist 75 nm exp. 15s (410 nm) dev. 20s

see - remaining Ag particles (swept by AFM tip) and
- sub-wavelength size dips width 30-60 nm, depth 10-15 nm

Conclusion and outlook

Plasmon printing may be used to print high resolution patterns using standard photoresist and broad-beam illumination with visible light



Future work

investigate effects of particle shape and areal density

replicate complex e-beam defined masks