



Rensselaer  
IEEE Student Branch



# Lithography & Patterning

Evan Chen

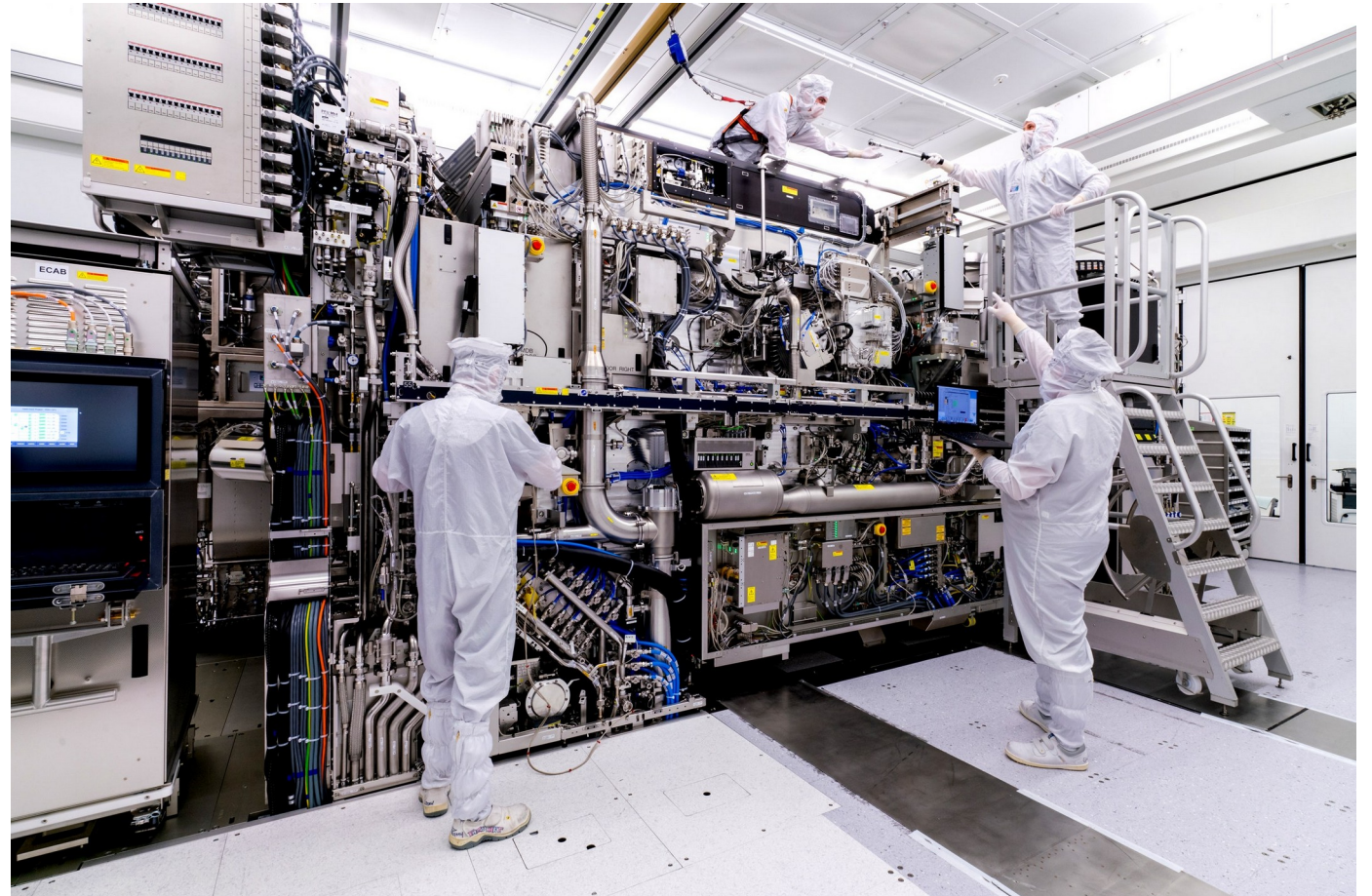
GBM Attendance



# Overview

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- Review of Fabrication Techniques
- Lithography Over the years
- Lithography Types & Settings
- Physics Behind Lithography
- Future State of Lithography



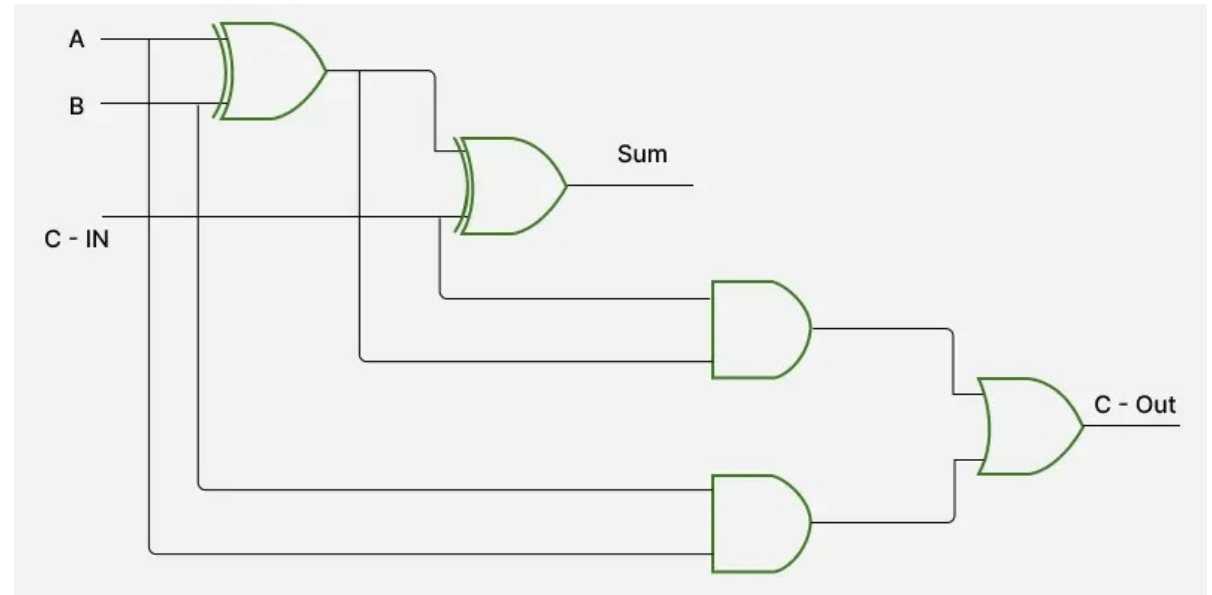
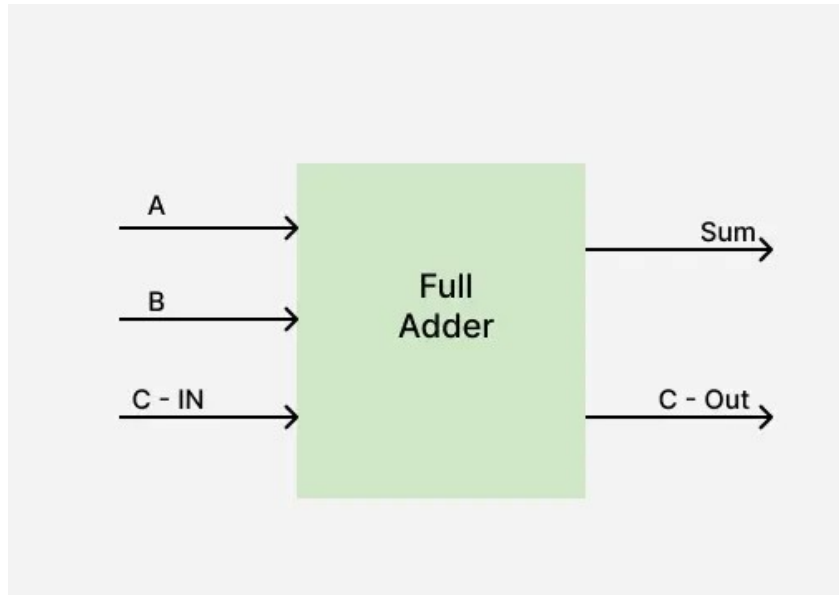
# What is Lithography? Why is Lithography? (How is Lithography?)

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Let's say you wanted to  
build a full adder out of  
transistors

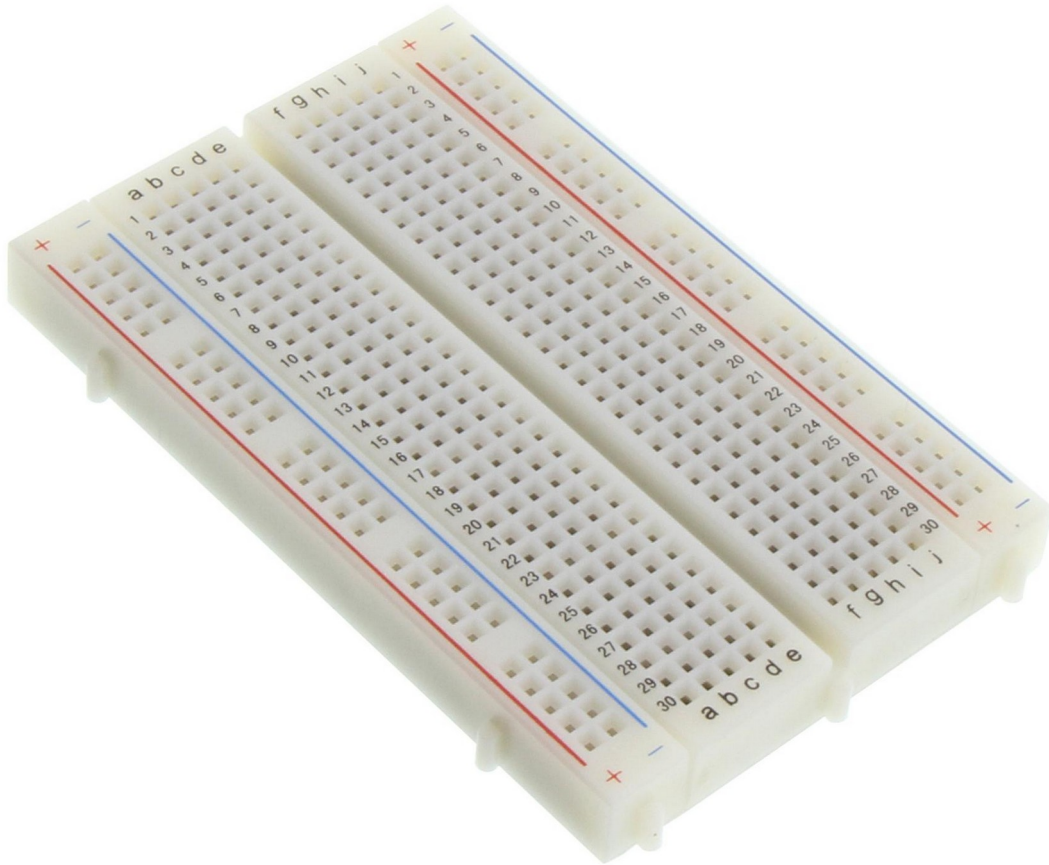
# What is Lithography? Why is Lithography? (How is Lithography?)

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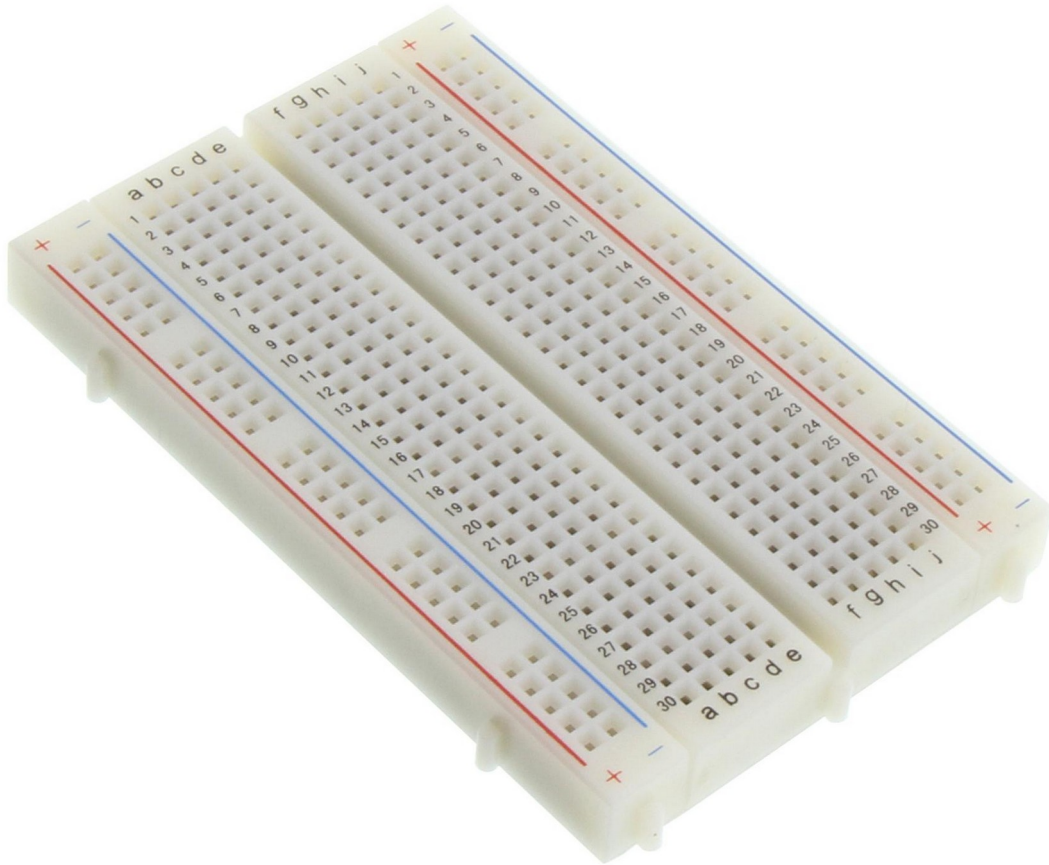
# What is Lithography? Why is Lithography? (How is Lithography?)

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# What is Lithography? Why is Lithography? (How is Lithography?)

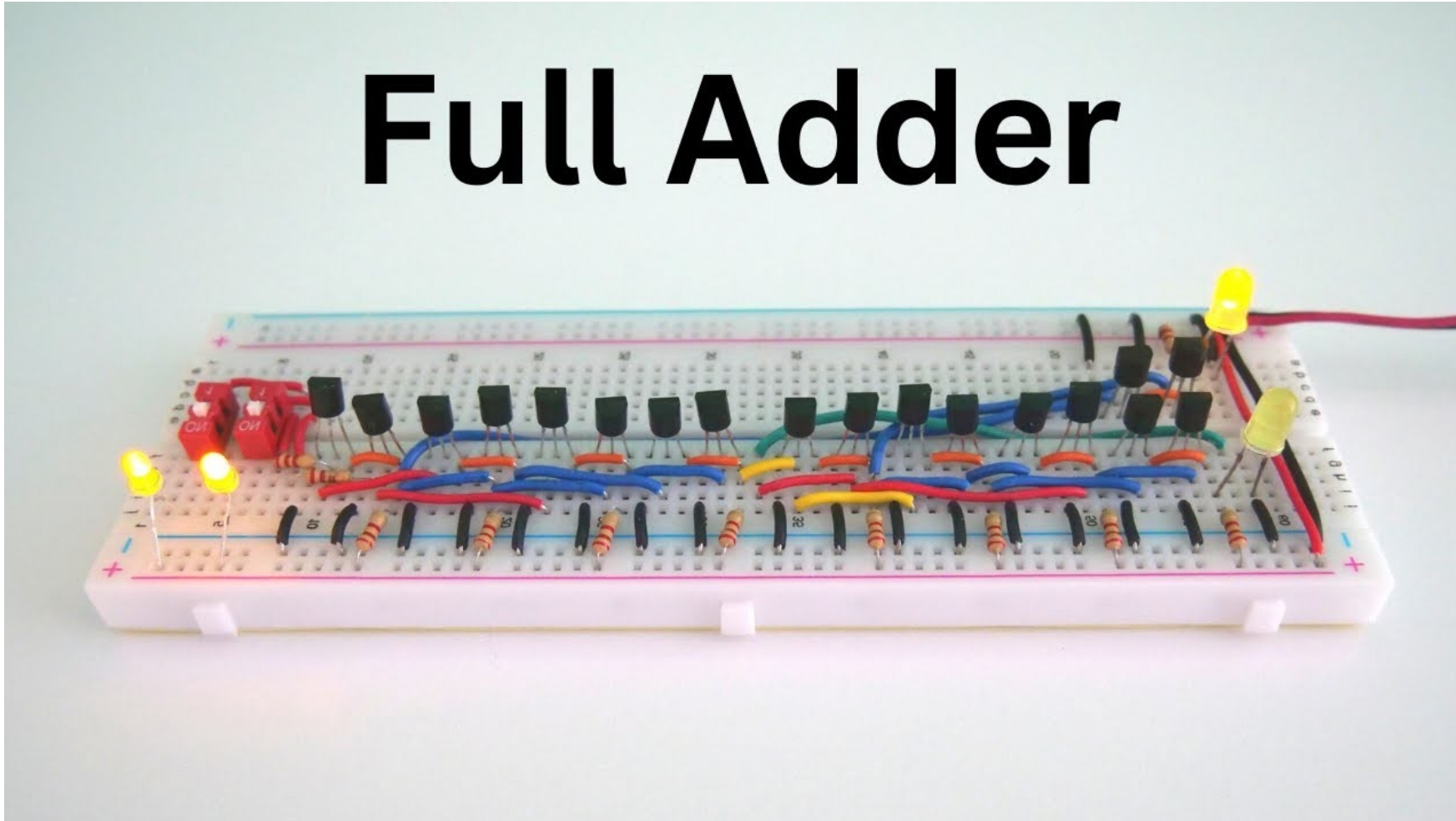
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What is Lithography? Why is Lithography? (How is Lithography?)

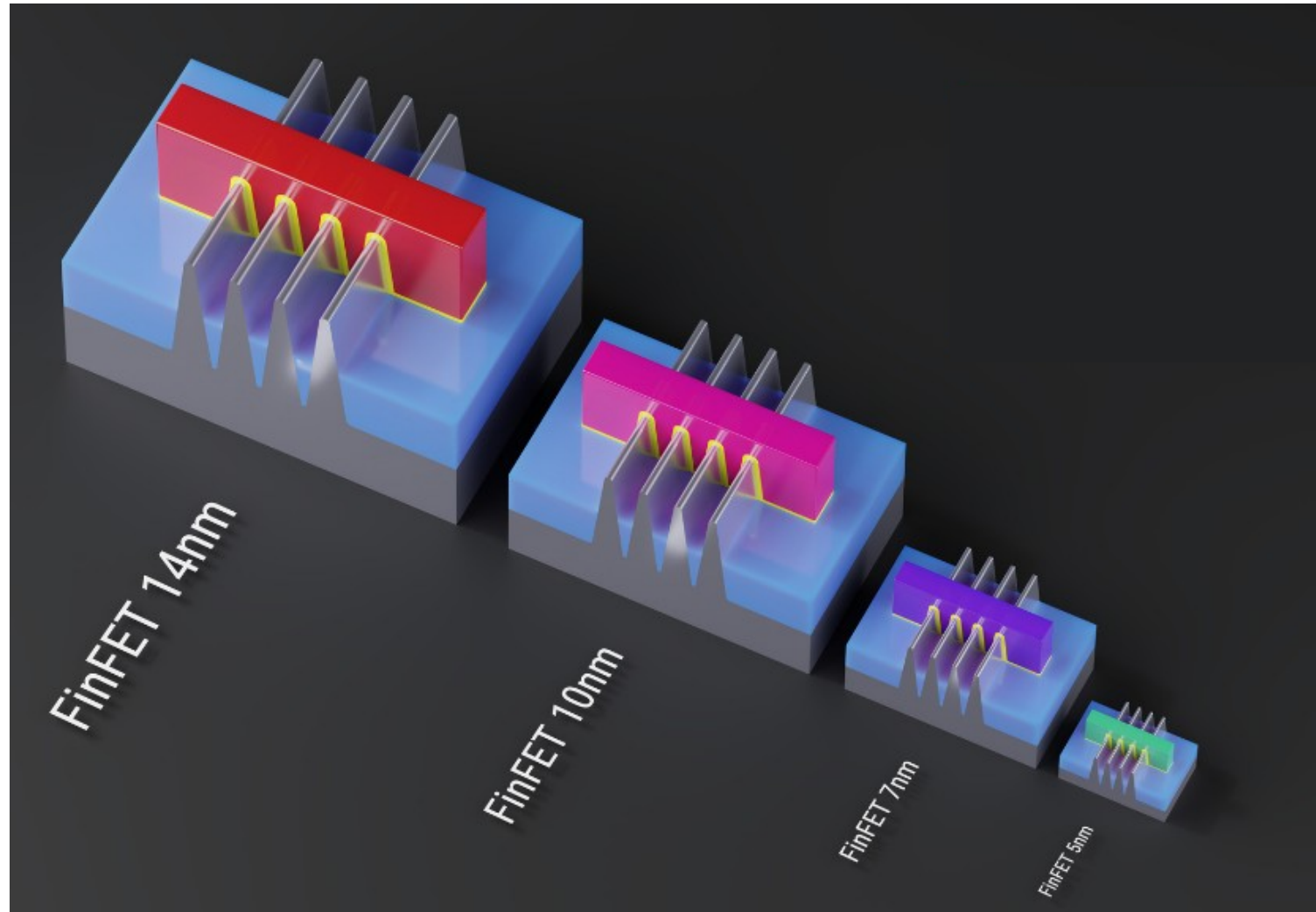
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# Full Adder



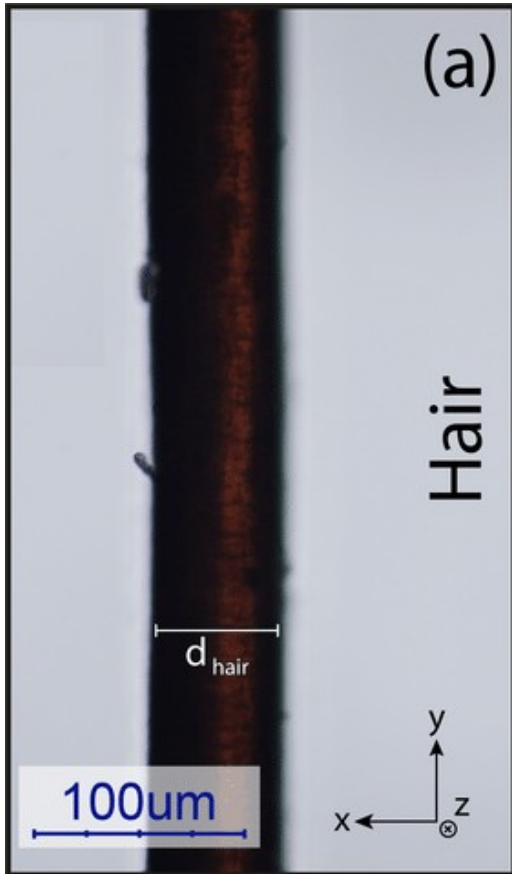
# What is Lithography? Why is Lithography? (How is Lithography?)

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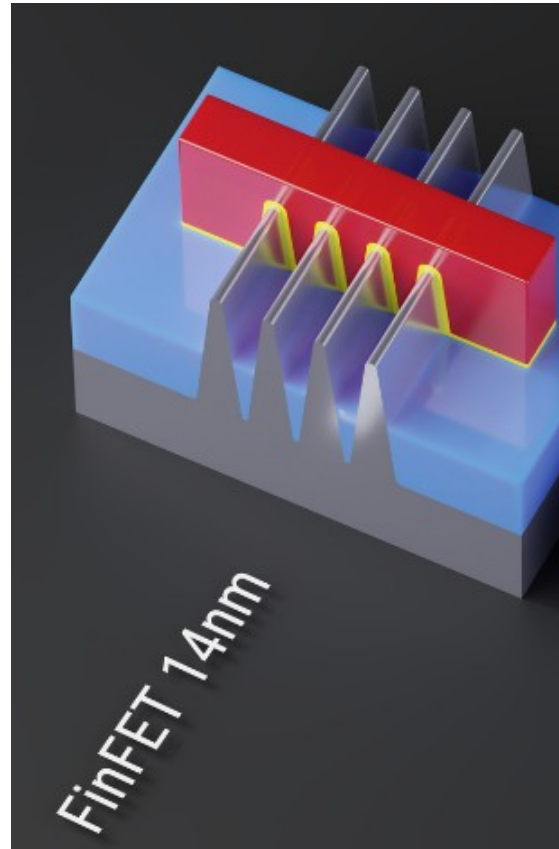


# What is Lithography? Why is Lithography? (How is Lithography?)

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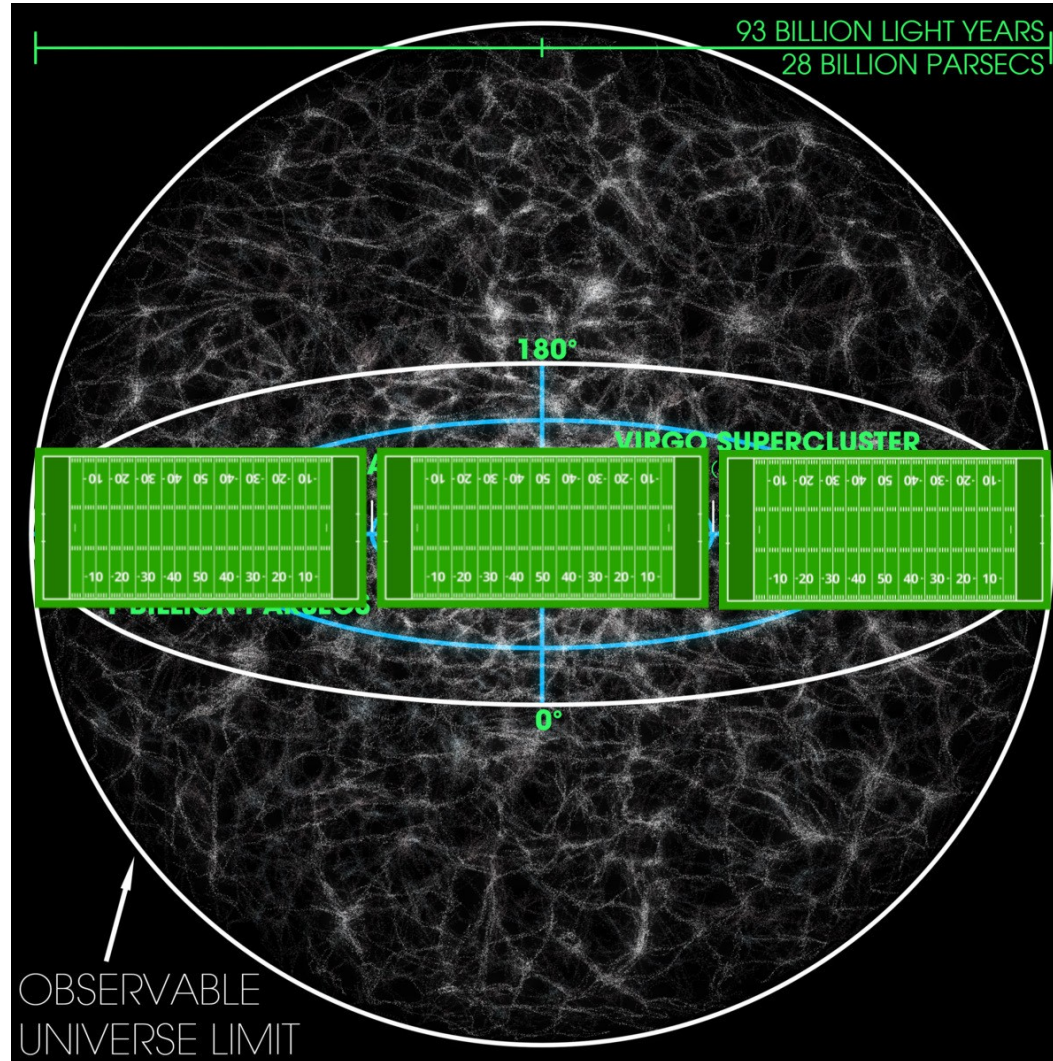
$60\mu\text{m} = 60,000\text{nm}$



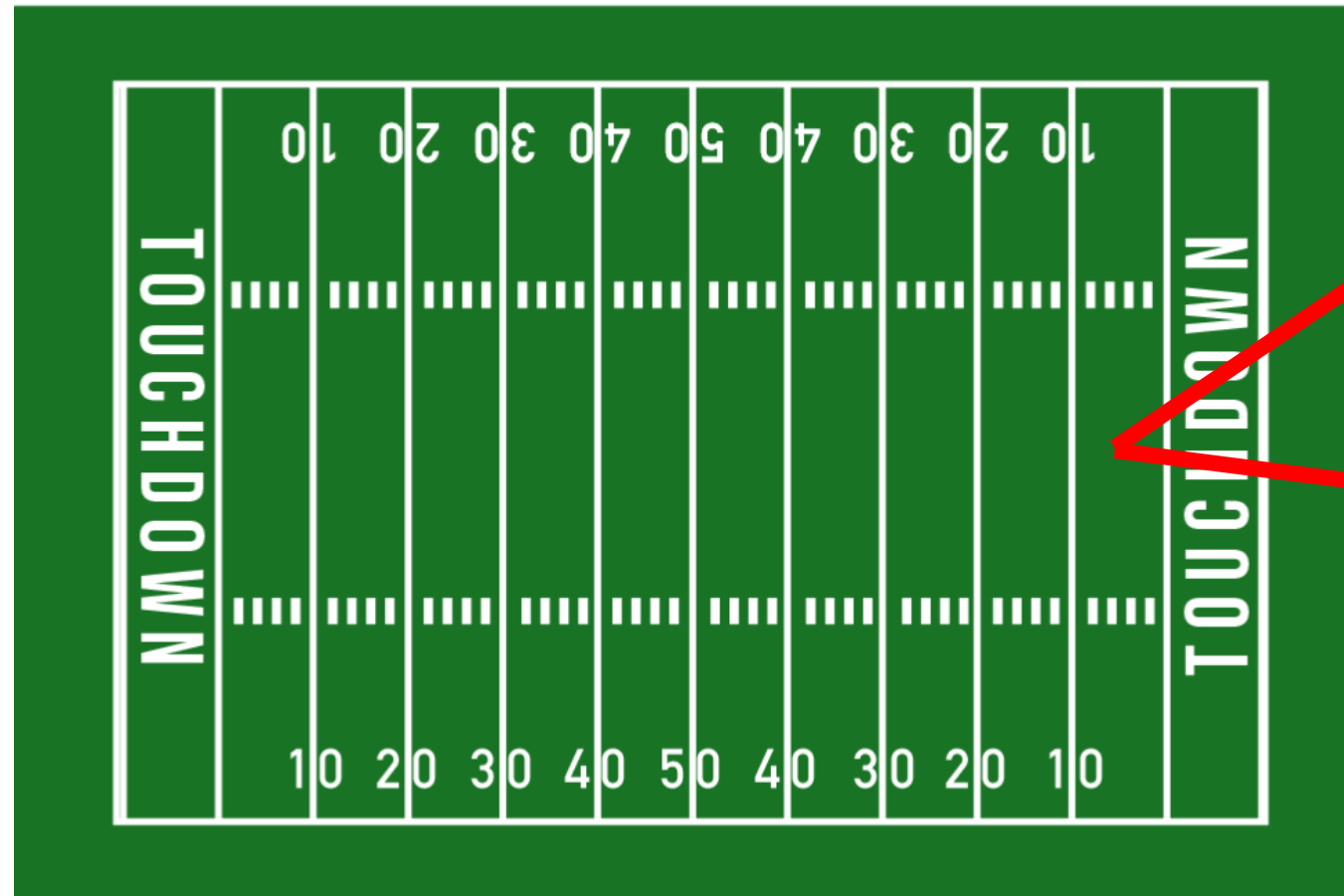
14nm

$$\frac{60,000}{14} \approx 4000$$

# What is Lithography? Why is Lithography? (How is Lithography?)



# What is Lithography? Why is Lithography? (How is Lithography?)



Human hair diameter (60 $\mu$ m)



14nm FinFET

# What is Lithography? Why is Lithography? (How is Lithography?)

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Probably not going to be  
able to wire 14nm  
transistors using hands,  
tools, machines, etc...

# What is Lithography? Why is Lithography? (How is Lithography?)

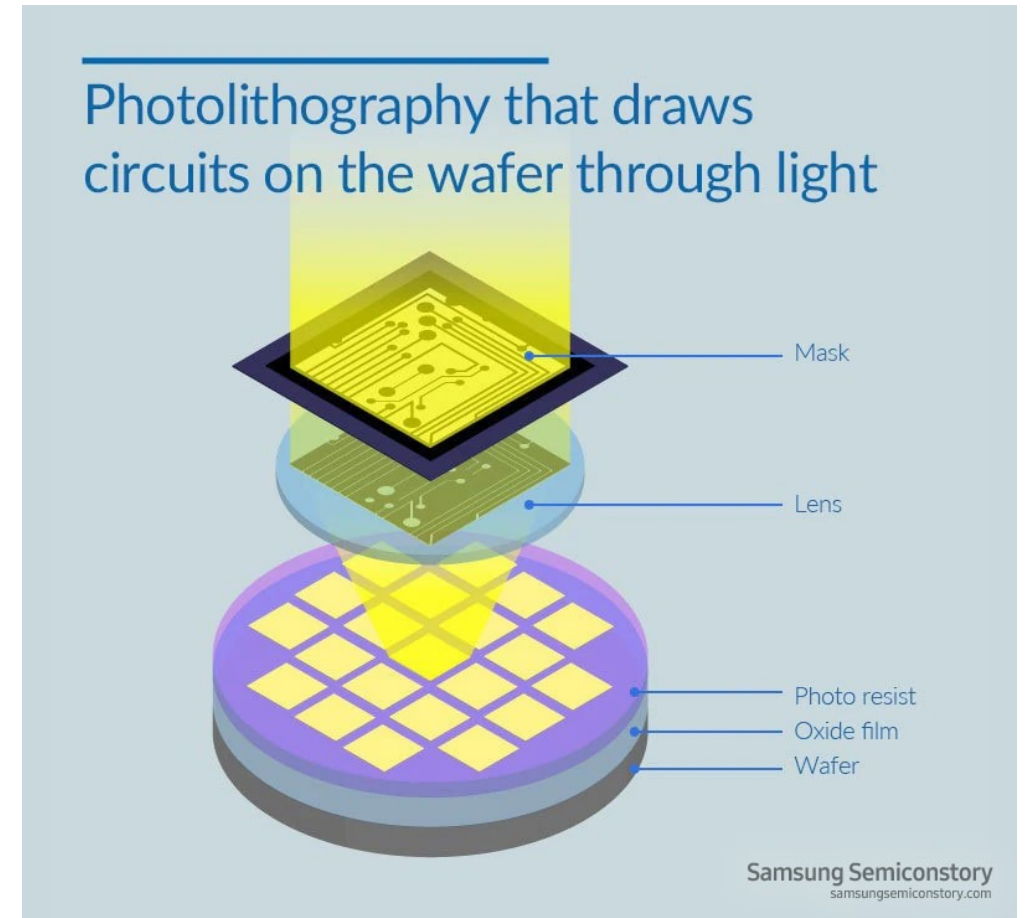
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The solution?

- **LITHOGRAPHY!**
- Basically, we'll design our transistors and circuits using light

What is Lithography?

- Method of transferring circuit design to silicon wafer
  - Patterns are too small to be transferred physically
  - Light has wavelength in scale  $\sim$ nm
  - Followed by less precise “blanket techniques”



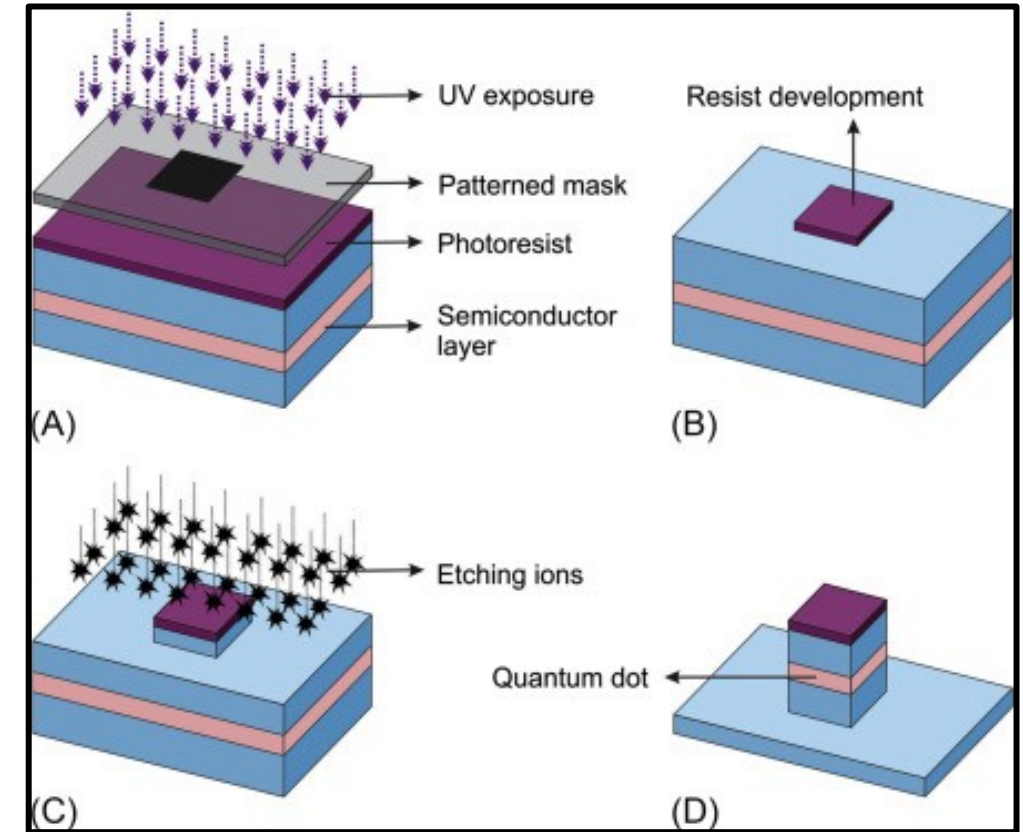
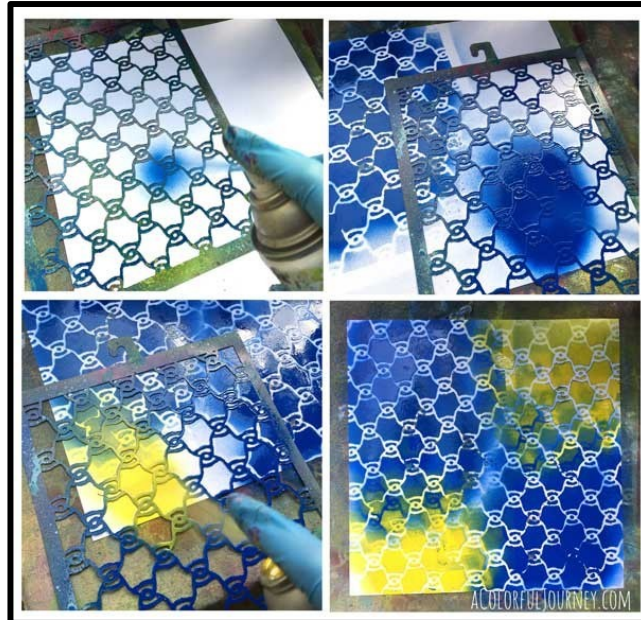
# Fabrication Techniques

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- Lithography (Framing)
- Implantation (Modification)
- Deposition (Additive)
  - Oxidation
  - Plating
- Etching (Subtractive)
  - Wet, Dry

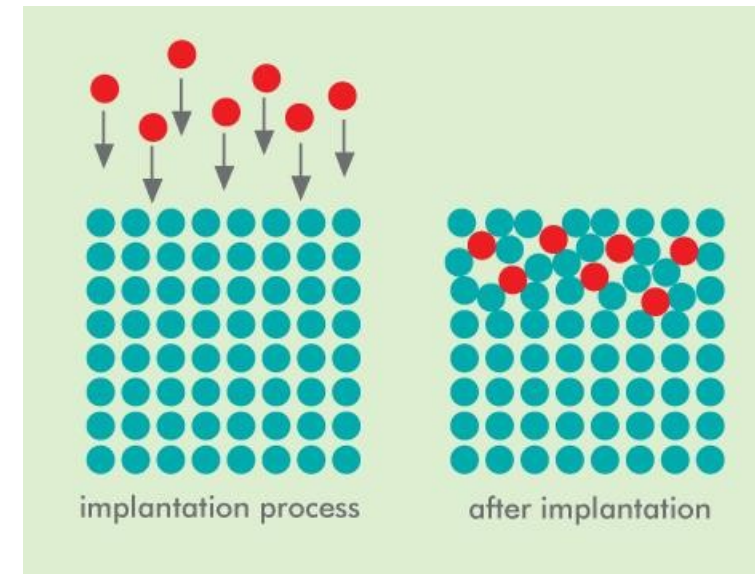
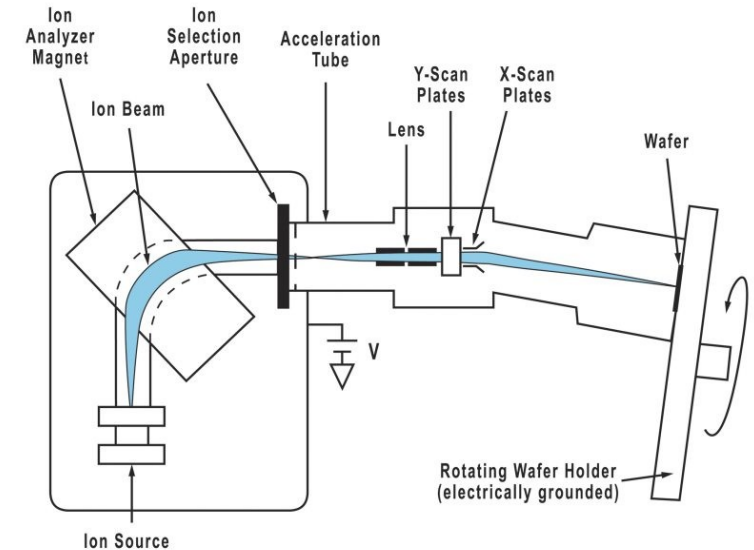
# Fabrication Techniques - Lithography

- Technique used to define where you want a pattern to be
- Involves wavelengths of light reacting with a chemical (photoresist)
- Material can be added/removed between the photoresist



# Fabrication Techniques - Implantation

- Used to modify properties of the wafer underneath
- In Silicon, dopants may result in excess electrons or holes (N, P-type)
- Slight changes in concentration results in large change in electrical conductivity ( $\sim 100\times$ )
- Always causes damage to substrate- must be repaired with an anneal step



# Fabrication Techniques - Deposition

- Additive technique for wafer fabrication
- 3 (main) types
  - Oxidation
  - Deposition
    - Many sub-categories:
      - CVD, LPCVD, PVD, PECVD...
  - Electroplating

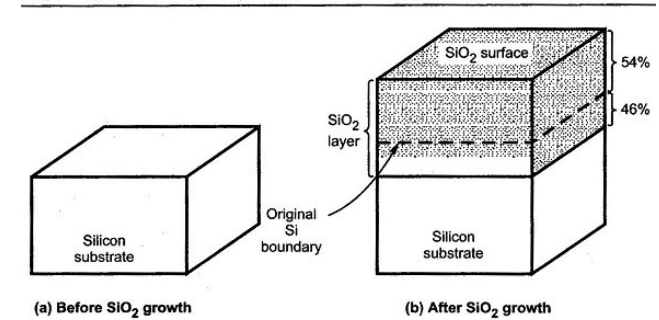
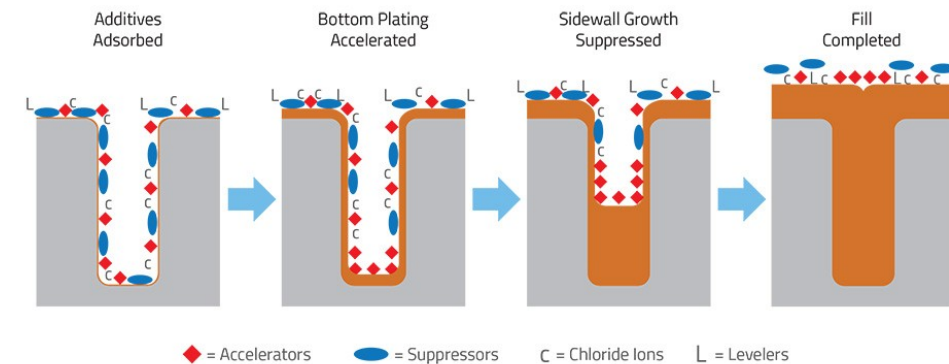
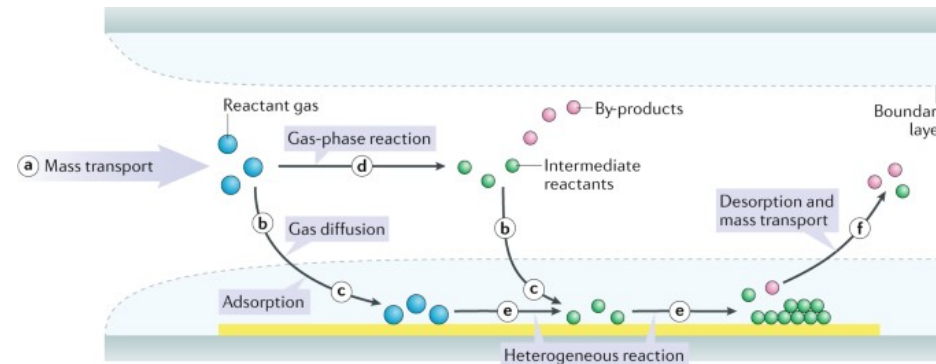


Fig. 1.4 Thermal Oxidation



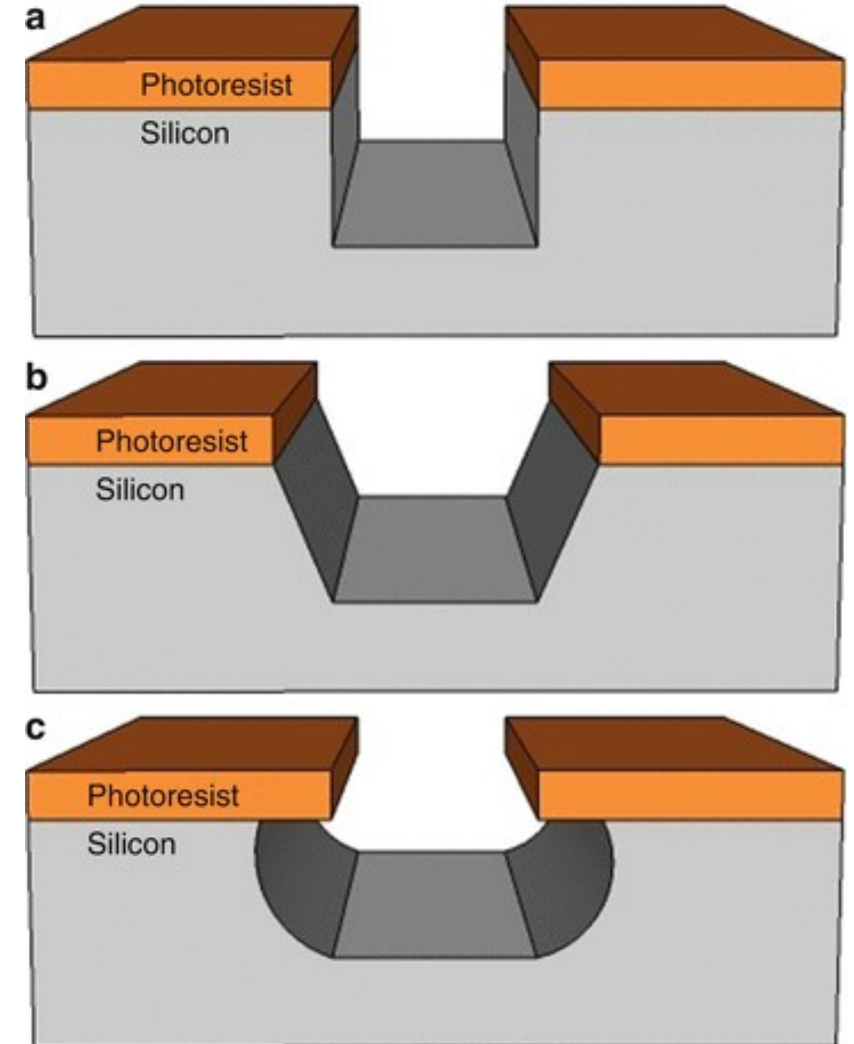
# Fabrication Techniques - Etching

## Two important characteristics

- Selectivity: How quickly one material is etched relative to another
- Anisotropy Ratio: How quickly material is consumed in a certain direction versus another

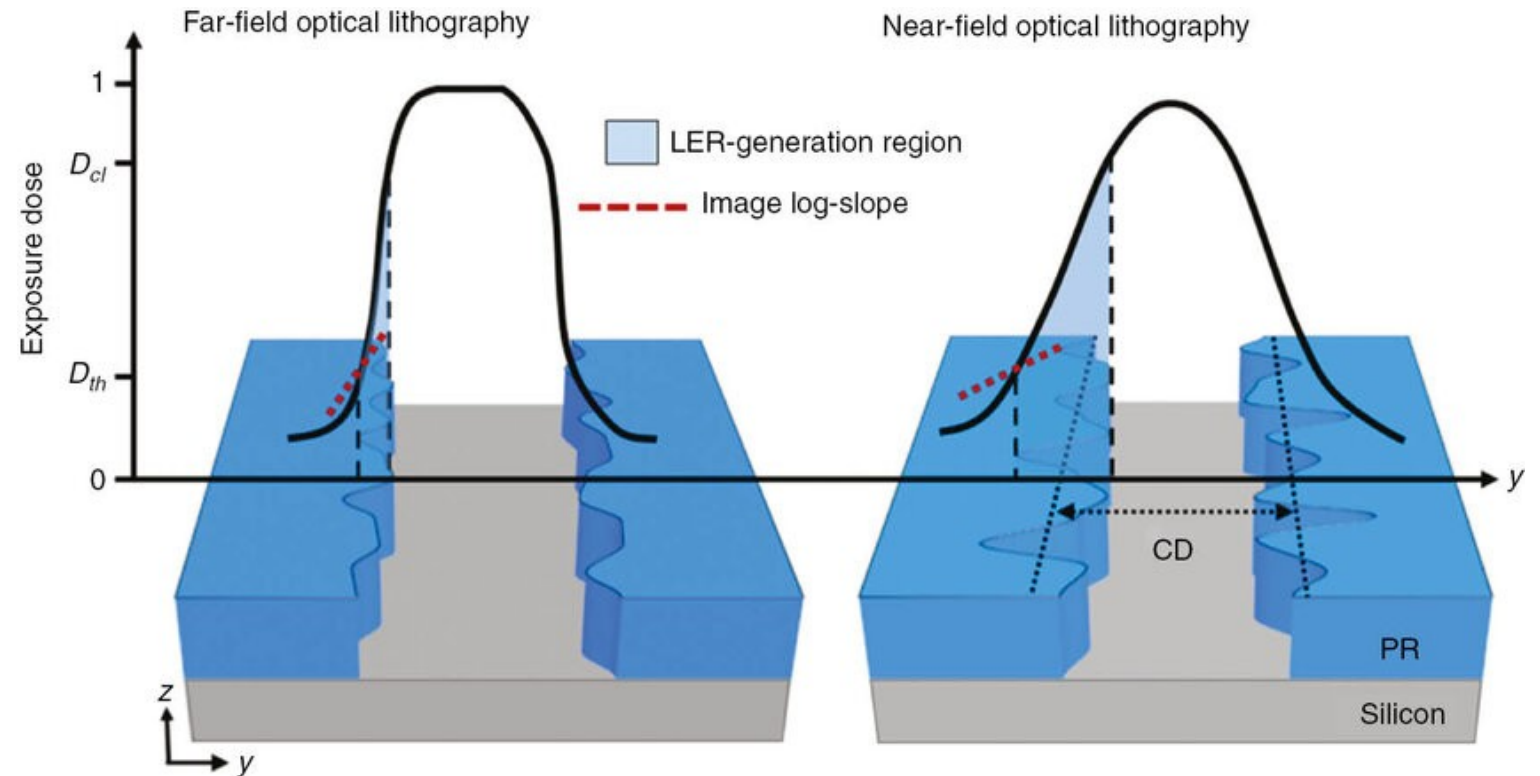
## Two main types

- Wet Etching (Typically with acids/other wet chemistry)
- Dry Etching (Typ. Reactive Ion Etching)



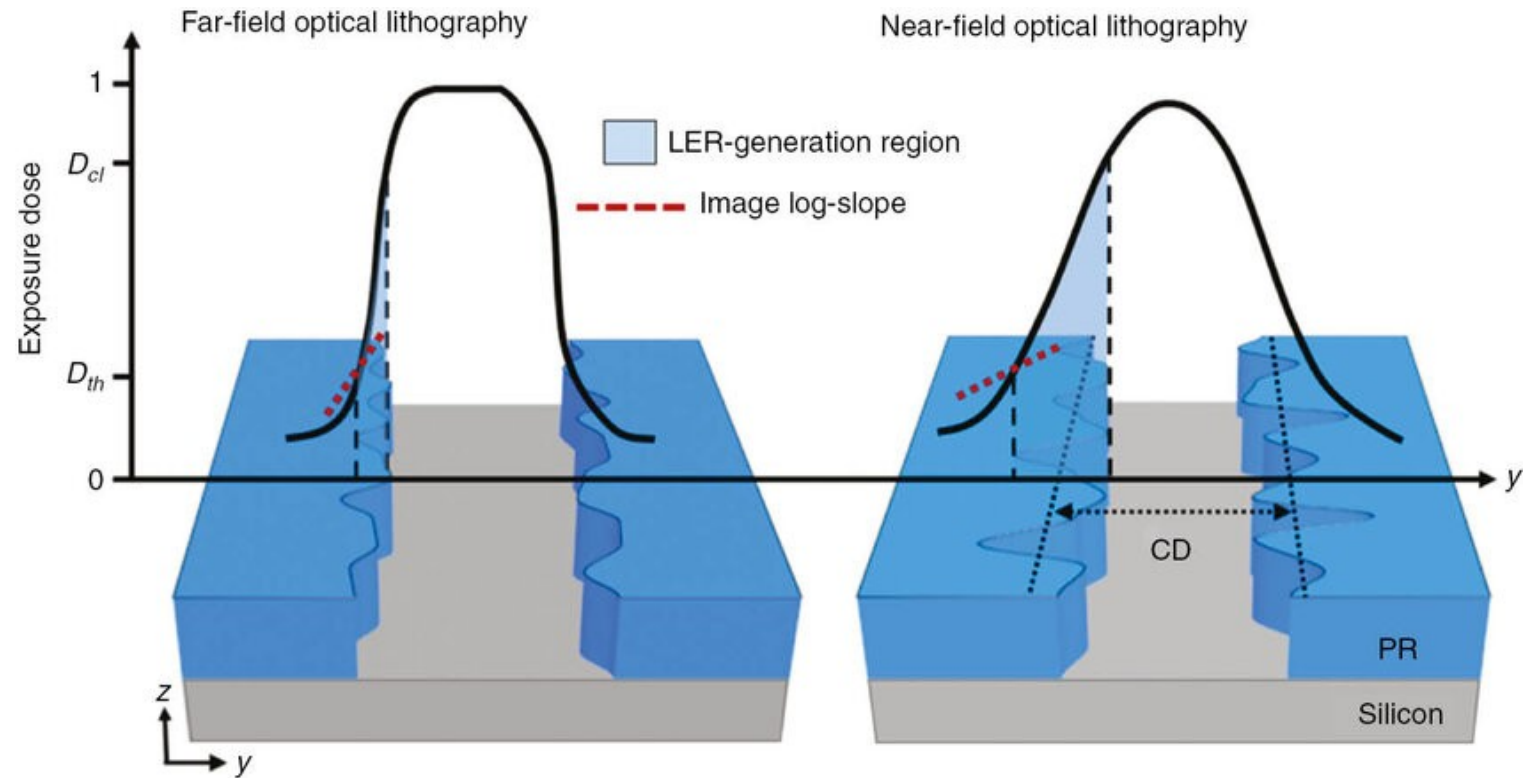
# Lithography Over the Years

- What is the goal when optimizing the lithography process?



# Lithography Over the Years

- What is the goal when optimizing the lithography process?
  - Better resolution!



# Lithography Over the Years- Characteristic Equation

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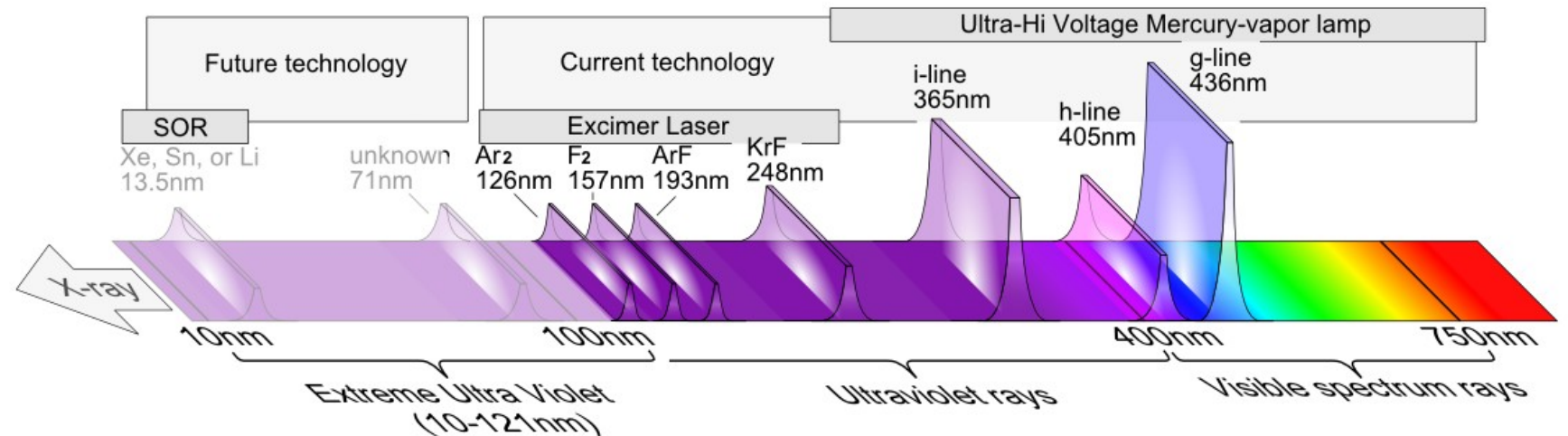
- CD: Critical Dimension (Minimum feature size)
- K1: Process Coefficient
  - Typ. 1, Can go to ~0.5 or lower
- Lambda: Wavelength of incoming light
- NA: Numerical Aperture
  - Typ. 0.5-0.7, can go above 1

$$CD = k_1 \frac{\lambda}{NA}$$

**We'll come back to this...**

# Lithography Over the Years- Wavelengths

- Mercury Lamp (UV)
  - G-line (436nm), H-line (405nm), I-line (365nm)
- Excimer Laser (DUV)
  - KrF (248 nm)
  - ArF (193nm)
  - EUV (13.5nm)



# Lithography Over the Years- Wavelengths

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| Technology generation | Wavelength (nm) | Exposure source |
|-----------------------|-----------------|-----------------|
| EUV G LINE            | 436             | Mercury         |
| EUV H LINE            | 405             | Mercury         |
| EUV I LINE            | 365             | Mercury         |
| Excimer laser         | 248             | KrF             |
| Excimer laser         | 193             | ArF             |
| Excimer laser         | 157             | F2              |
| Extreme ultraviolet   | 13.5            | Tin vapor       |

????

[https://www.youtube.com/watch?v=ZPa\\_RKFTBPc](https://www.youtube.com/watch?v=ZPa_RKFTBPc)

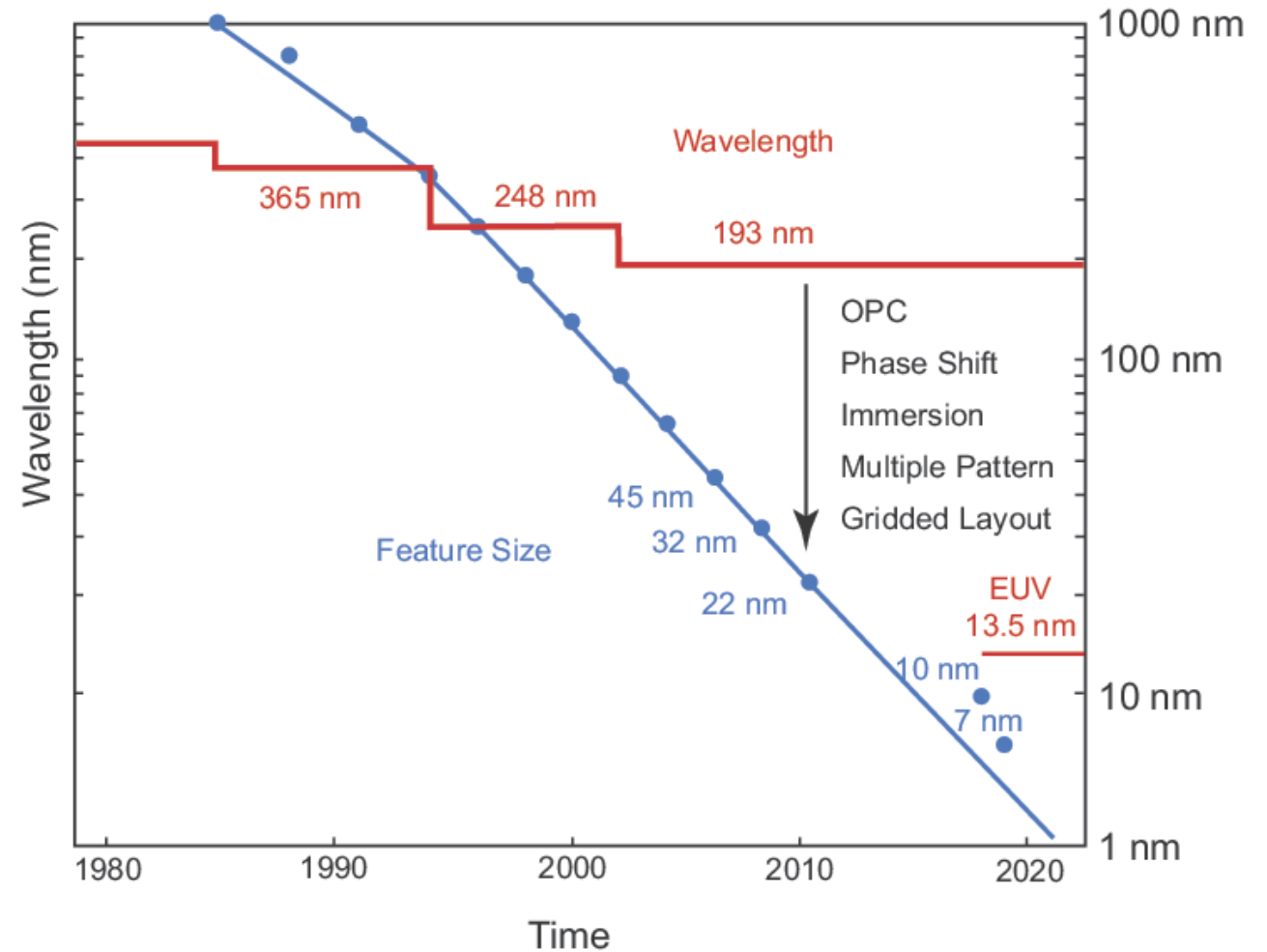
# Lithography Over the Years- Why 193???

Before 1990:

- “Like drawing thick lines with a sharp pencil”

After 1990

- “Mask Designer’s Nightmare”



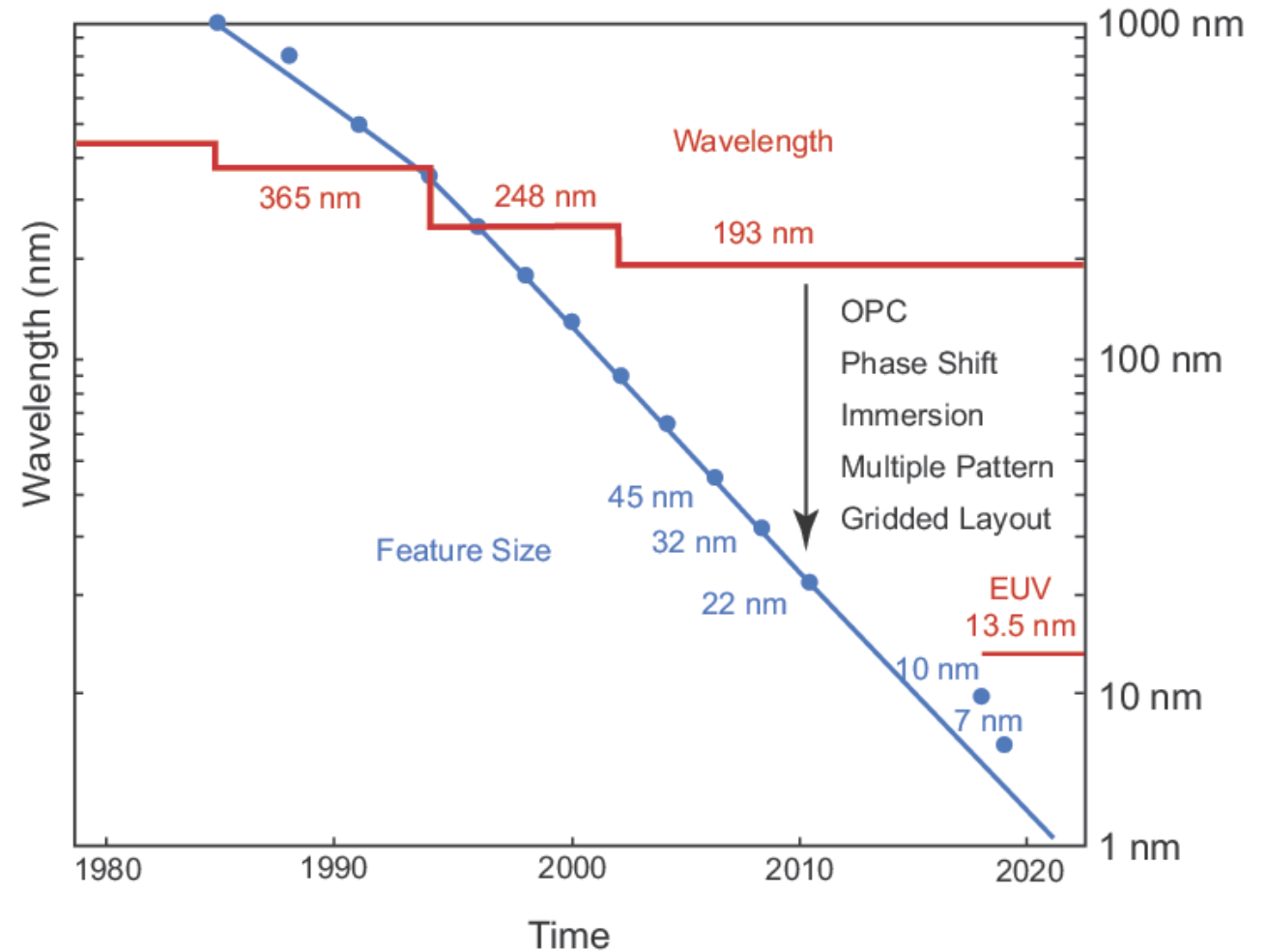
# Lithography Over the Years- What happened to 157?

## Technical Challenges:

- Poor Photoresist
- Needed new reticle design
- Expensive processing

## Upcoming Solutions (for 1990s)

- Immersion technology!?
- EUV *supposed* to come out in 2001



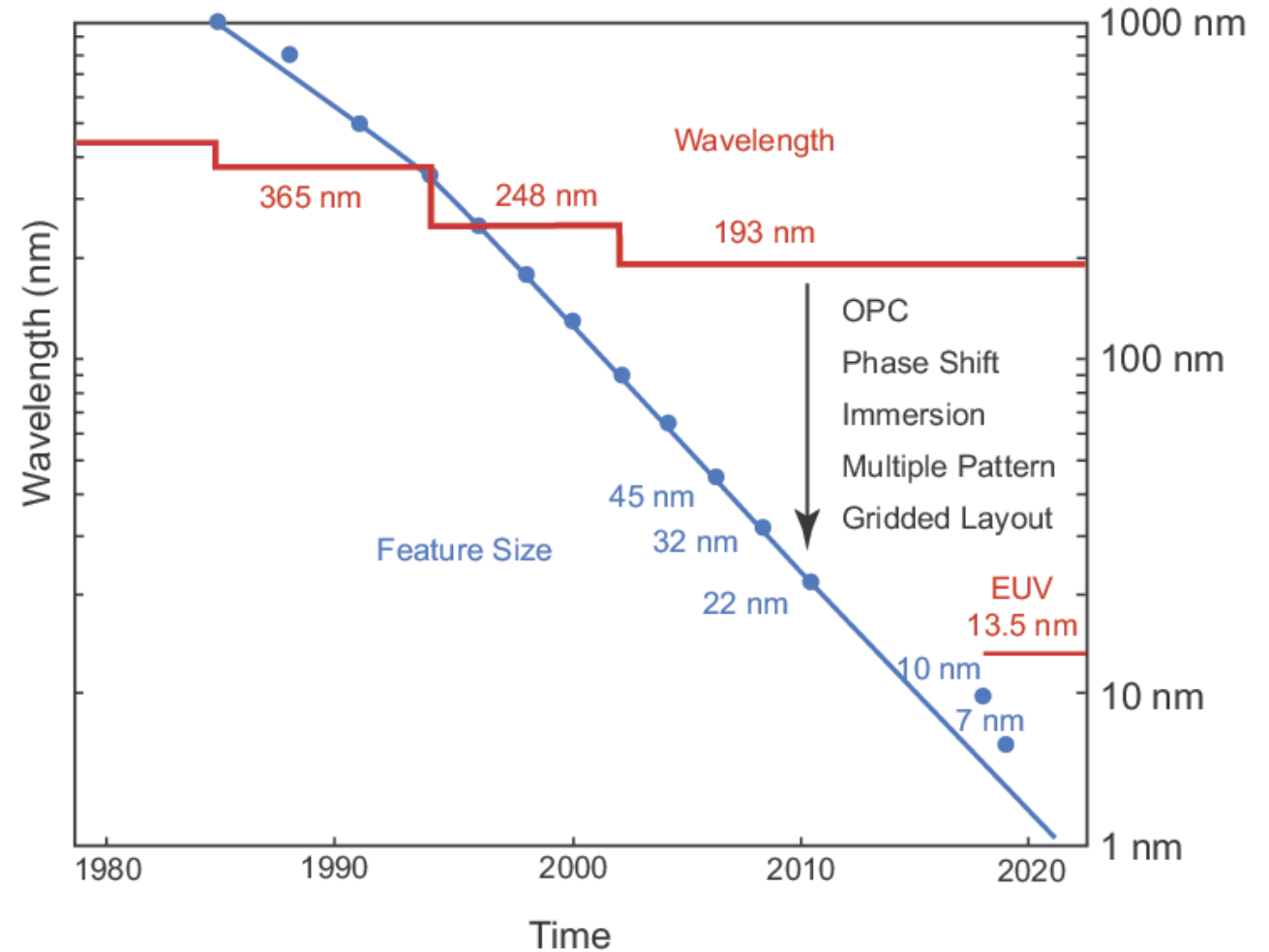
# Lithography Over the Years- What happened to 157?

## Technical Challenges:

- Poor Photoresist
- Needed new reticle design
- Expensive processing

## Upcoming Solutions (for 1990s)

- Immersion technology!?
- EUV *supposed* to come out in 2001
  - (GTA6 of Semiconductor Industry)



# Brute Force for Moore's Law (k1)

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## Resolution Enhancement Techniques

- Optical Proximity Correction
- Phase Shift Masks
- Double Patterning Techniques



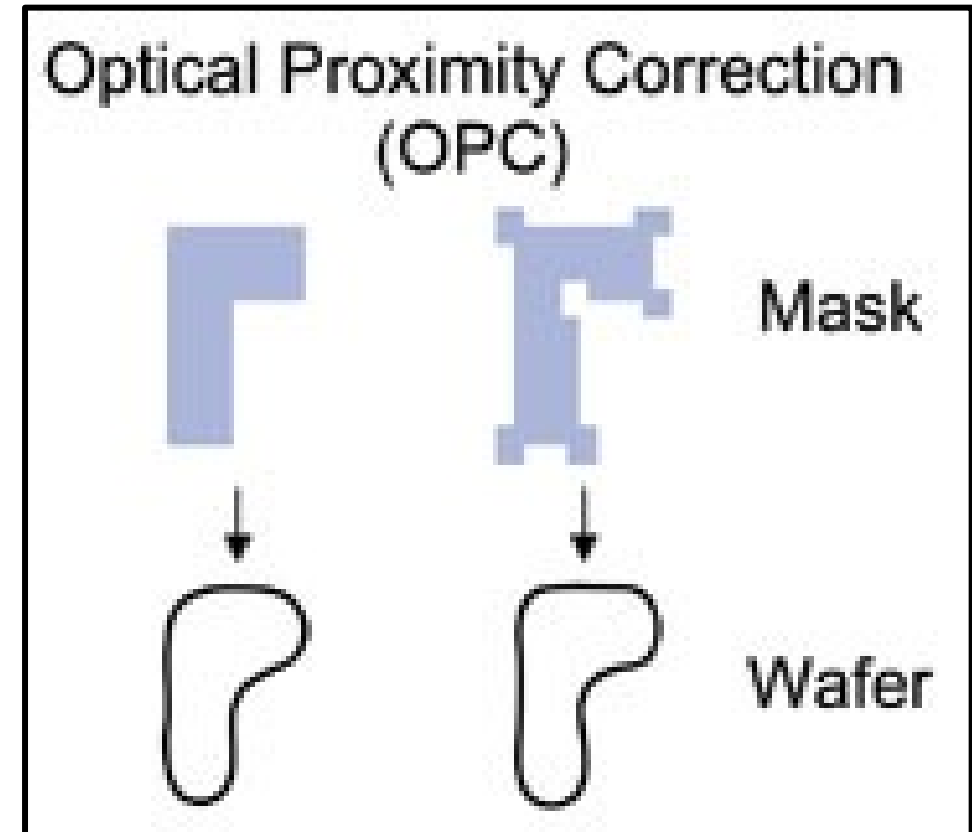
(image unrelated)

# Brute Force for Moore's Law (k1) - OPC

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## Optical Proximity Correction (OPC)

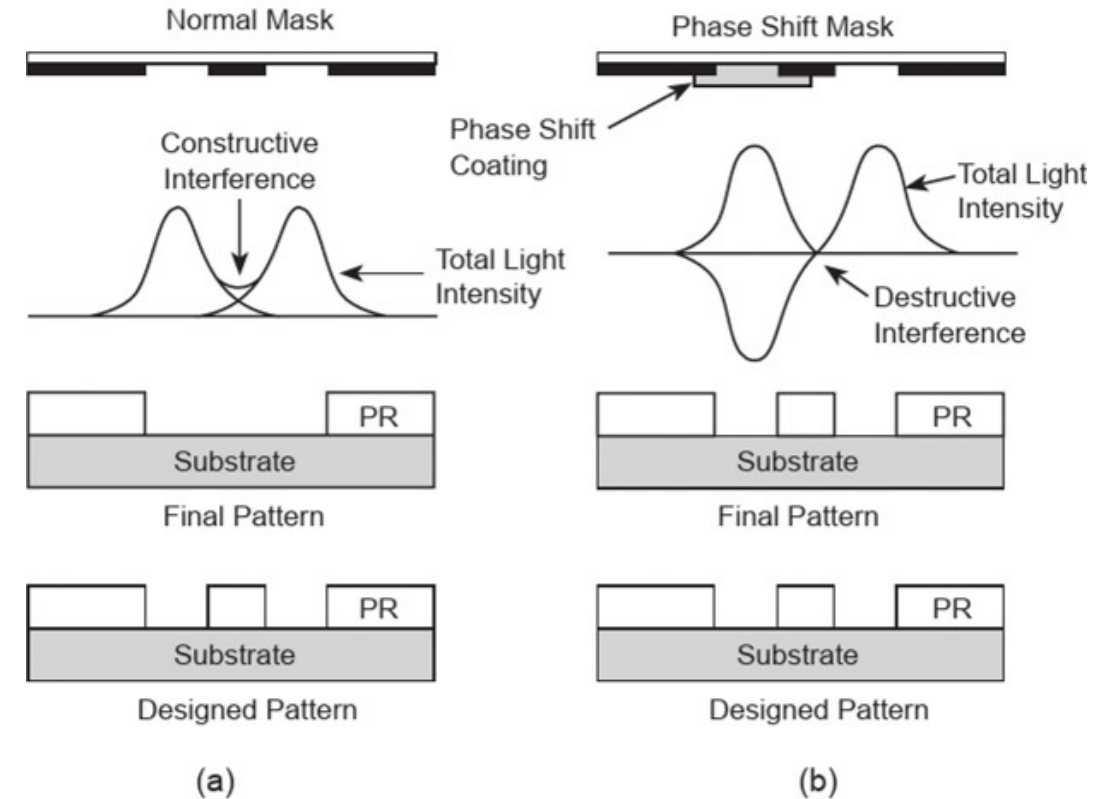
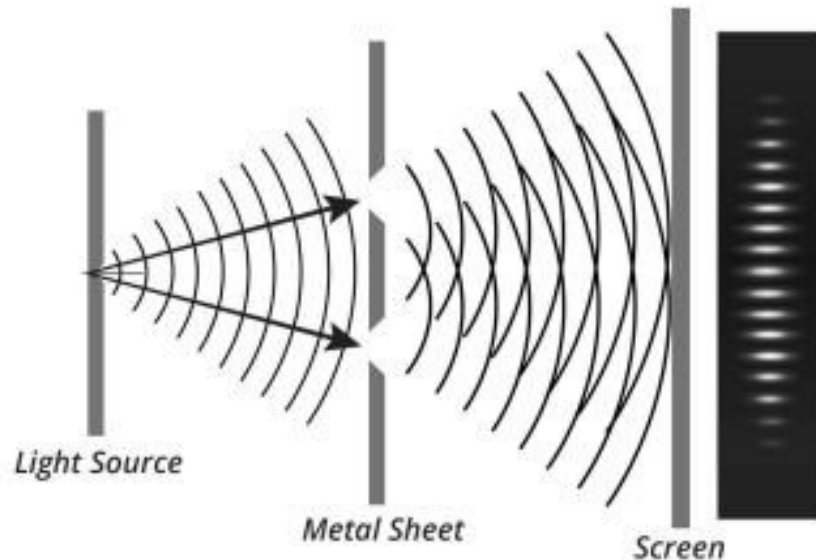
- Constructive/Destructive Interference
  - Introduce serifs/additional patterns so OUTPUT looks correct (mask doesn't)
- VERY interesting field for optics engineering & computer science



# Brute Force for Moore's Law ( $k_1$ ) - Phase Shift Masks

## Phase Shift Masks

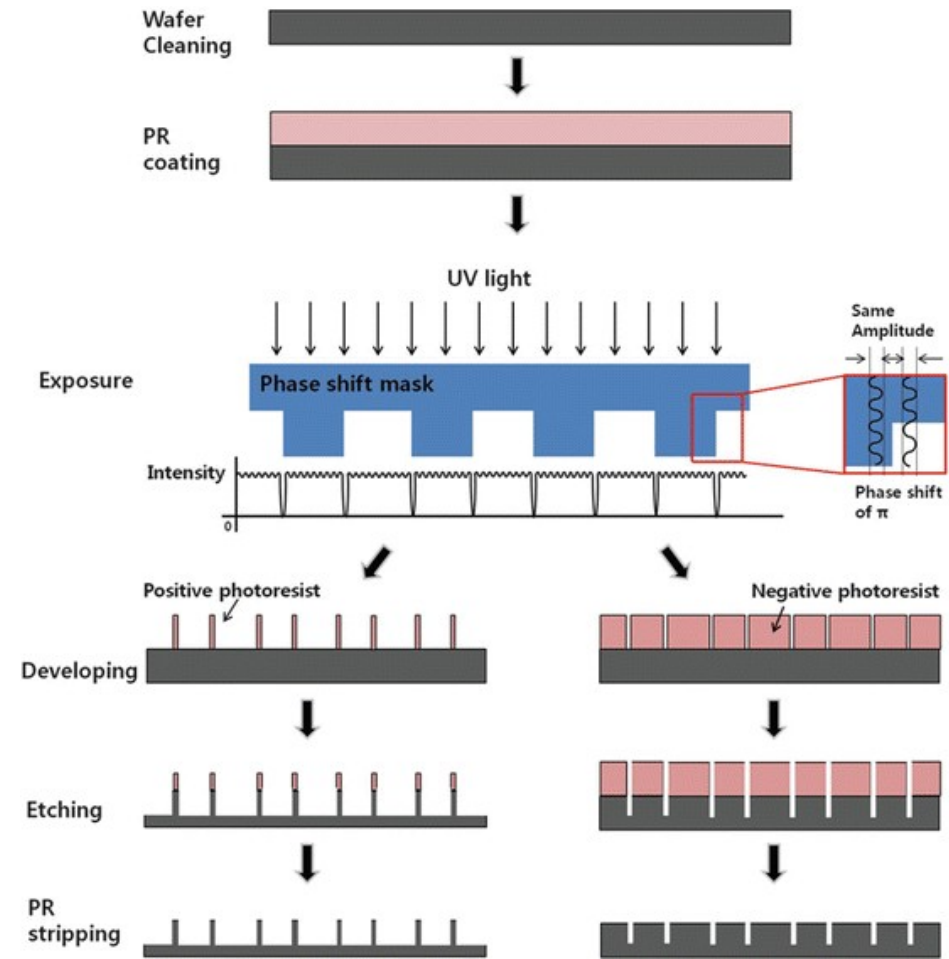
- Control interference for better feature fidelity



# Brute Force for Moore's Law (k1) - Phase Shift Masks

## Phase Shift Masks

- Mask Design No longer Binary
- Designed constructive/destructive interference for high-resolution output

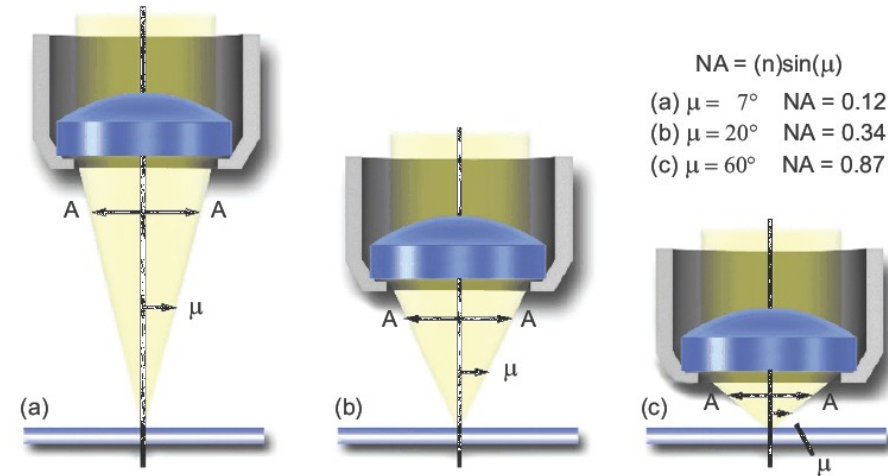


# Brute Force for Moore's Law (NA) - Immersion Lithography

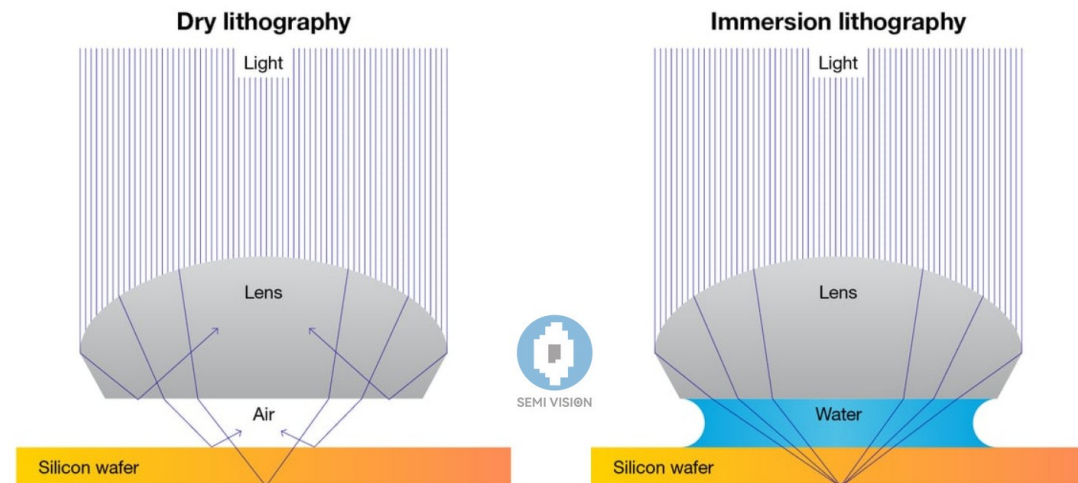
## Immersion Lithography

- Increase Numerical Aperture (Sharper Focusing of light)
- $NA = n \sin(\theta_{max})$

Numerical Aperture and Airy Disc Size



$$CD = k_1 \frac{\lambda}{NA}$$



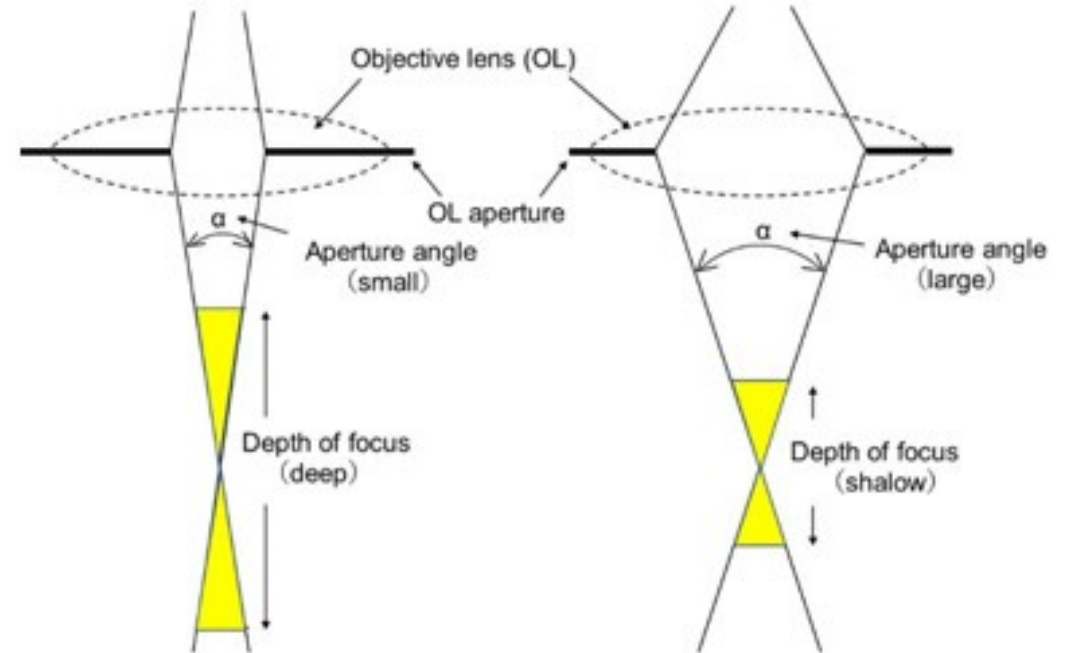
# Brief Aside - The issue with NA

## Depth of Focus (DoF)

- More precision in distance from lens
- In EUV, photoresist needs to be ~10s of nm thick
- DoF inversely proportional to NA

$$\text{DOF} = K_2 \frac{\lambda}{\text{NA}^2}$$

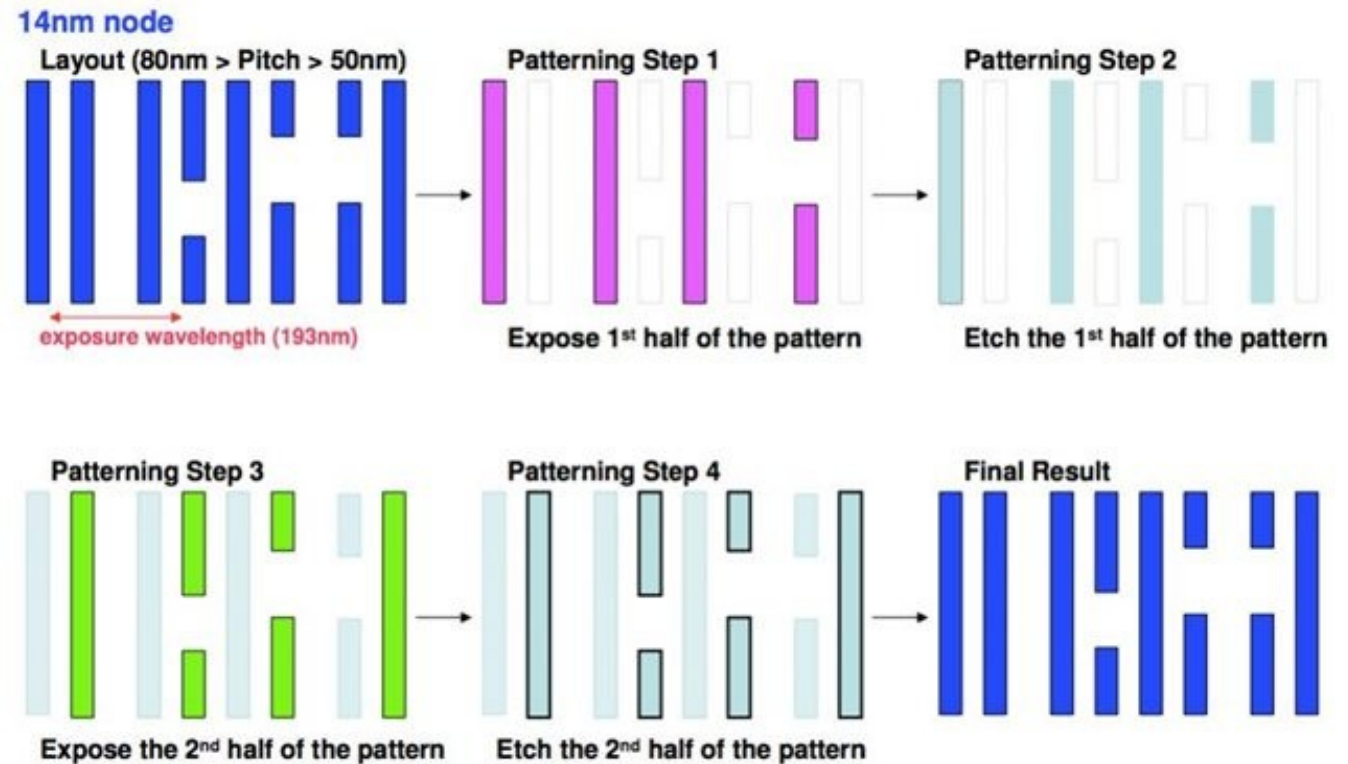
$K_2$  : depending on the criteria used to define acceptable imaging & on the type of feature



# Brute Force for Moore's Law (k1) - Double Patterning

- Solve interference problem by just making more masks
  - 2x, 4x patterning

POV: Mask designers selling more masks to do the same work



# Mask Design

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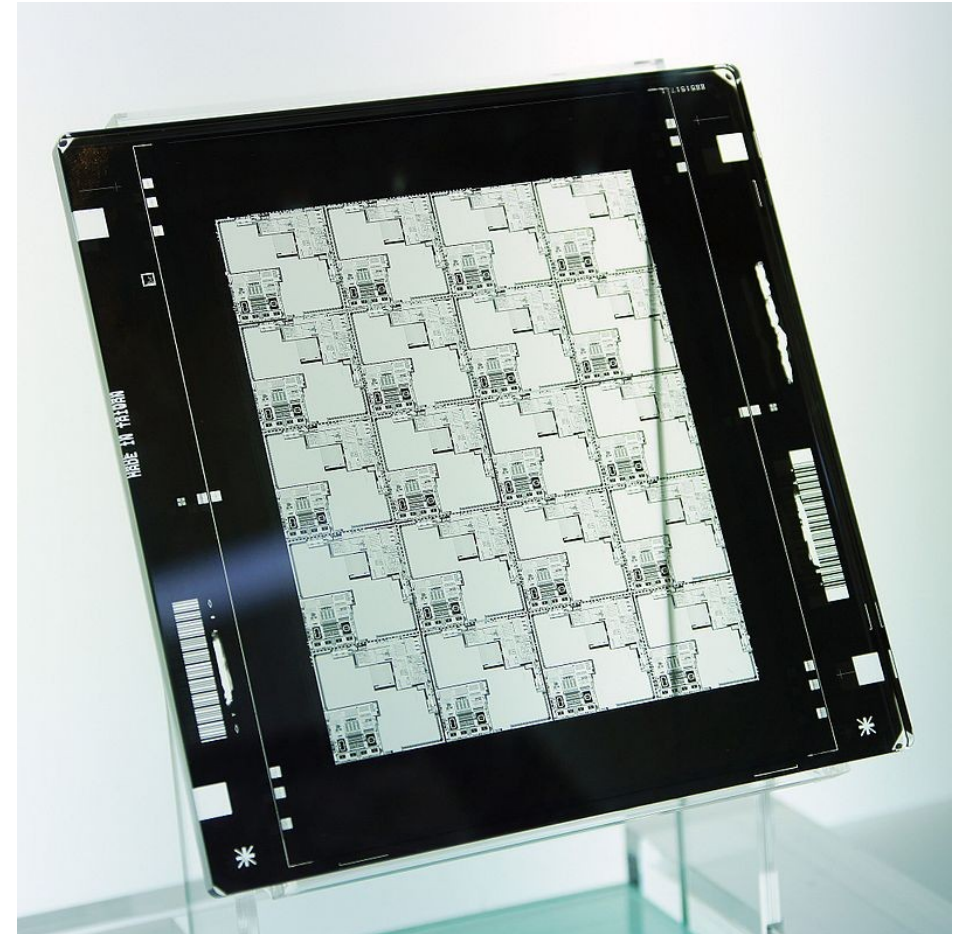
Exposure Area:

- Limited by Reduction Lenses
- ~26x33 mm max

DUV/Older systems:

- Quartz (Fused Silica)
- Chromium
- Can cost ~10-100k

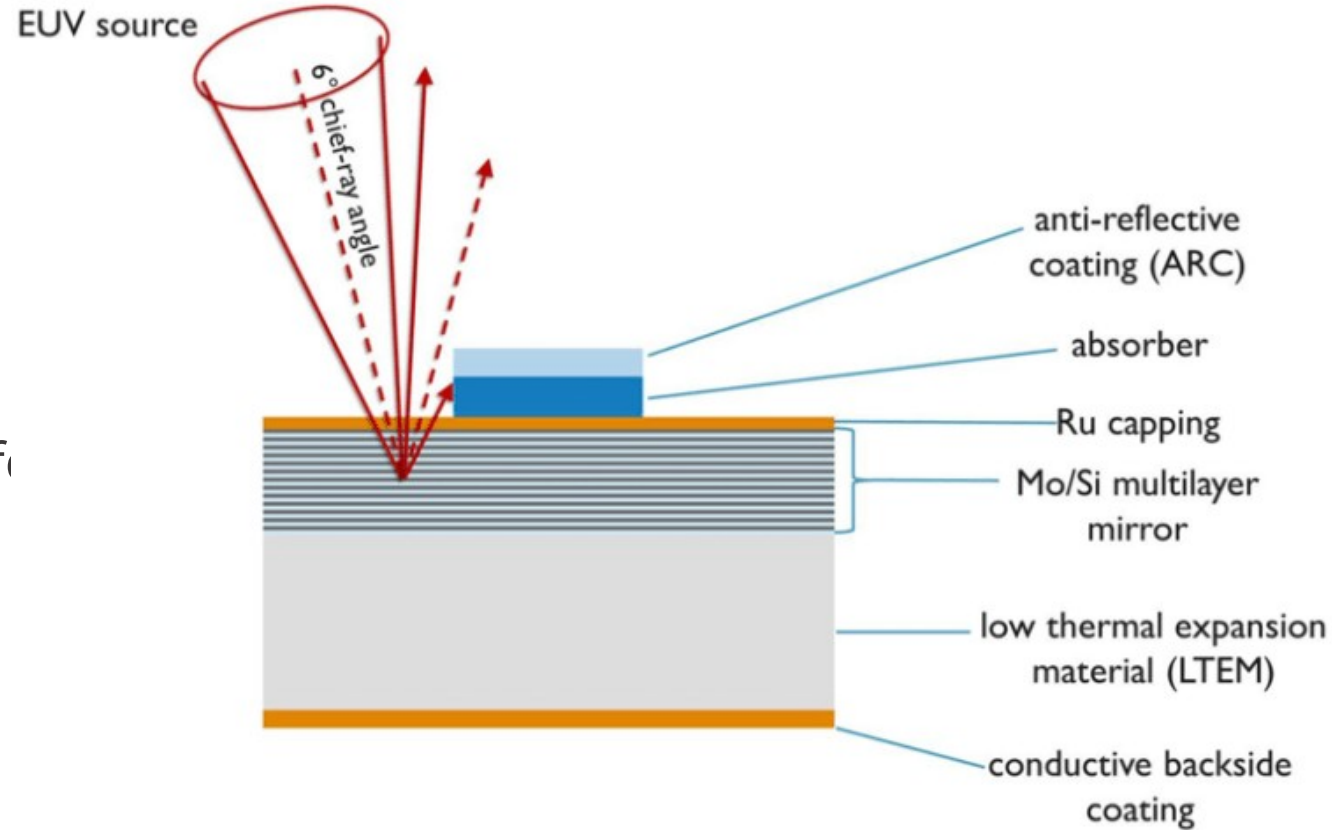
[https://youtu.be/9RZreu5z\\_Gc?si=rI32Z36lvvmAOuUI](https://youtu.be/9RZreu5z_Gc?si=rI32Z36lvvmAOuUI)



# Mask Design (EUV)

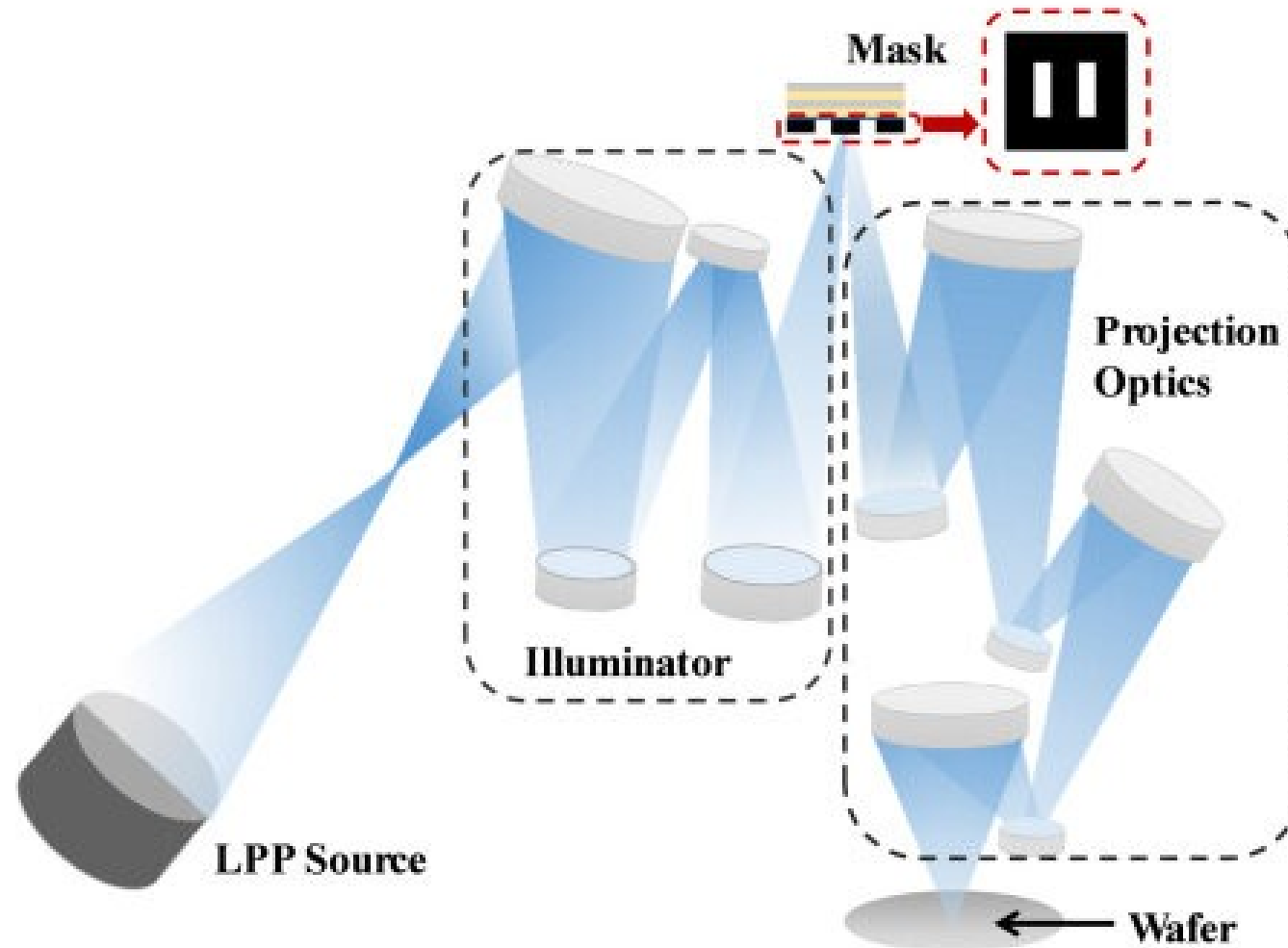
## Extremely Expensive

- “Mirror mask”
- ~70% of energy is absorbed
  - 11 mirrors  $\rightarrow 0.7^{11} = 2\%$  energy transfer
- 50+ layers of Molybdenum + Silicon
- Can cost ~500k each



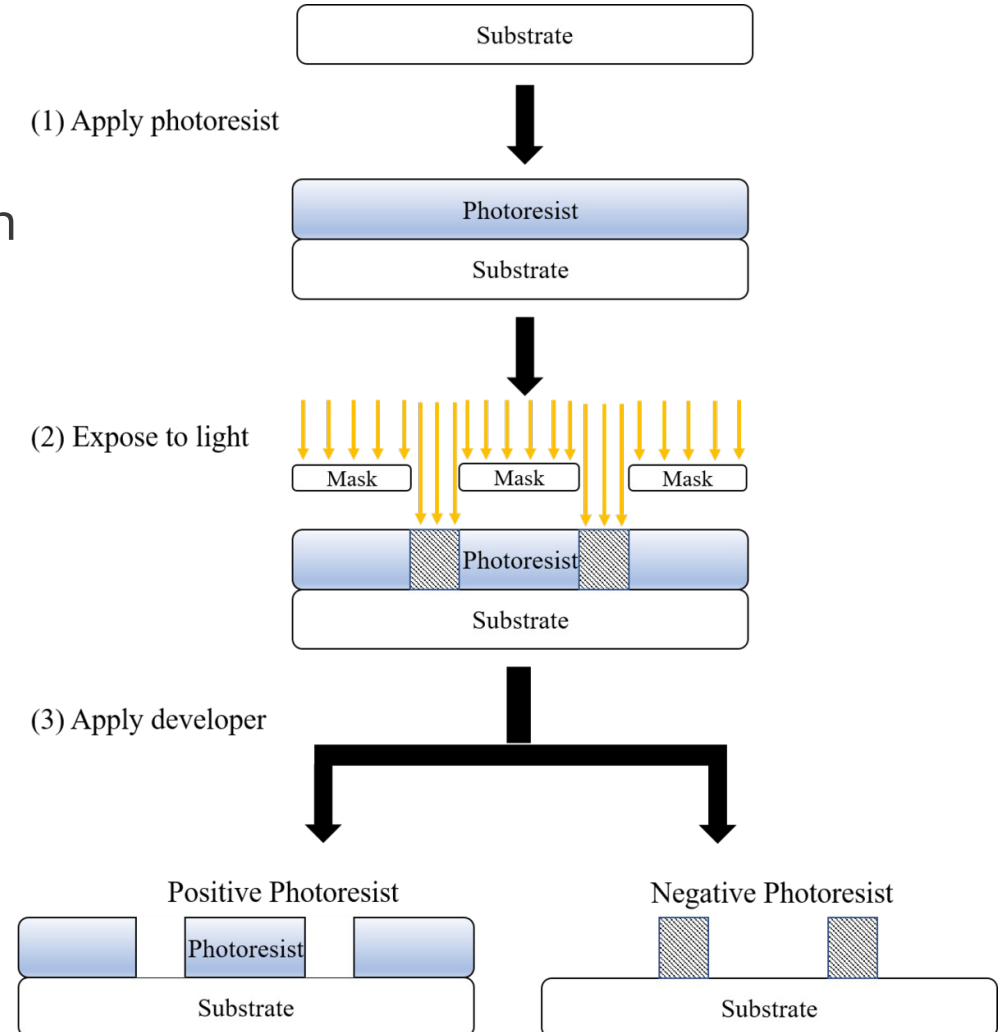
# Mask Design (EUV)

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# Photoresist

- Large, Organic polymers
- When exposed to light, cross-linking occurs between polymers
- Good photoresist requires the following
  - Specific wavelength sensitivity
  - High uniformity
  - Very strong chemical resistance (When exposed)
  - Easy development (Removal of “blank” areas)
  - *Limiting factor for new wavelengths!*



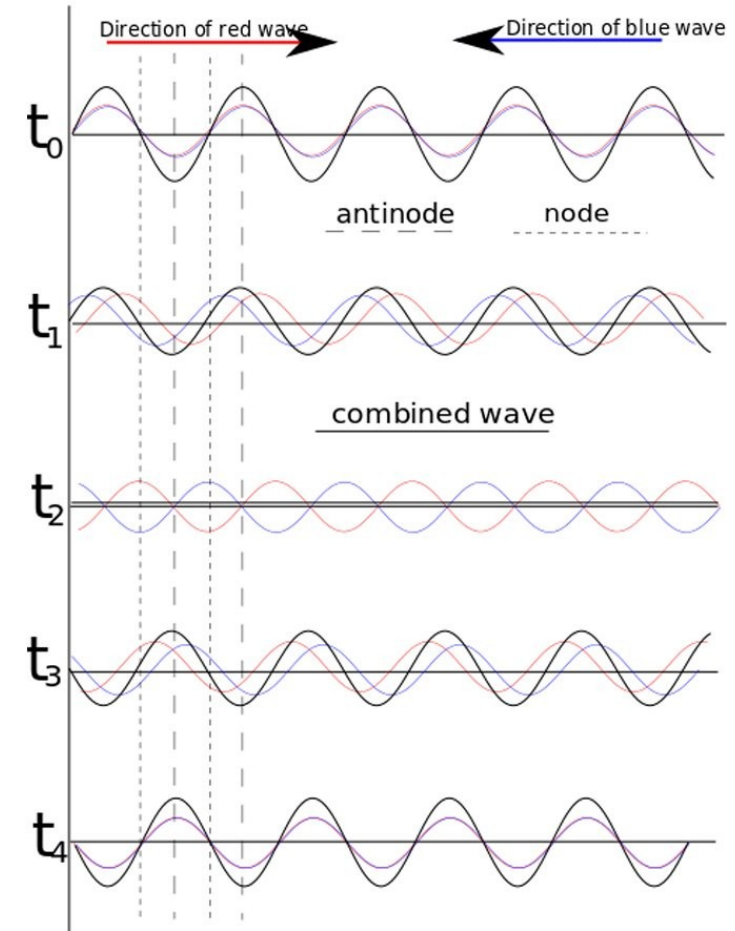
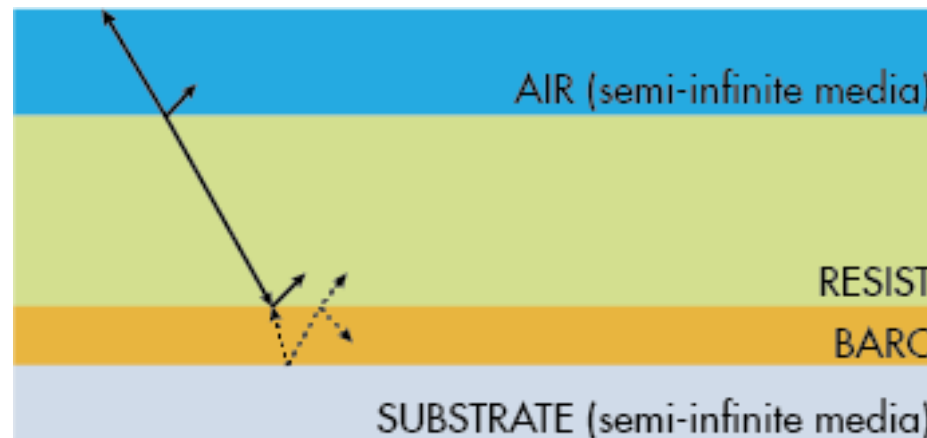
# Weird Photoresist (EUV)

## Etch rate additives

- Actual resist is too thin to work long enough...

## BARC/Underlayers

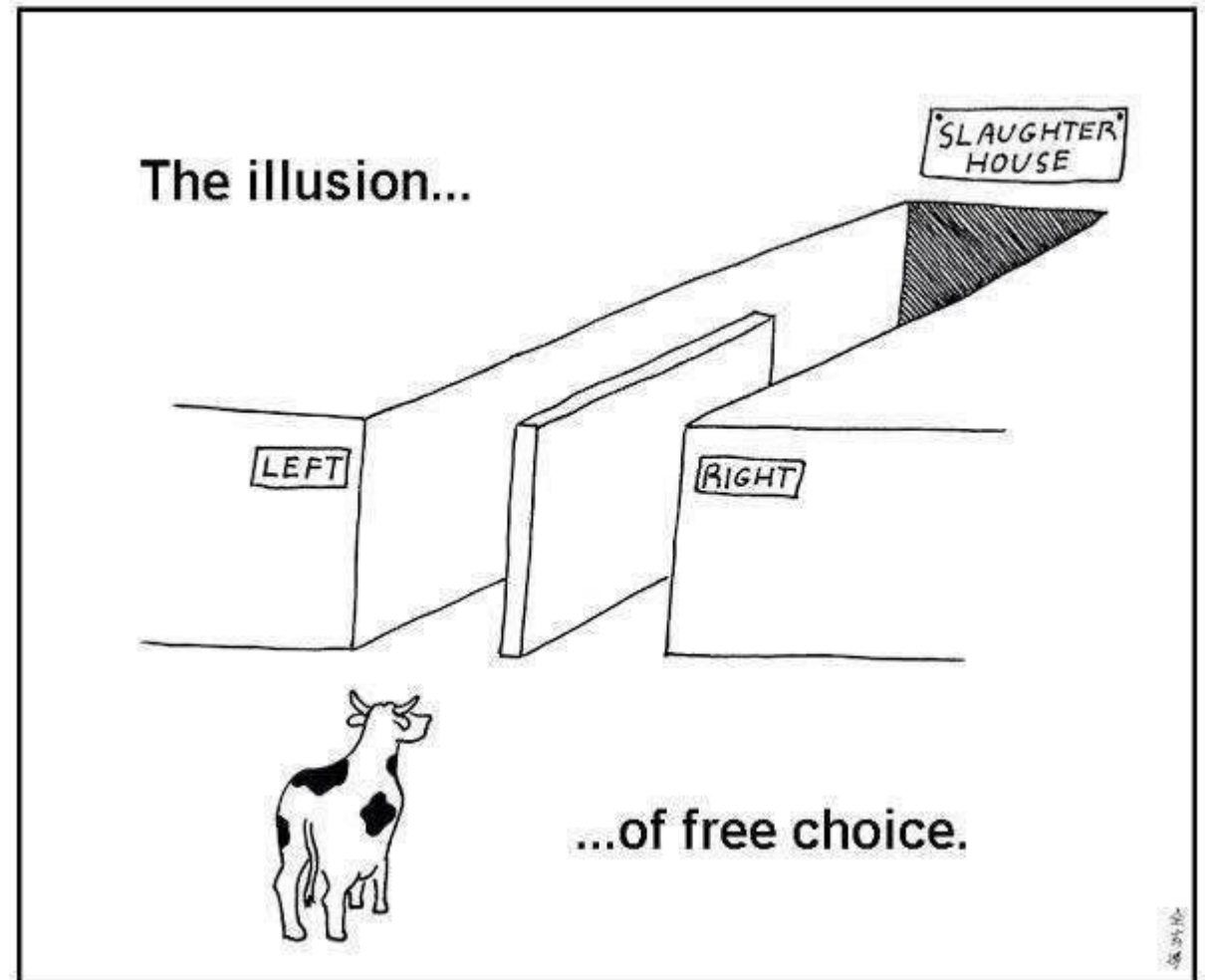
- Reduce "Standing waves"
- Improve adhesion/resolution



# Lithography Types- “Choose your own adventure”

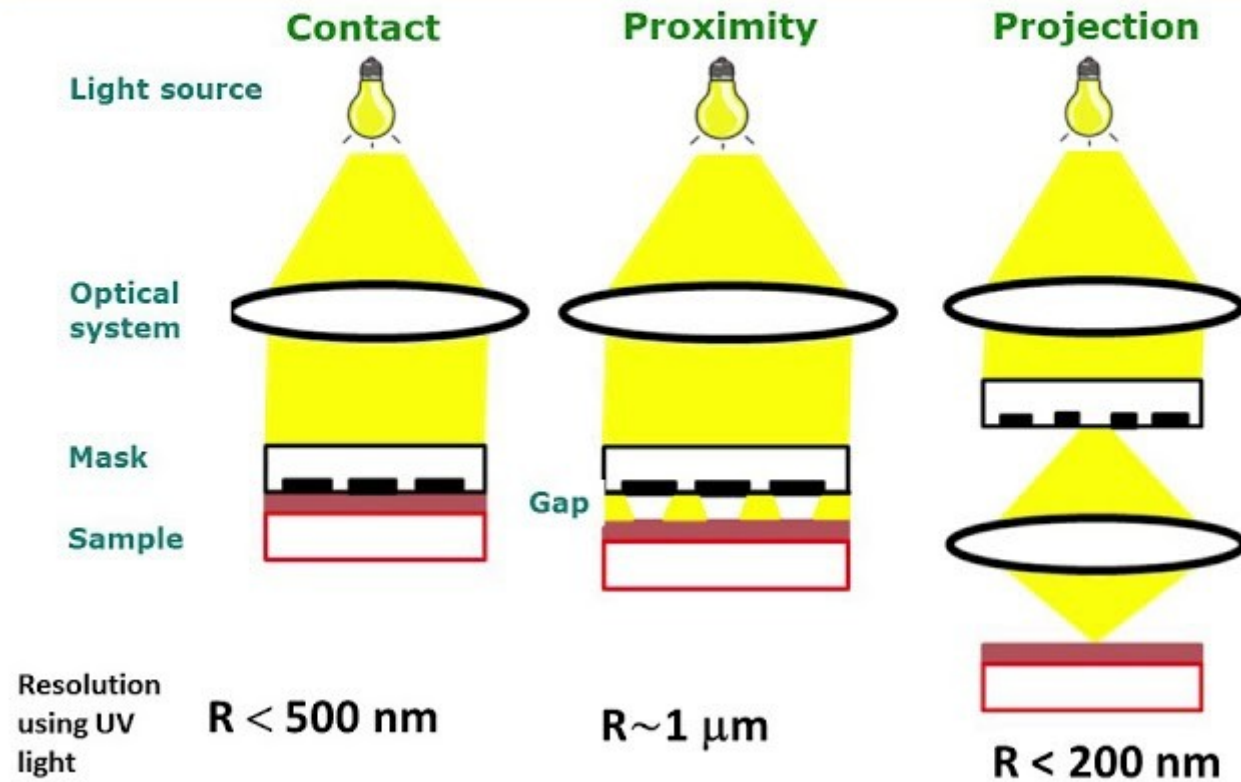
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- Contact
- Non-Contact
- Projection
- E-Beam\*



# Lithography Types- “Choose your own adventure”

## Optical lithography: techniques



# Lithography Types- Performance Comparison

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- Each are useful!
  - Which would you use for...
    - Academic (Very low volume)
    - Industry (High Volume)
    - Research

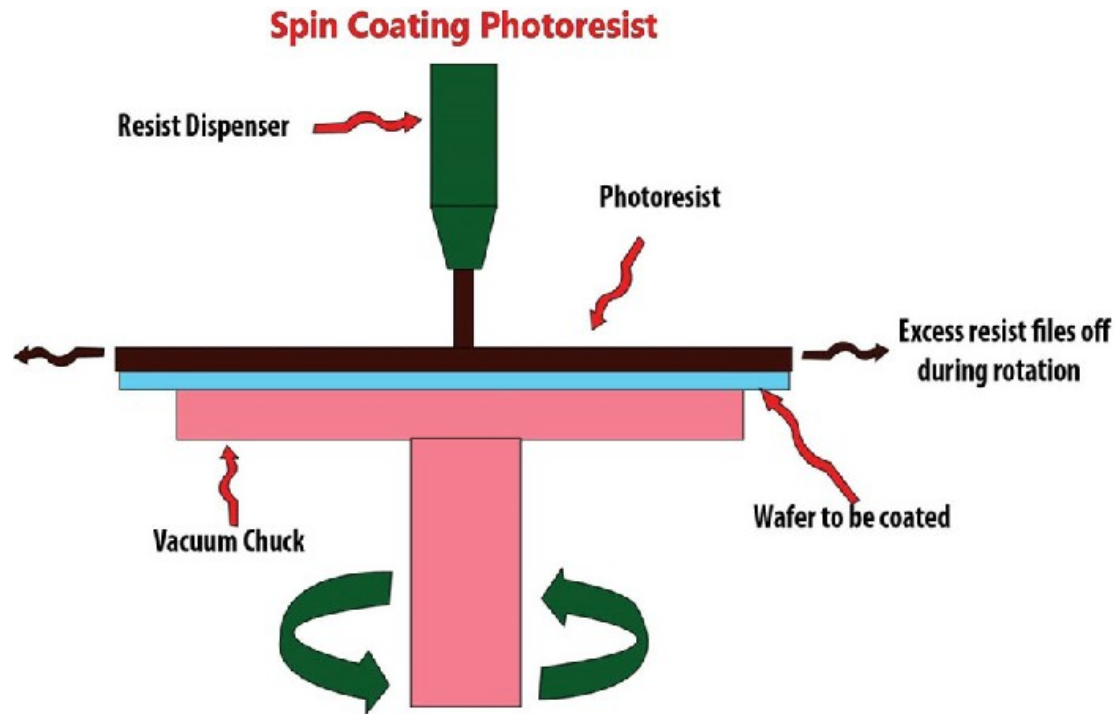
| Parameter   | Contact   | Non-Contact | Projection | E-beam    |
|-------------|-----------|-------------|------------|-----------|
| Cost        | Low       | Low         | High       | High      |
| Speed       | Med       | High        | High       | Low       |
| Defectivity | Very High | Low         | Low        | Low       |
| Resolution  | Med       | Low         | High       | Very High |
| Complexity  | Low       | Med         | High       | Med       |

# Lithography Procedure

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- Spincoat
- Soft-Bake
- Expose
- Post-exposure Bake (Optional)
- Develop
- Hard-Bake

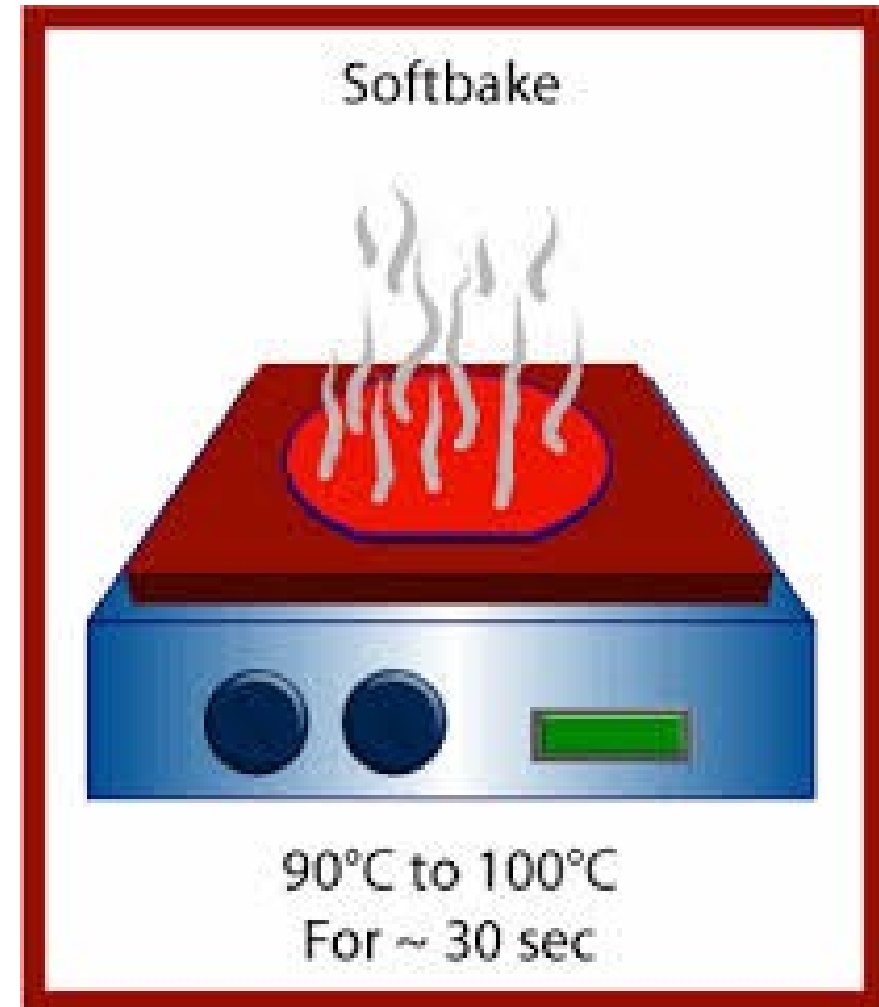
# Lithography Procedure- Spincoat



# Lithography Procedure- Softbake

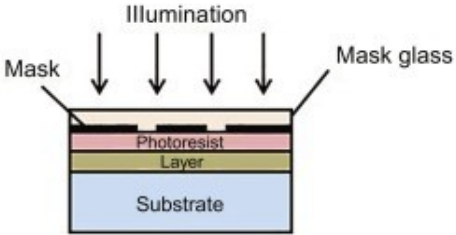
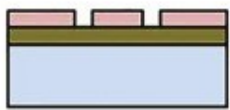
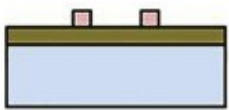
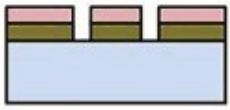
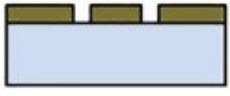
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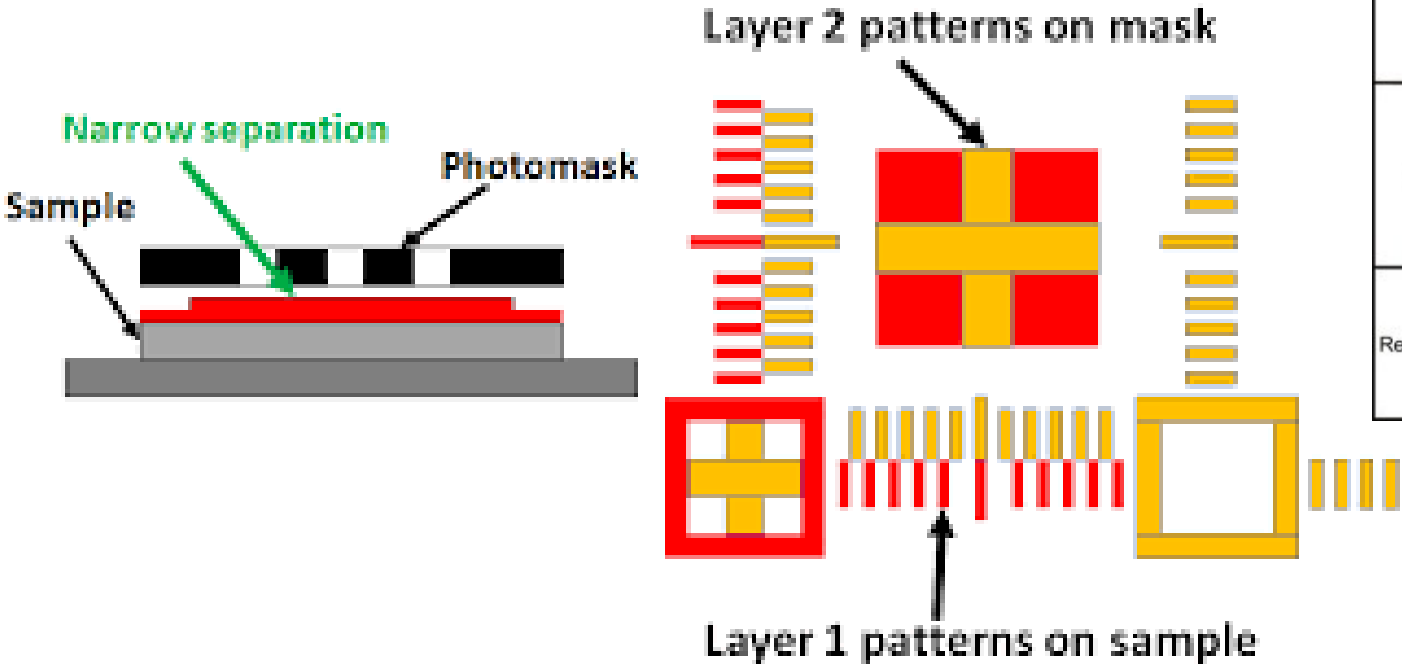
- Solidify photoresist
- Removes solvent
- Can be done with hotplate in research applications
- Integrated in lithography machine for industry applications



# Lithography Procedure- Exposure

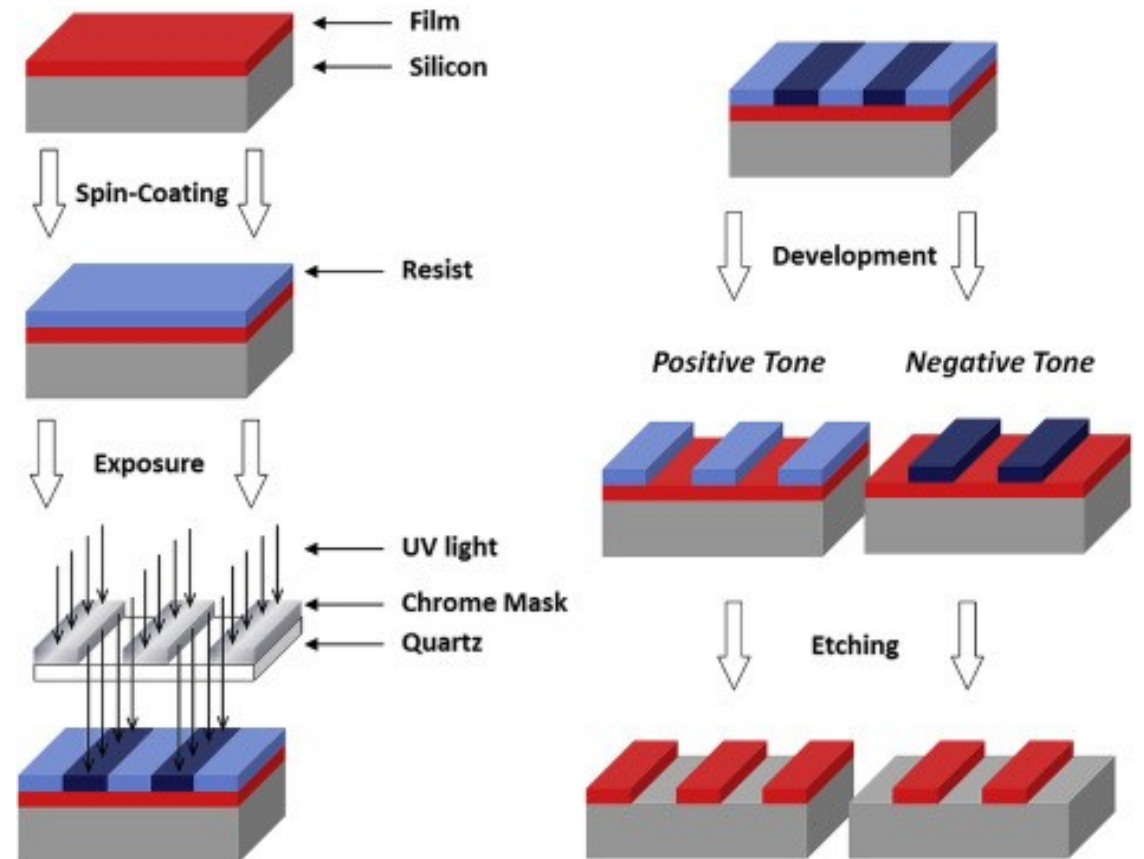
- Align with previous layers of mask
- Use lightsource (EUV, DUV, etc) to bond photoresist

|              |                                                                                      |                                                                                      |
|--------------|--------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Illumination |   |                                                                                      |
| Development  | Positive resist                                                                      | Negative resist                                                                      |
|              |   |   |
|              |   |   |
|              |  |  |



# Lithography Procedure- Develop

- Dissolves un-bonded photoresist



# Lithography Procedure- Modern Systems

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[https://youtu.be/h\\_zgURwr6nA?si=Jx0LdQDefZijwbs1](https://youtu.be/h_zgURwr6nA?si=Jx0LdQDefZijwbs1)

# Future State of Lithography

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- High-NA EUV Resolution Enhancement Techniques
- Higher Power Source (Free Electron Laser)
- Larger exposure field? (Reticle)
- Mechanical Improvements for High-Throughput/Precision
- Cutting Cost???



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# The End

Thanks for listening!

GBM Attendance

