

# Advanced Metamaterial-Based Structures for Optical Applications in the Far Ultraviolet



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Collaboration: Coatings lab (GSFC) & Nanoscience Center (NRL)

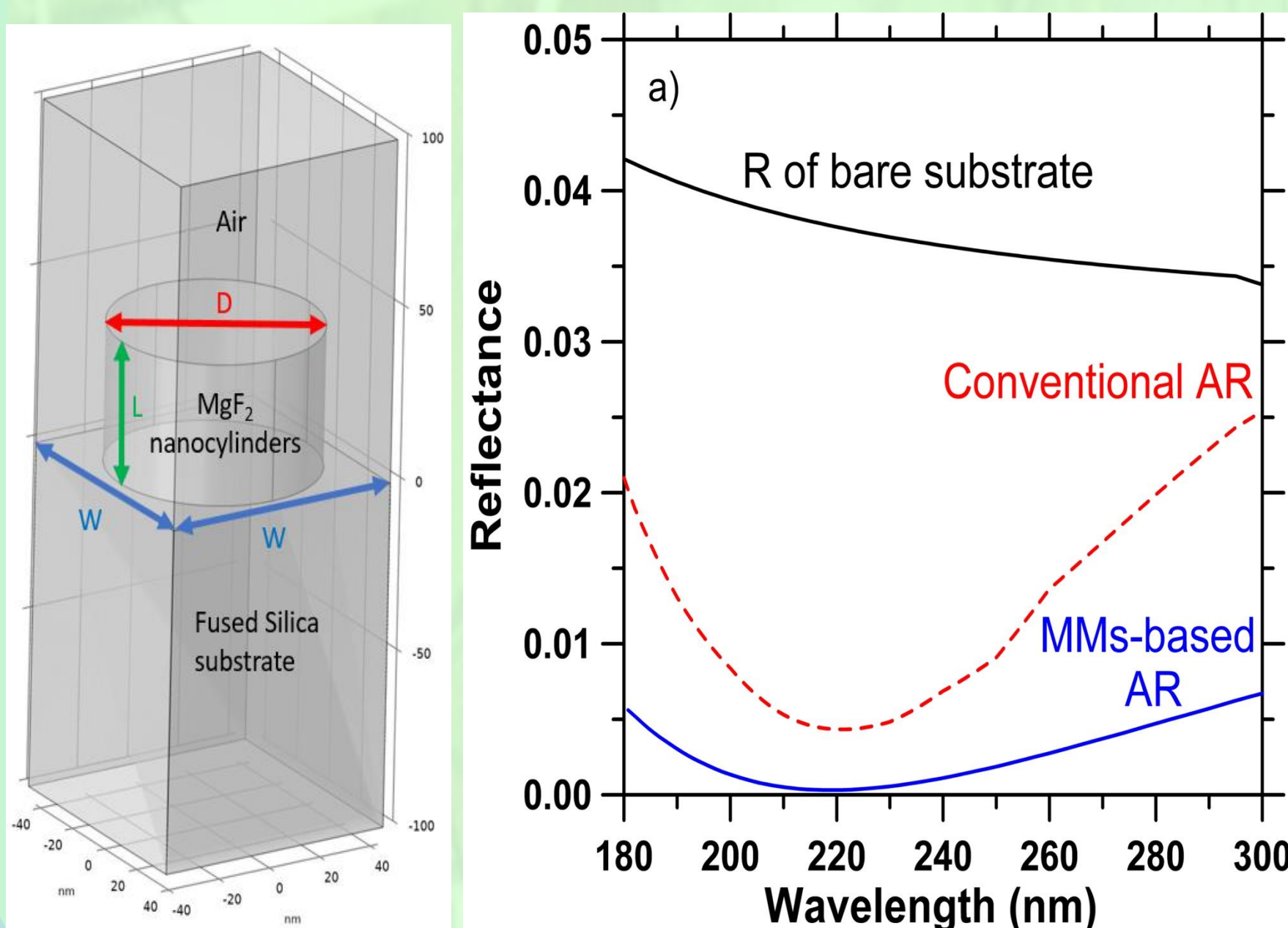
## Motivation

Metamaterials are patterned materials with geometries tailored to synthesize the optical index of interest. Our goals are:

- Develop a nanofabrication recipe for  $\text{MgF}_2$  (for the first time!) Demonstrate the nanofabrication recipe
- How good & uniform are the nanostructures?
- Experimentally demonstrate an antireflection (AR) surface for fused silica and  $\text{CaF}_2$  in the deep ultraviolet (DUV)

## AR Surface Design

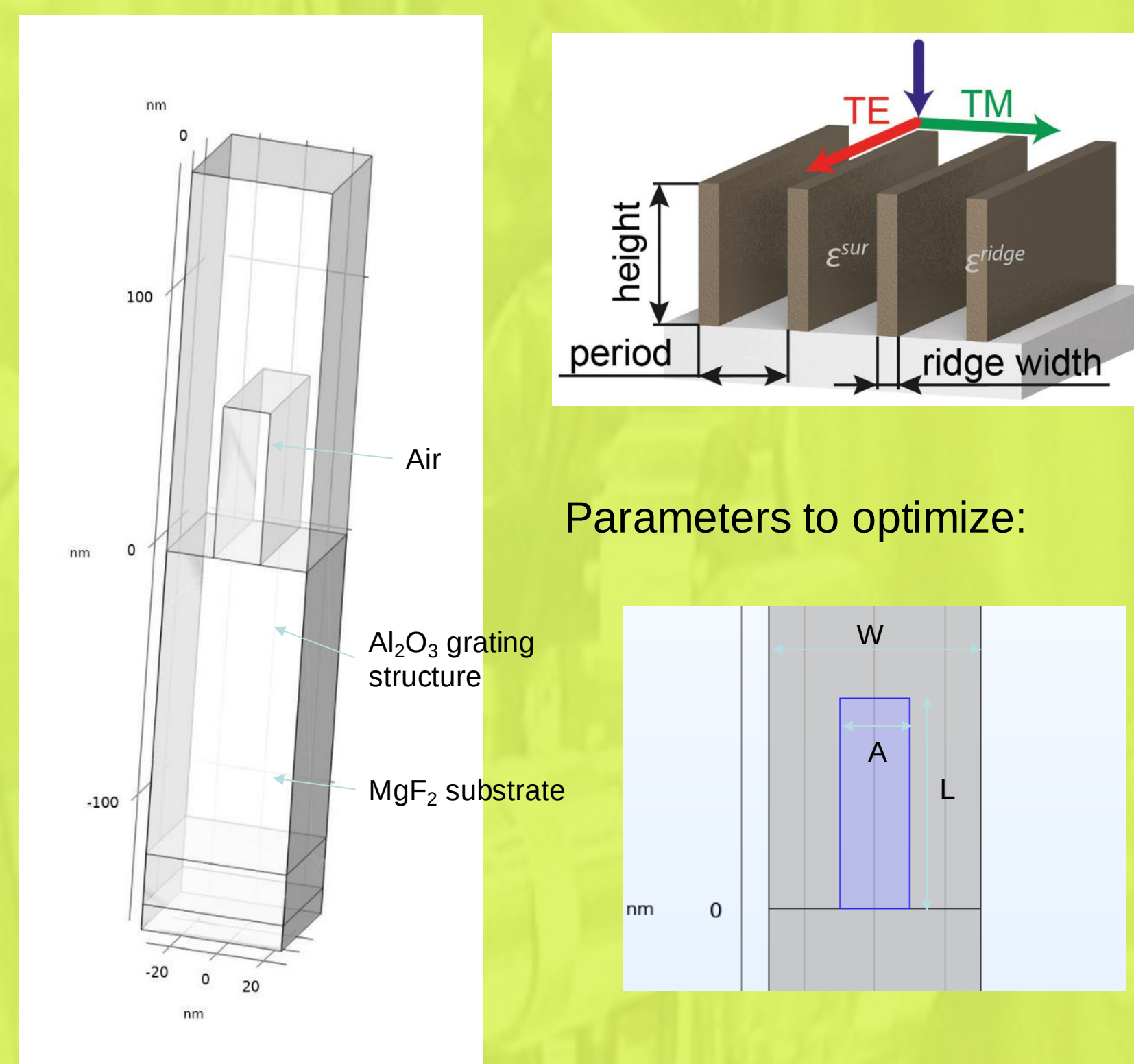
Maximizes transmittance and minimizes reflectance losses in the 170-300 nm range



## Polarizer Tuned at 122nm

Transmissive WGP's normal incidence, large acceptance angles, compact, light-weight, simple integration into optical systems

Dielectric ( $\text{Al}_2\text{O}_3$ ) WGP's Heat control, hard, stable, harsh environments, cleanable



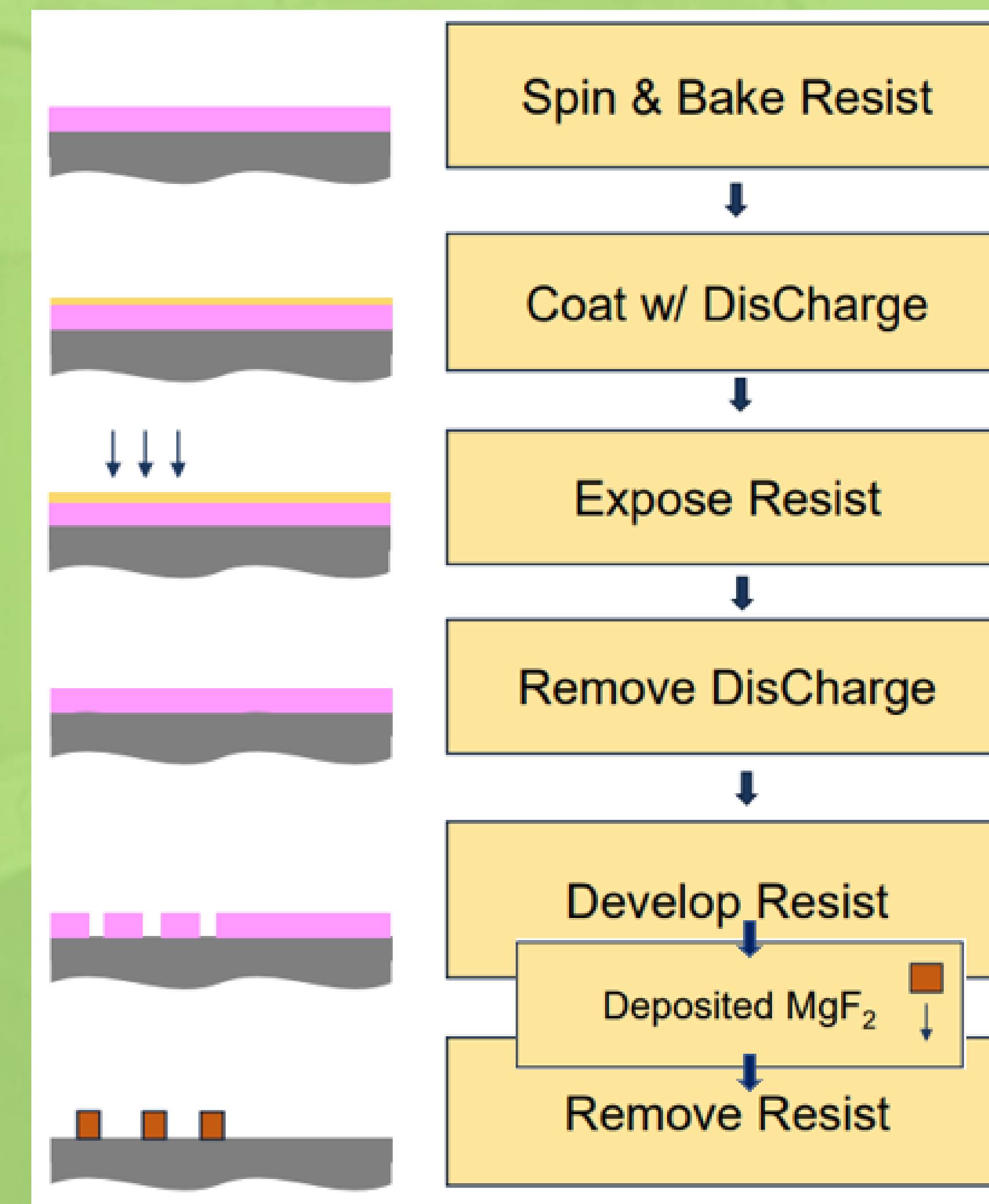
Metamaterial condition:  $W \ll \lambda$  where  $\lambda$  is 122 nm, reference wavelength where the polarizer is optimized at.  $W$  is the pitch.

- Merit functions:
- 1-Maximize TE/TM ratio
  - 2-Maximize  $\mu = (\text{TE}-\text{TM})/(\text{TE}+\text{TM})$
  - 3-Maximize  $\kappa = \mu \cdot \sqrt{(\text{TE}+\text{TM})/2}$

## Nanofabrication

Sketch of the nanofabrication process using e-beam lithography and lift-off.

Nanofabrication: Nanoscience Institute (NRL)

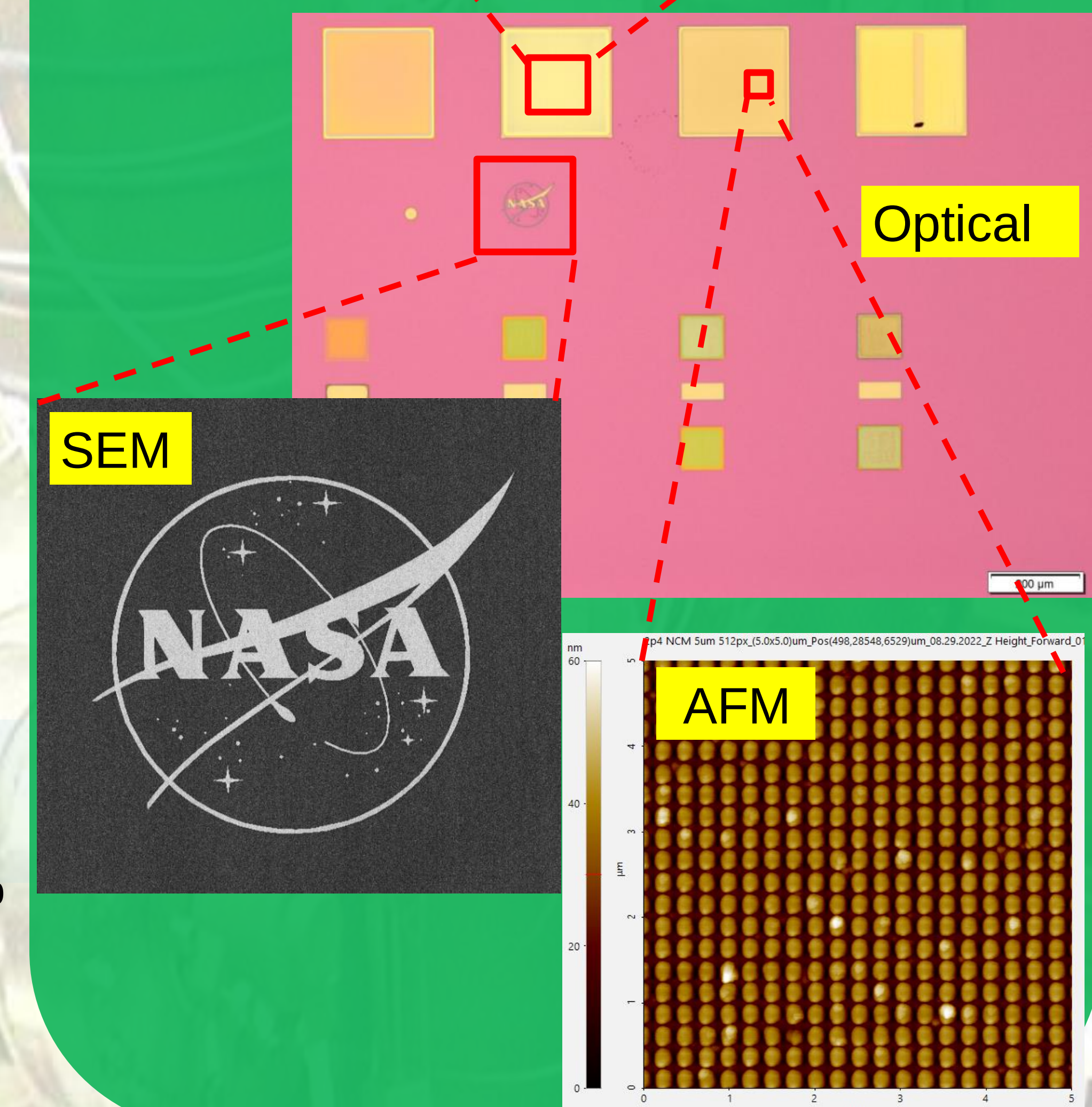
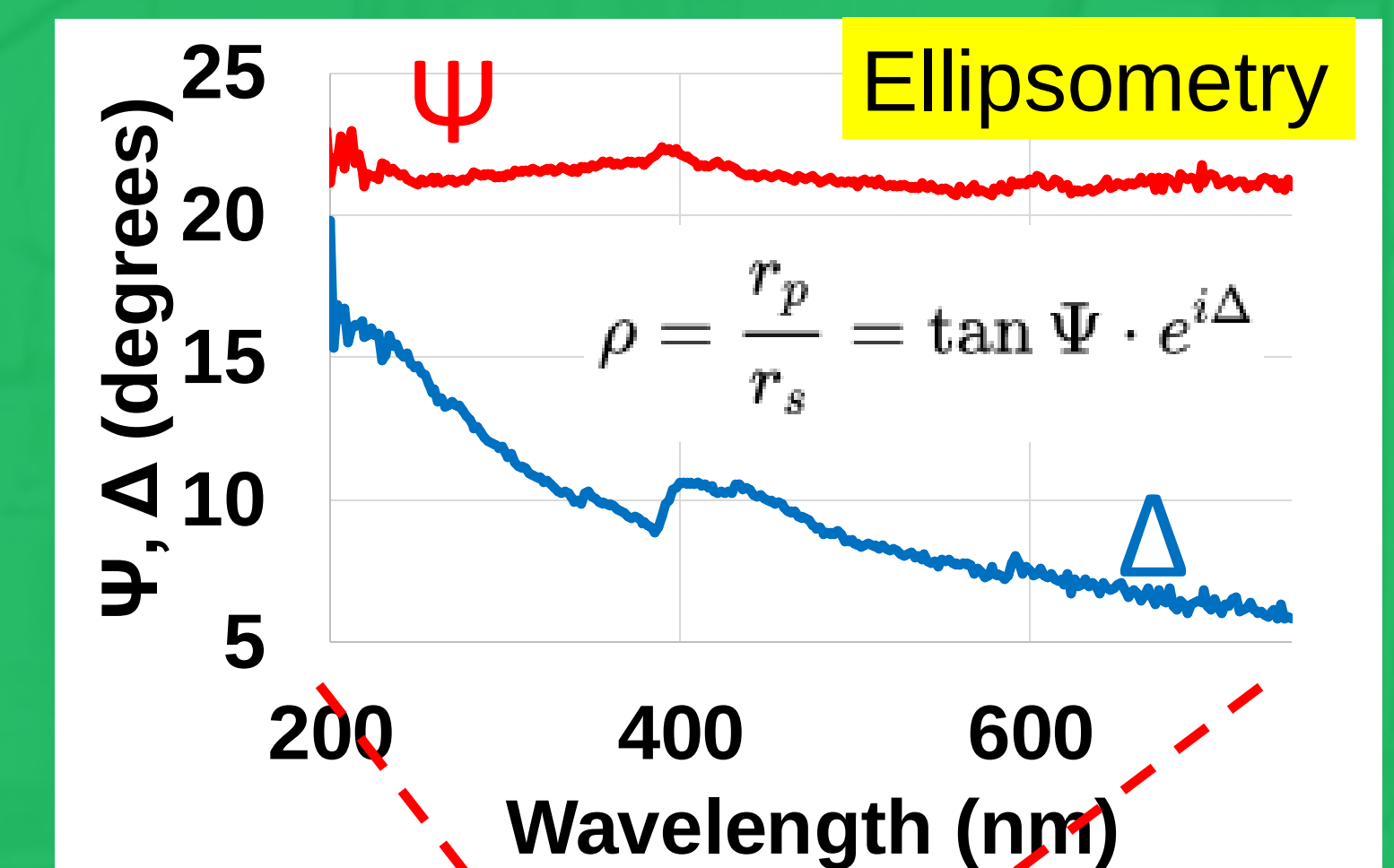


Demonstrated:

- Uniformity in period: >97%
- Individual cylinder defect rate: <1%
- Cylinders with volume > 25% of mean: <2%

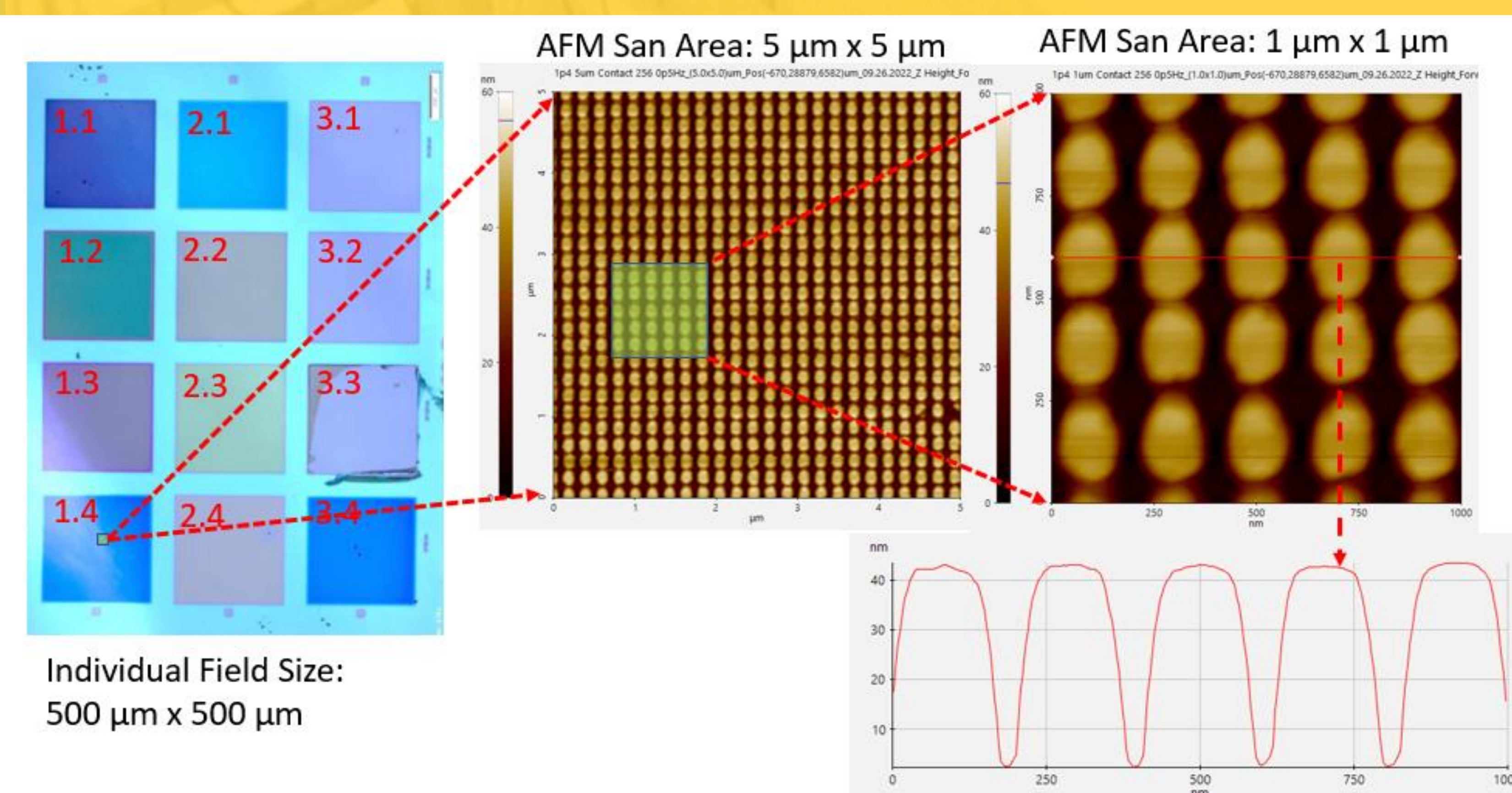
## Characterization

Optical and Electron Microscopy (NRL), AFM Topography and Ellipsometry (GSFC)



## Results

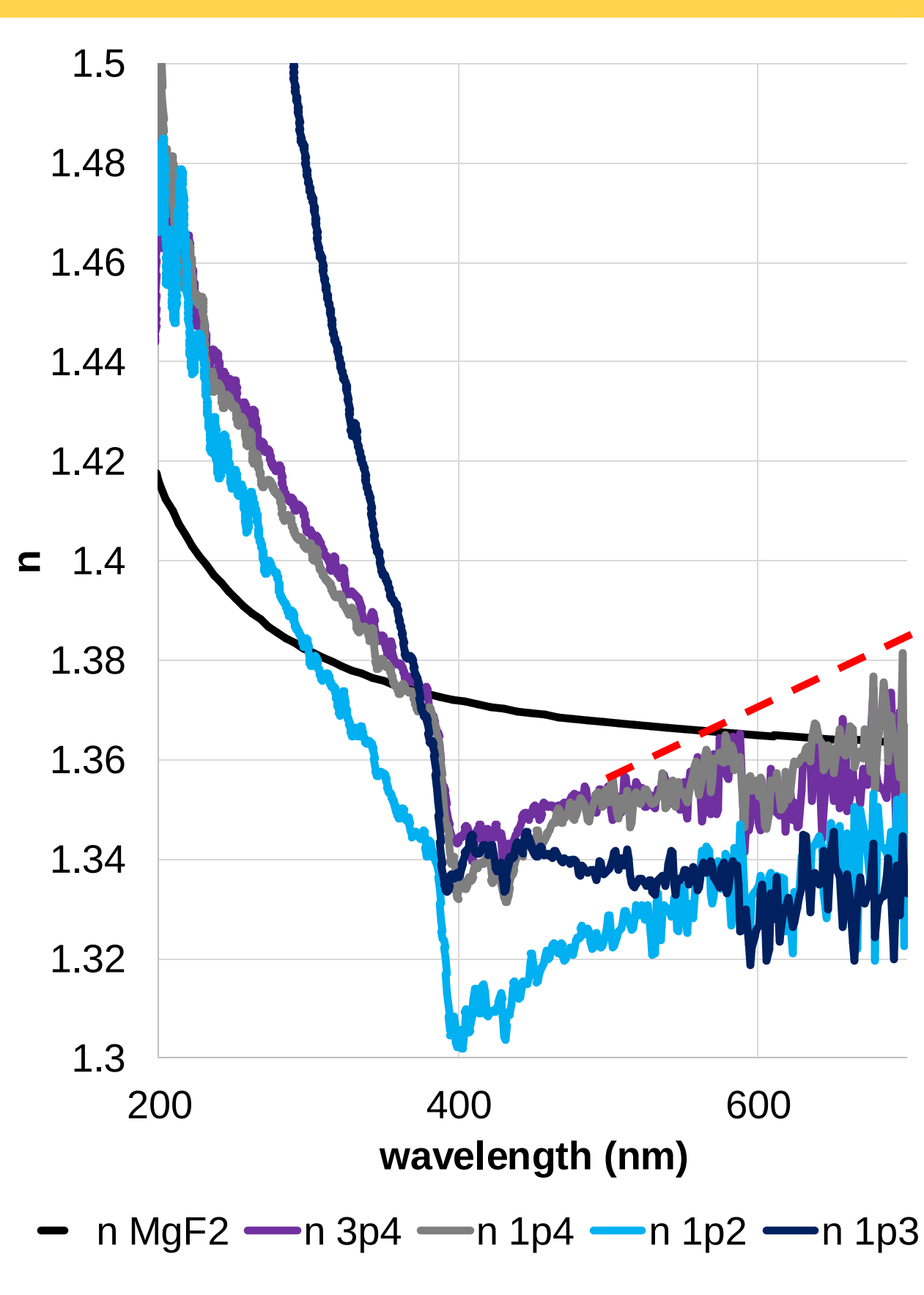
Preliminary results on  $\text{MgF}_2$  nanocylinders are very promising!



$\text{MgF}_2$  nanocylinders on fused silica substrate with increasing magnification. Nanocylinders in Field 1.4 have a period of 200 nm, a diameter of 150 nm, and a height of 43 nm. Note the excellent uniformity

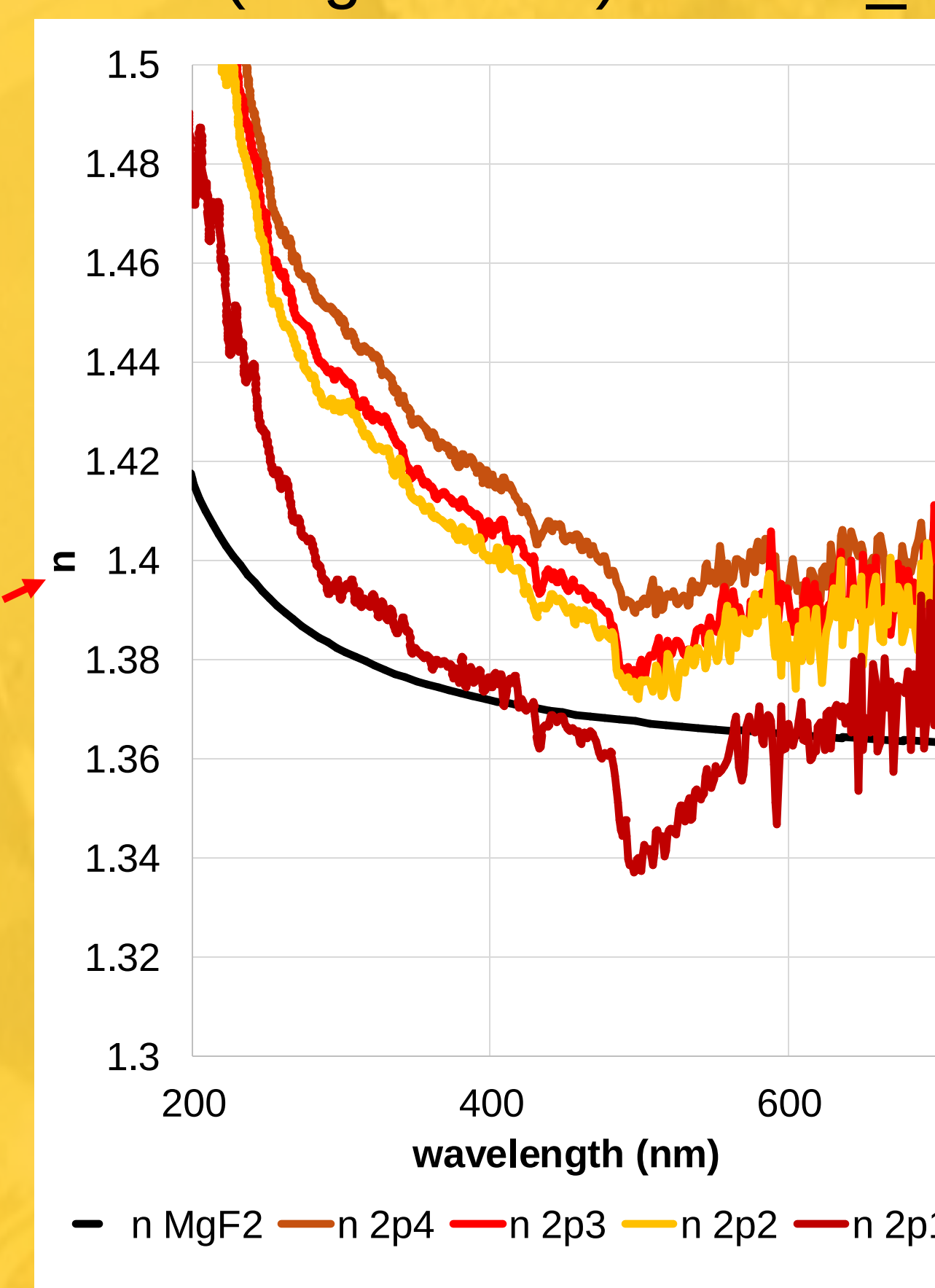
Periods  $\approx 200$  nm

$n_{(\text{engineered})} < n_{\text{bulk\_MgF}_2}$



Periods  $\approx 250$  nm

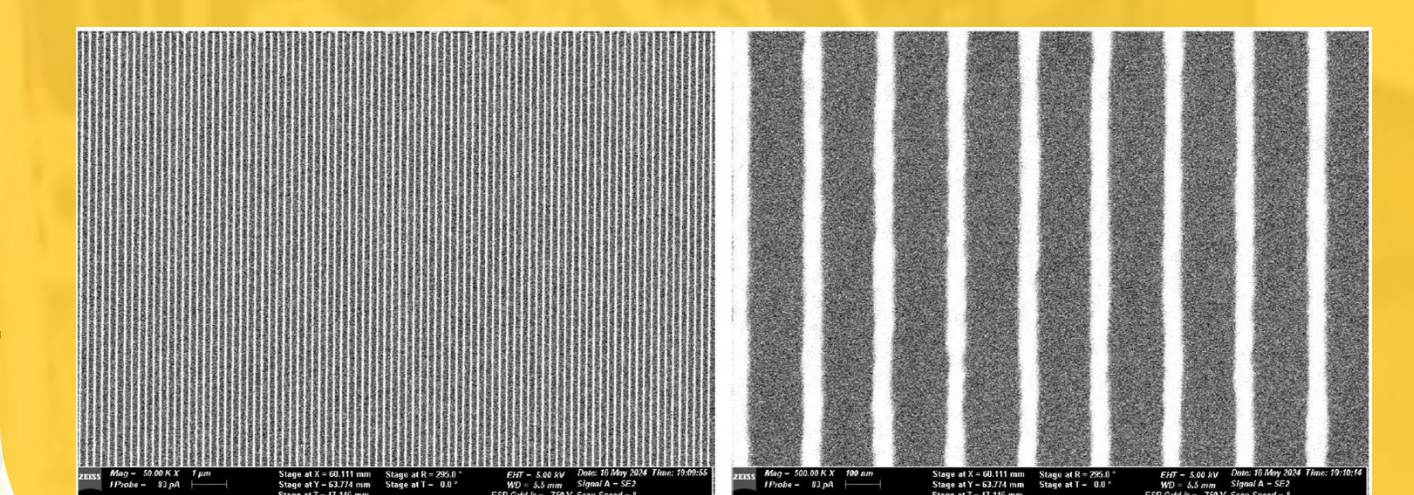
$n_{(\text{engineered})} > n_{\text{bulk\_MgF}_2}$



## Results

Preliminary results WGP

- Next step: Pattern transfer onto  $\text{Al}_2\text{O}_3$



## Conclusions

- We developed a nanofabrication recipe and successfully fabricated  $\text{MgF}_2$  nanocylinders
- Demonstrated engineered refractive indexes in the DUV
- Next steps involve nanostructures with smaller sizes, including periods and diameters < 100 nm
- Foothold for the usage of MMs in DUV through a collaboration between GSFC and NRL

## Acknowledgments

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