Metasurface fabrication

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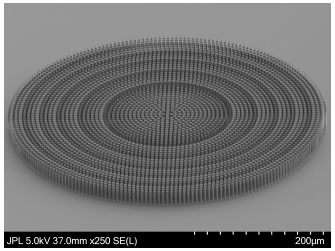
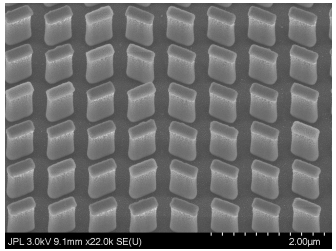
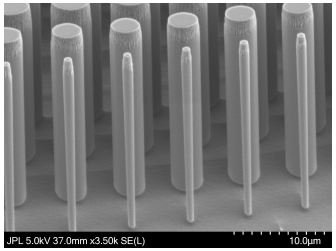
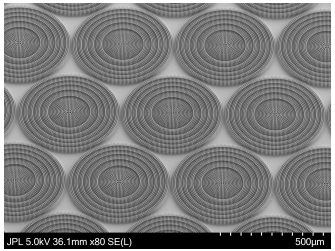
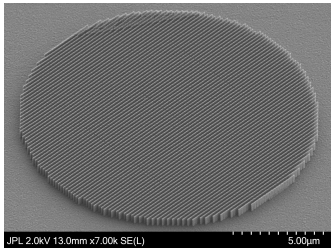




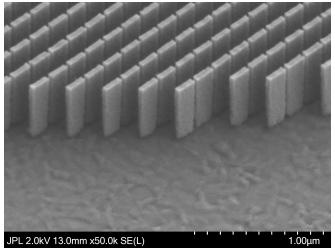


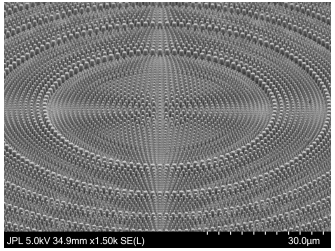




Outline

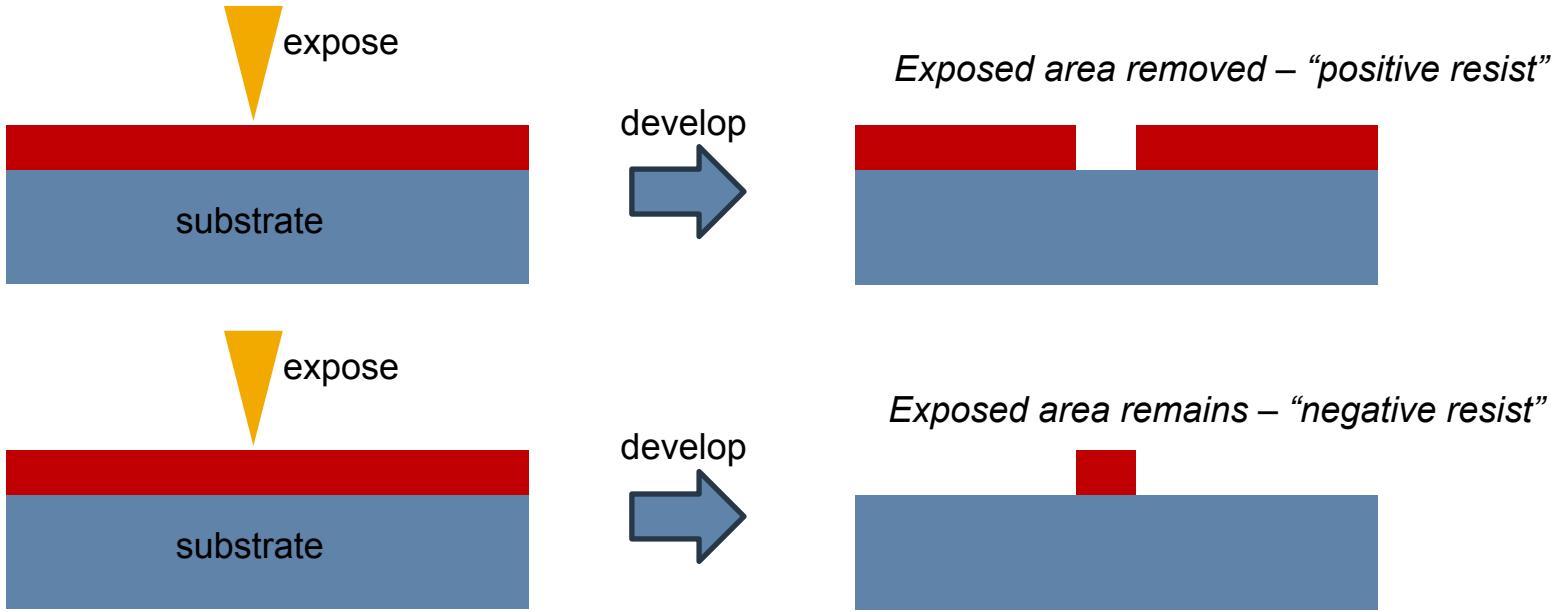
- Microfabrication 101
  - Patterning (lithography)
  - Material deposition (evaporation, sputtering, atomic-layer deposition)
  - Material removal (etching)
  - (Surface preparation, surface cleaning, handling, dicing, material interactions…)
- Metasurface fabrication – examples
- Challenges
  - Material selection
  - Resolution and Aspect Ratio
  - More challenges..





Patterning - microlithography

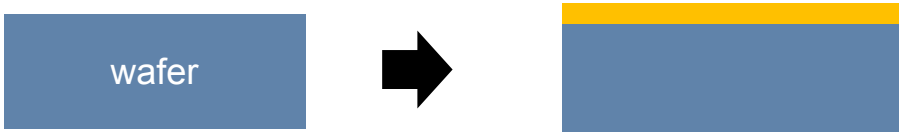
- “Make or break bonds in a resist.”



- Photo-lithography vs electron-beam lithography

Deposition

- “Adding material”



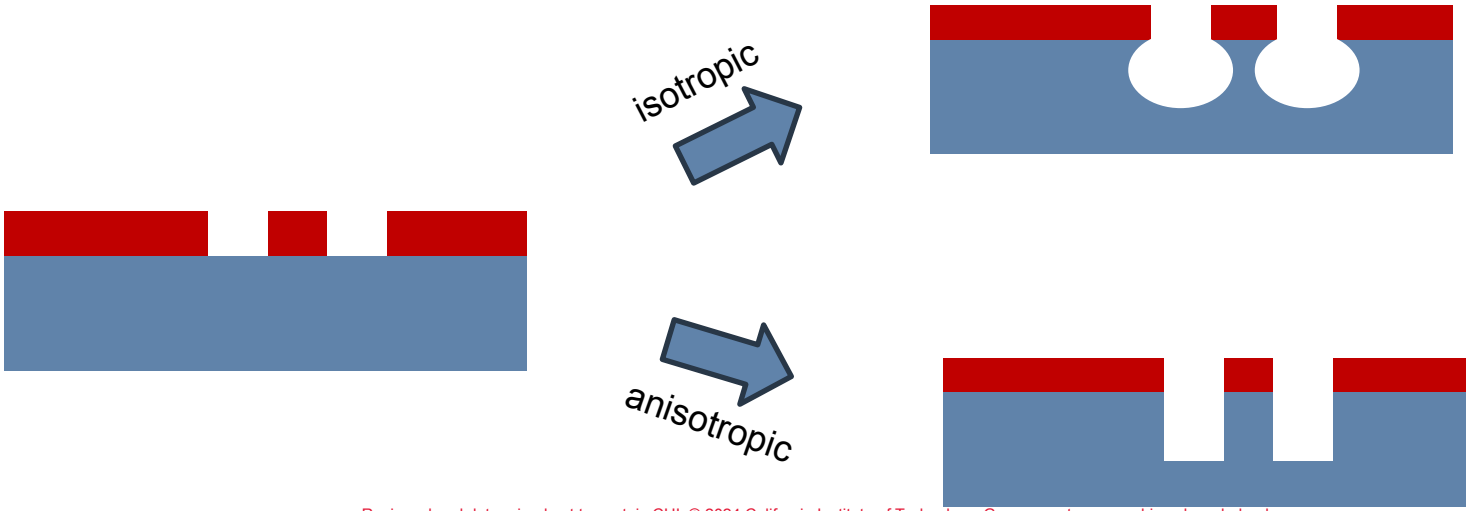
Less conformal

More conformal

evaporation sputtering chemical vapor deposition (CVD) atomic-layer deposition (ALD)

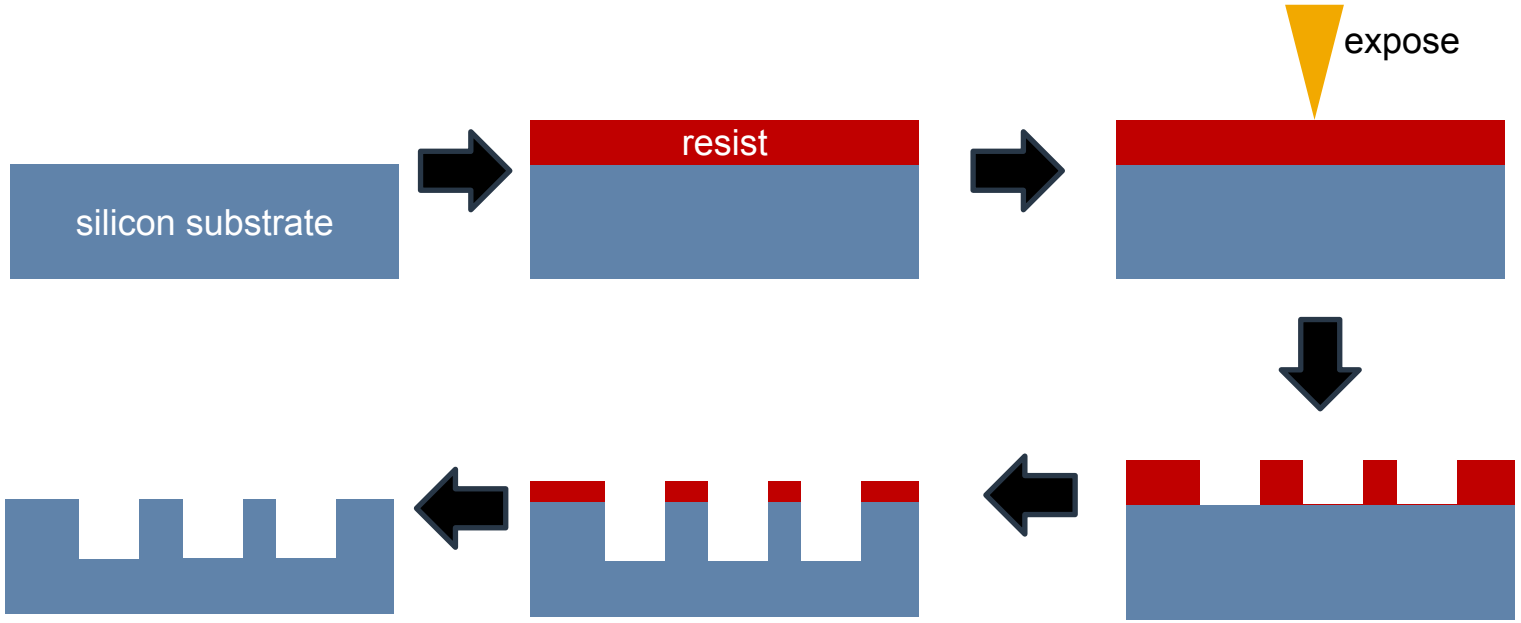
Etching

- “Removing material”
- Wet etch vs dry (plasma) etch
- Isotropic vs anisotropic
- Selectivity

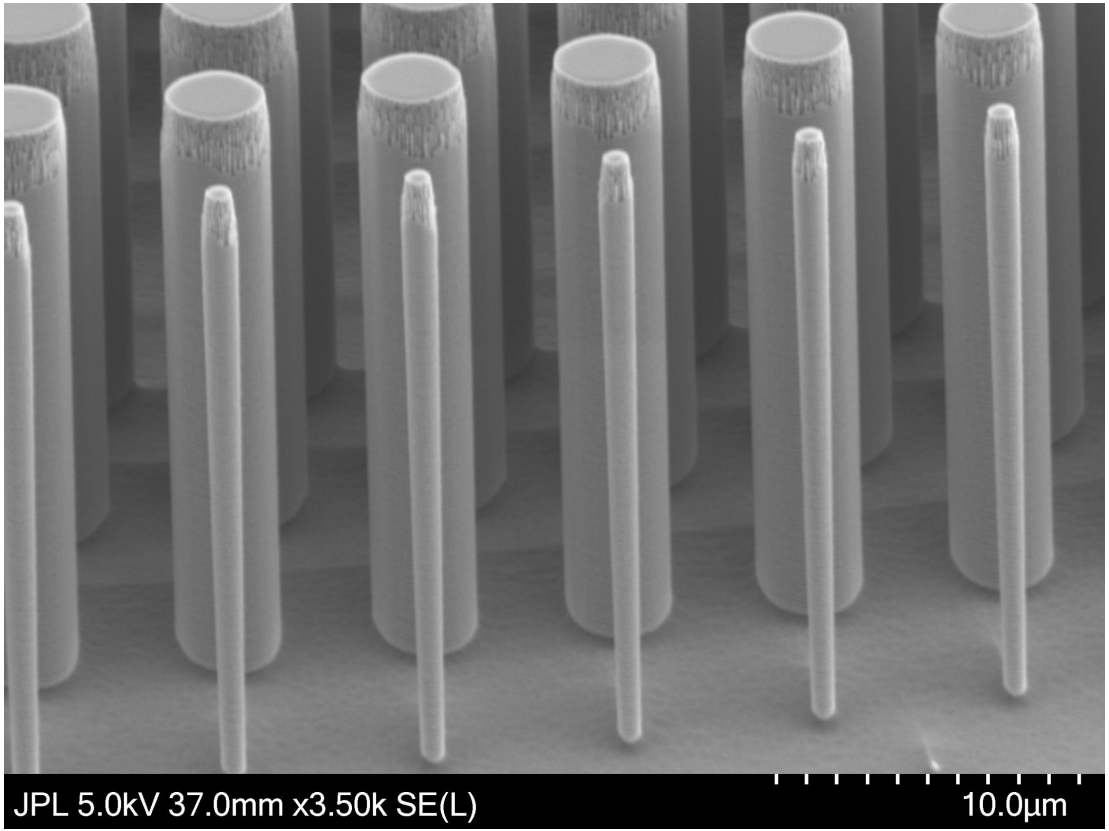


Metasurface fabrication – Example 1

Silicon metasurface – photoresist mask

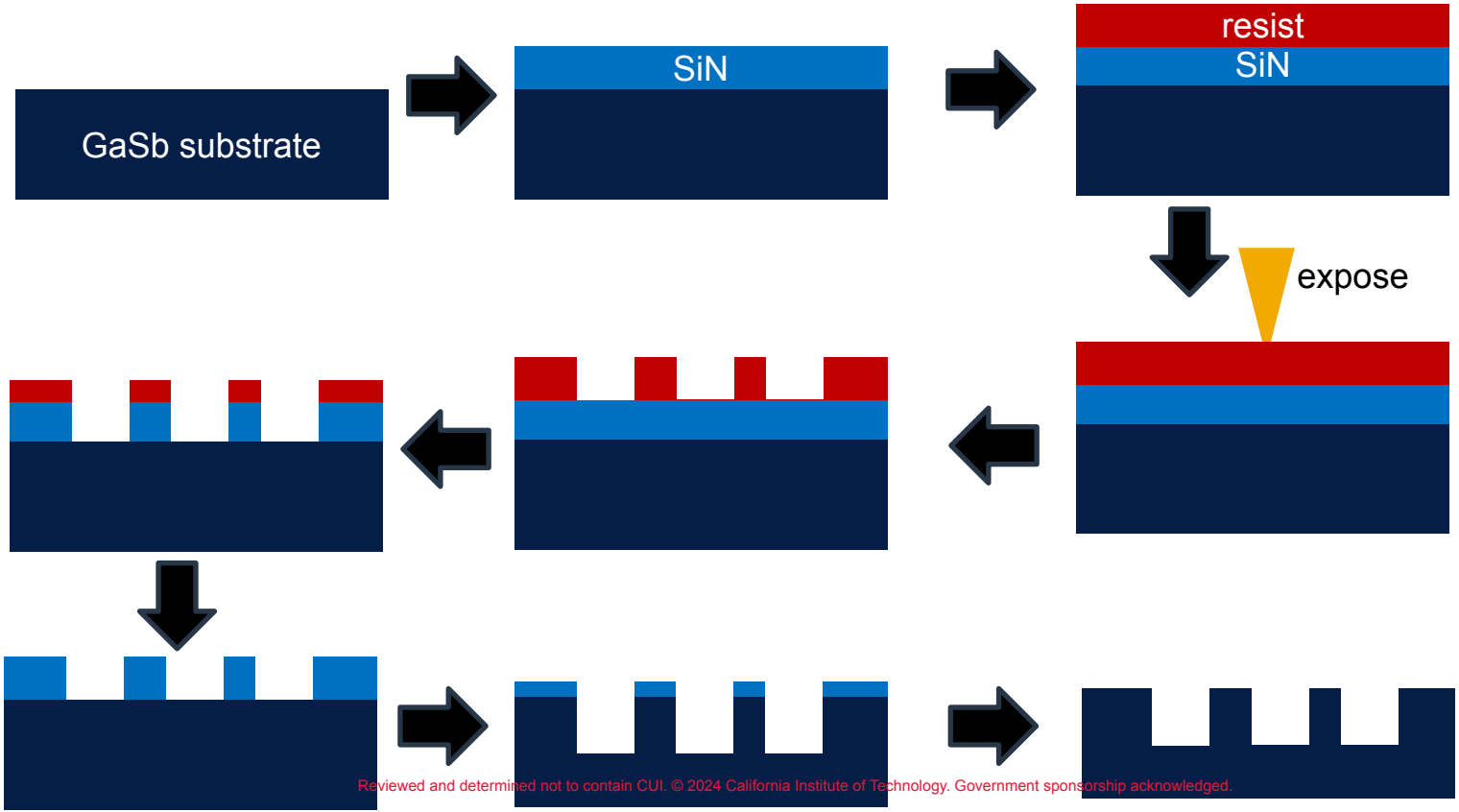


Example 1

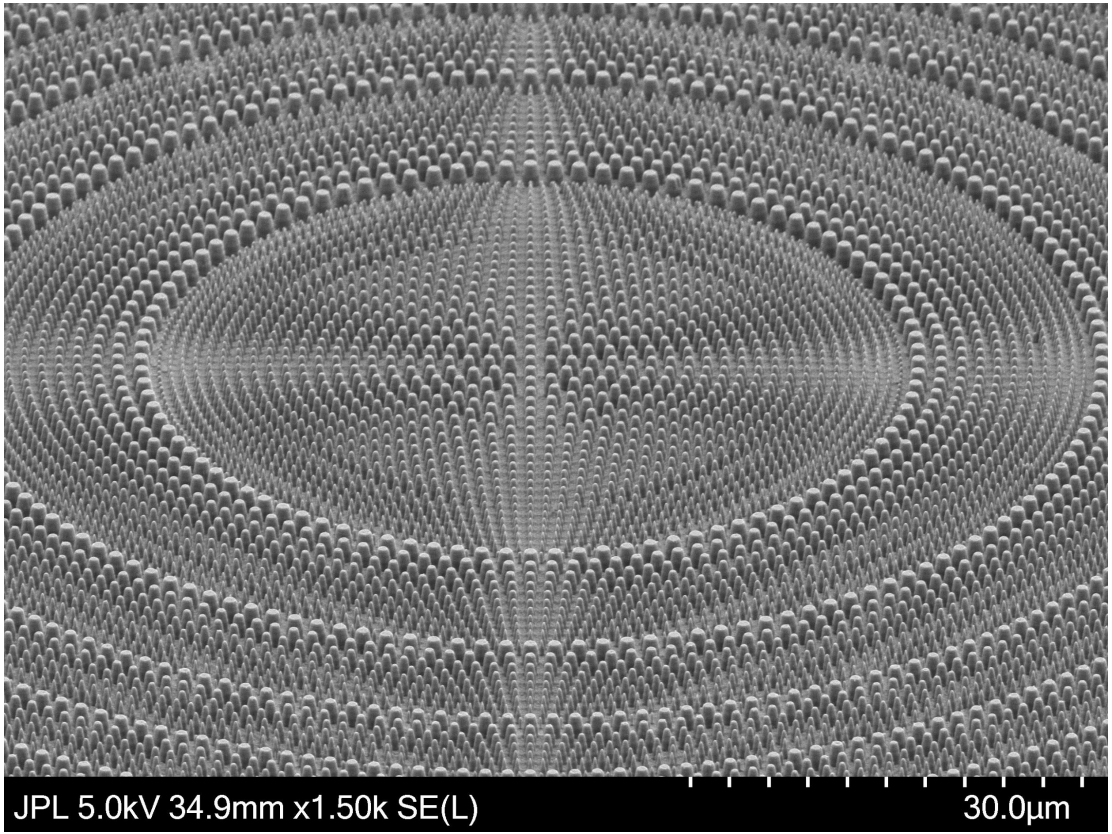


Metasurface fabrication – Example 2

GaSb metasurface – SiN hardmask

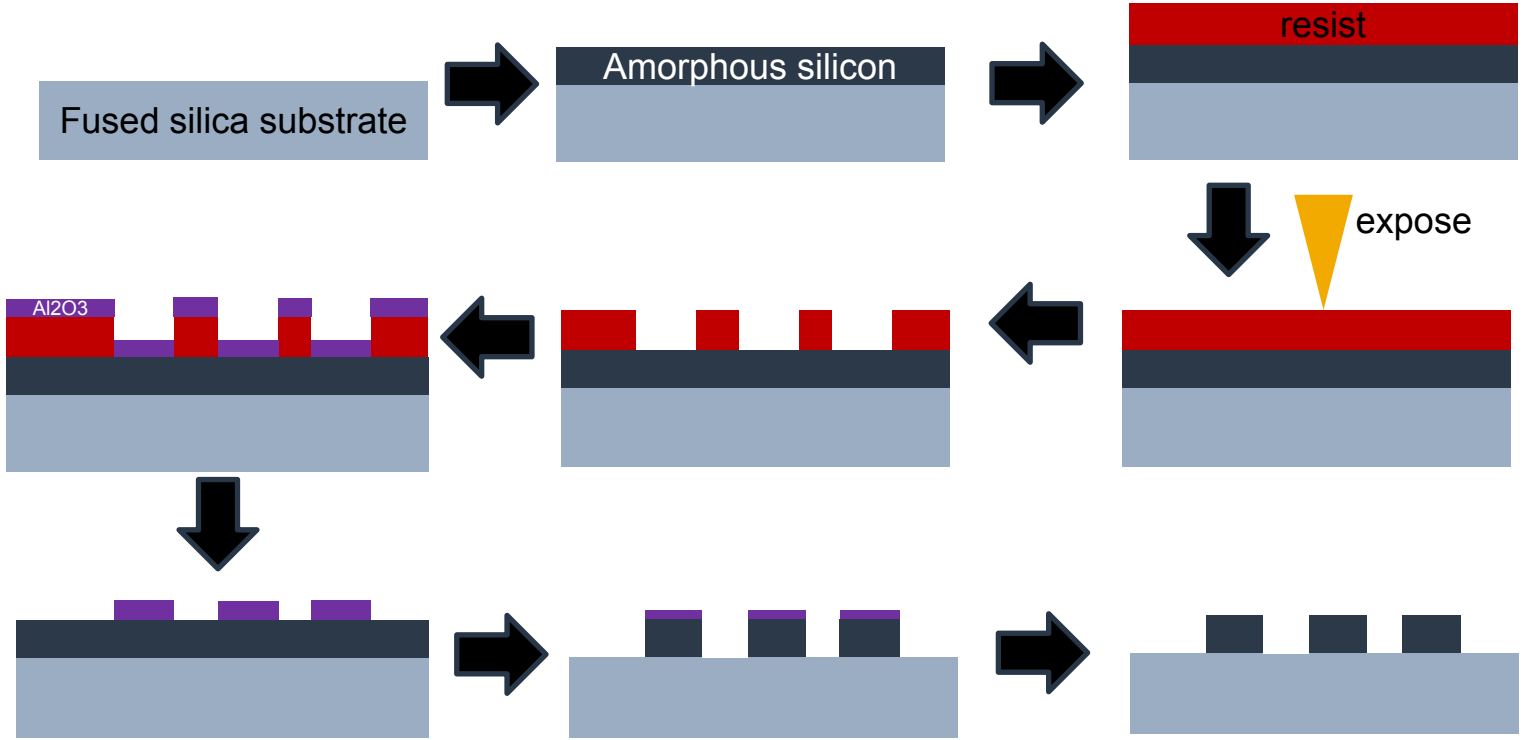


Example 2

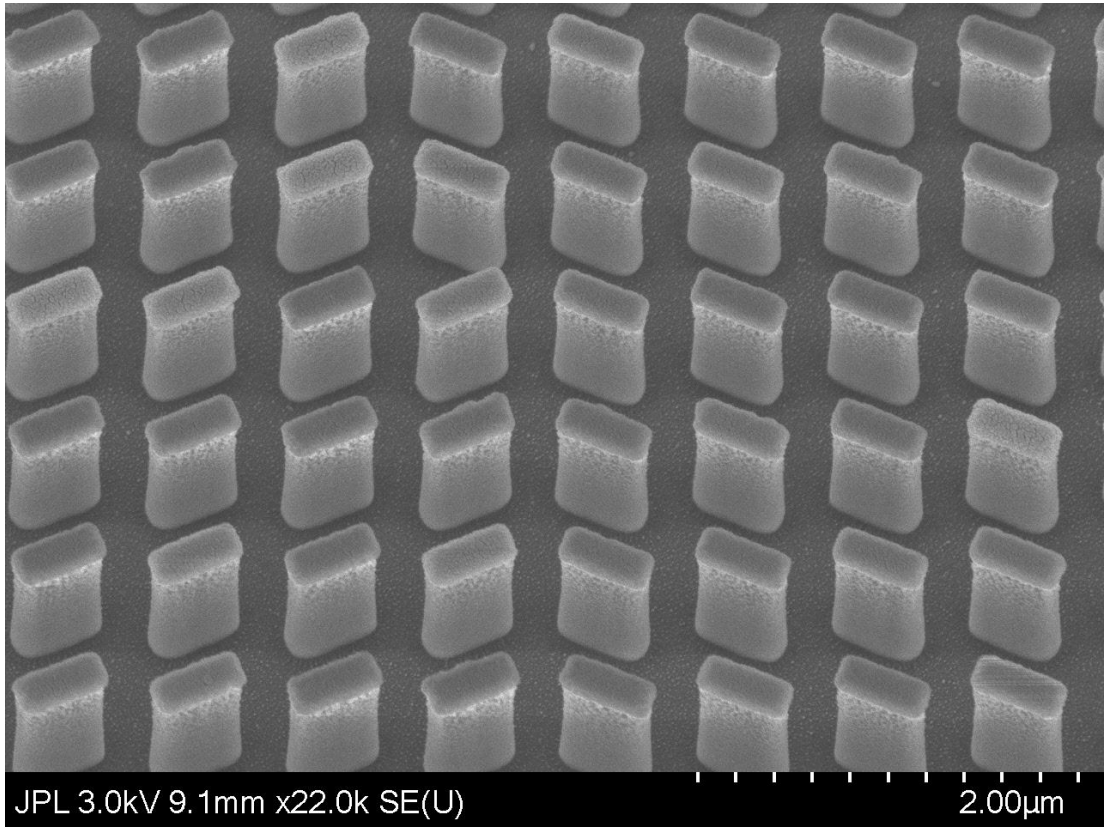


Metasurface fabrication – Example 3

Amorphous silicon metasurface on fused silica, Al2O3 hardmask

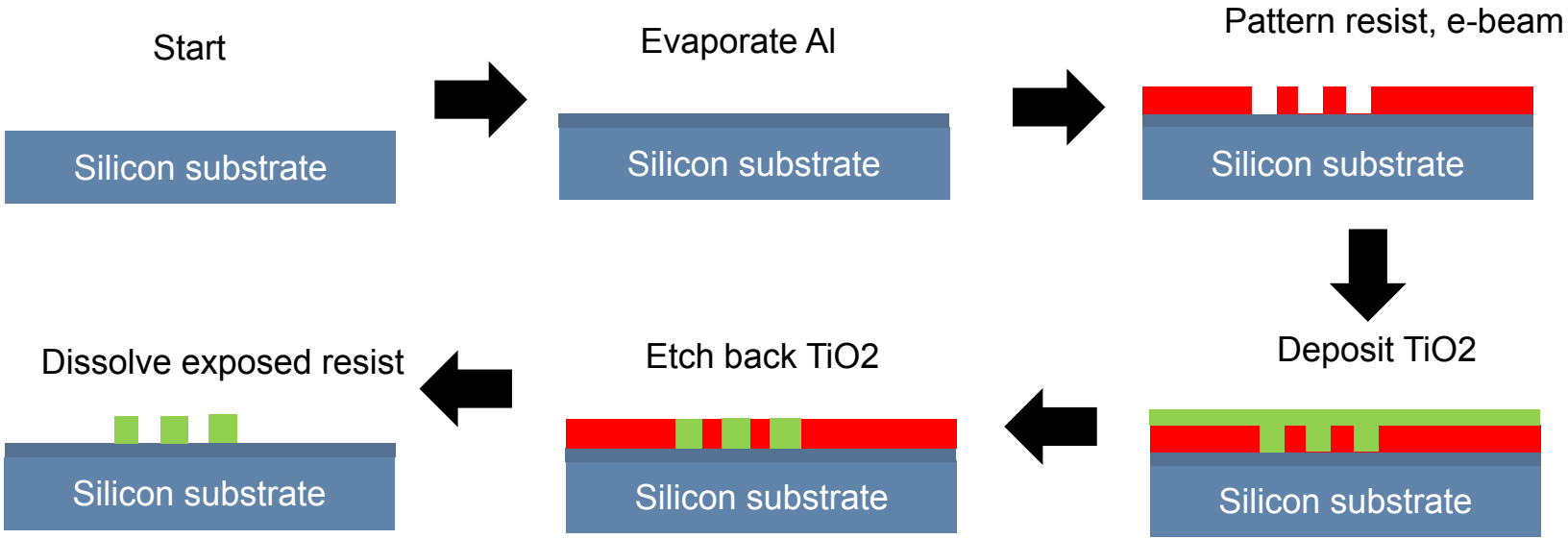


Example 3

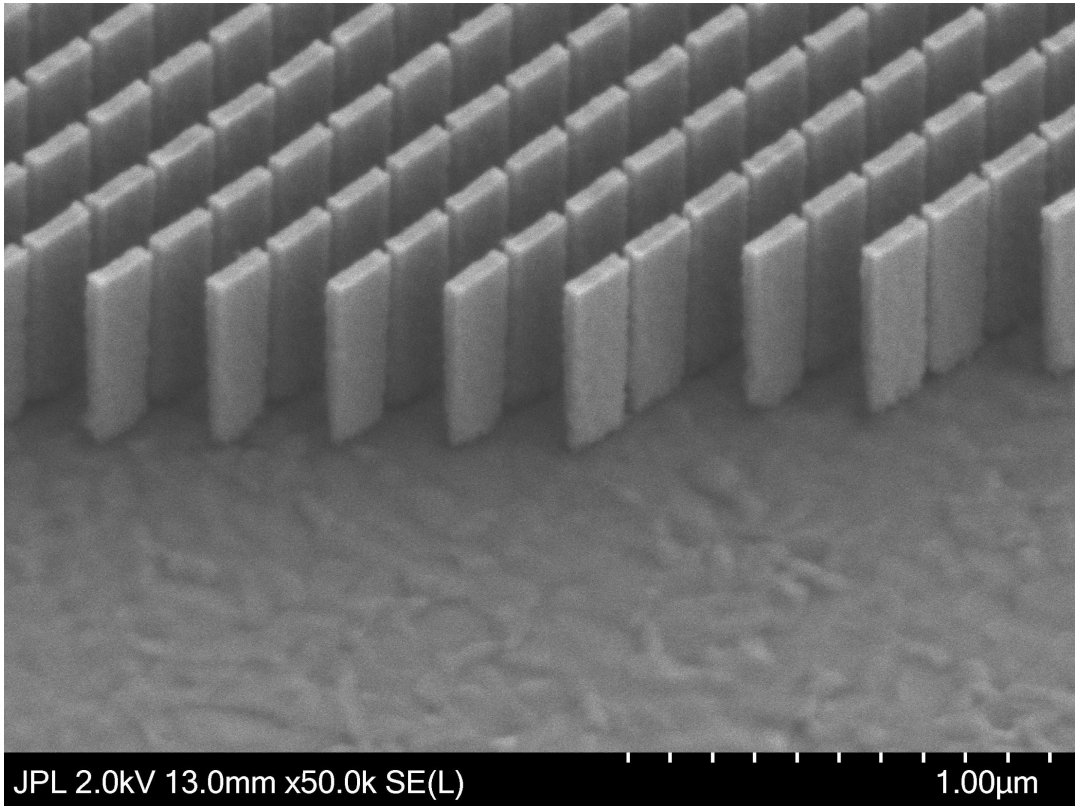


Metasurface fabrication – Example 4

TiO2 metasurface on aluminum



Example 4

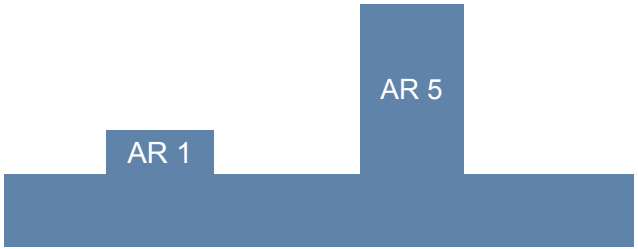


Materials and wavelength

- Silicon is a common material choice for microprocessing.
  - Accessible, low cost, easy handling, well developed etch chemistry (SF6/C4F8)
  - High refractive index, n=3.4. Meaning 50% of light lost from entering/exiting substrate.
    - One mitigation strategy is to use amorphous silicon (aSi) on fused silica.
  - Not transparent below ~1 micron.
    - Use other materials transparent below 1 micron (SiO2, SiN, TiO2, diamond, sapphire...)
- Use of other materials than silicon may require significant process development.

Resolution and aspect ratio

- Resolution describes the ability to print or otherwise make small features.
- Aspect Ratio (AR) describes the height-to-width ratio of a structure
  (often the critical dimension, CD, is used for calculating AR).
- Resolution and AR are often inter-related.
- For example, typically more challenges involved when targeting 20 nm resolution in a 100 nm tall feature (AR 5), than in a 20 nm tall feature (AR 1).
- Aspect-ratio dependent etch rate.

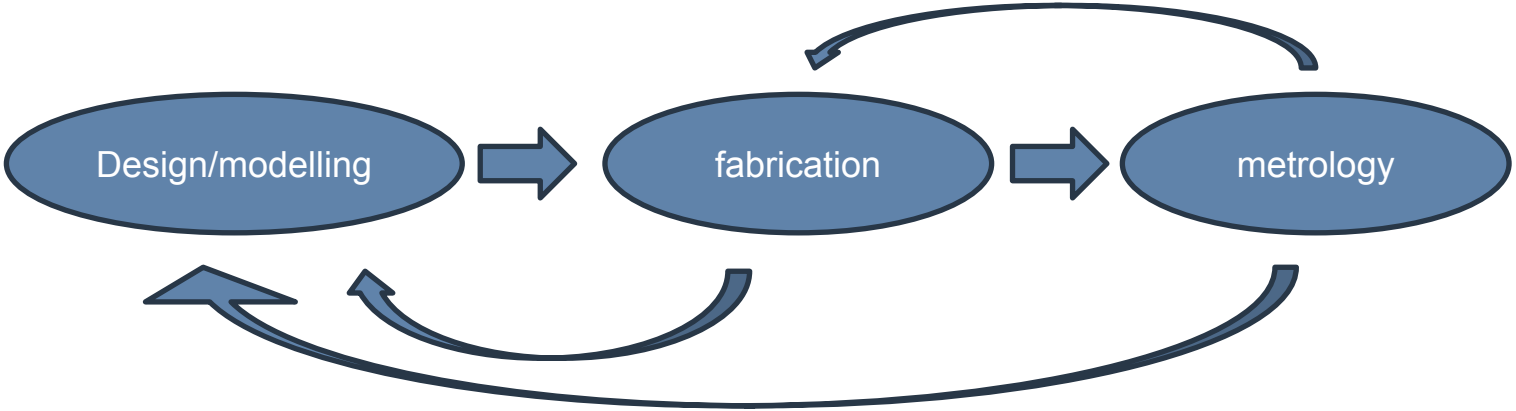


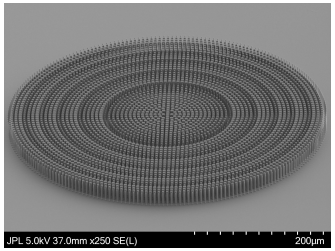
Challenges

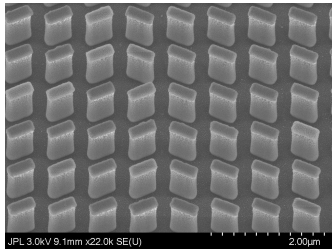
- Aspect-ratio dependent etch rate
- Depth-dependent etch profile
- Non-uniformities in deposition rate and/or etch rate
- Tool performance “drifts” over time
  (and/or rapidly changes due certain processes being run before)
- Particle contamination

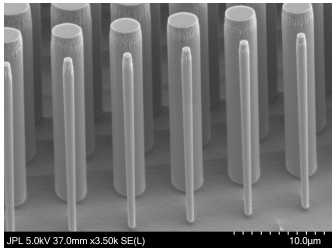
Closing thoughts

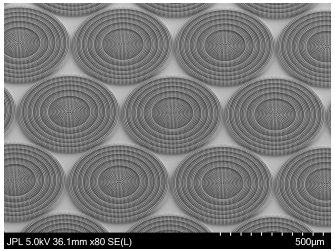
- To succeed in making high-precision optical metasurfaces, in my view several things are needed:
  - an understanding of metasurface design tolerances
  - a good way of measuring metasurface performance
  - a willingness to iterate on design, fabrication and metrology

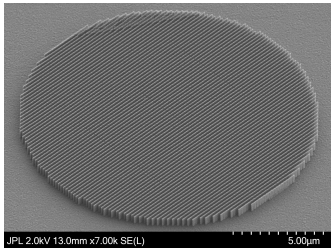


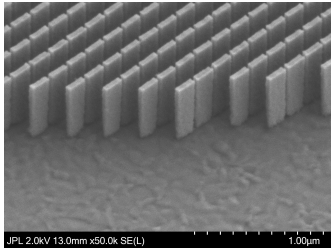


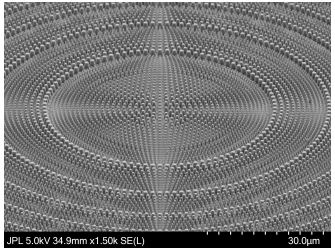












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Thank you!