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Introduction to Nanofabrication: Top Down to Bottom Up

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The NACK National Center is located at Penn State University

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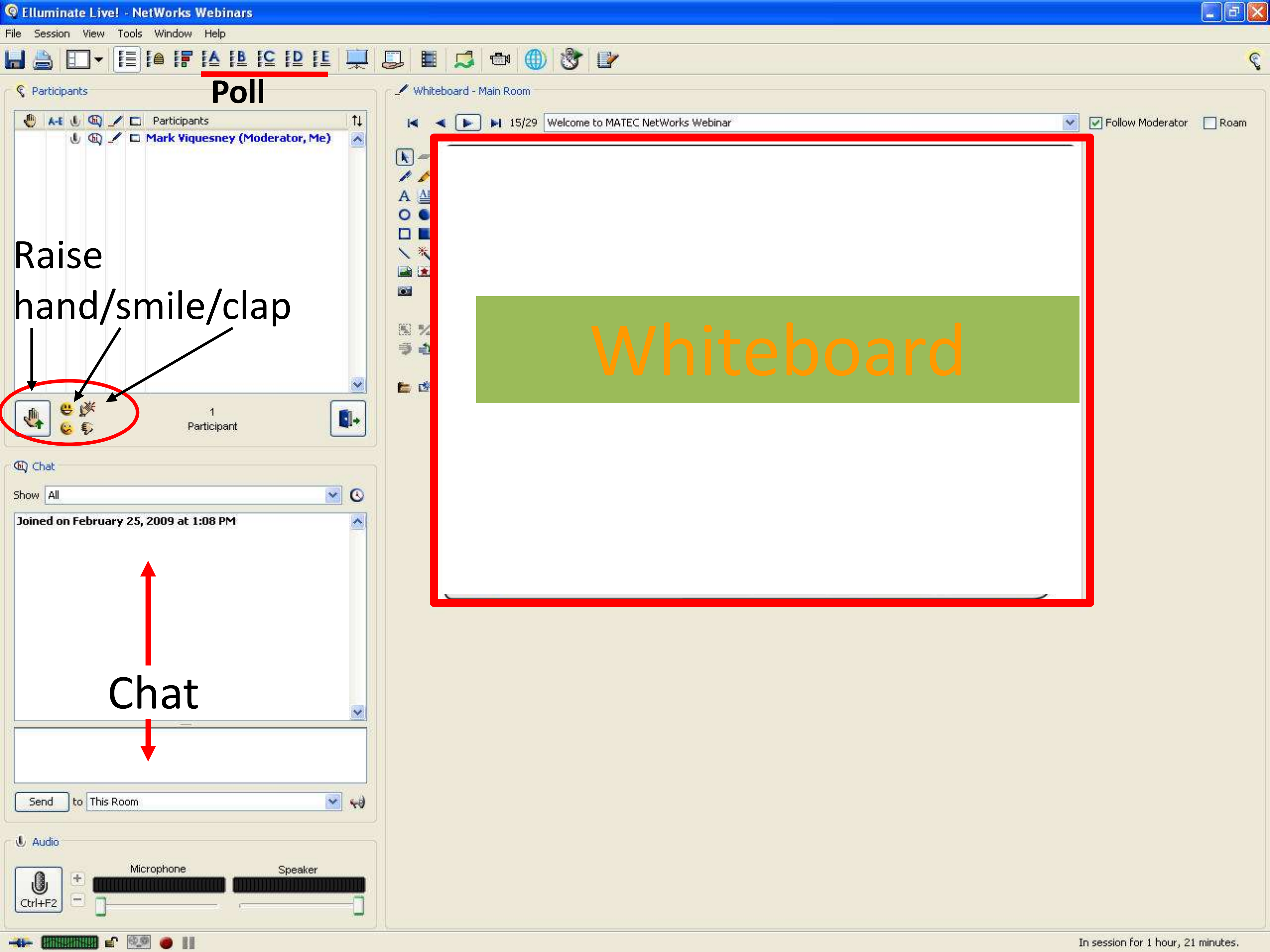

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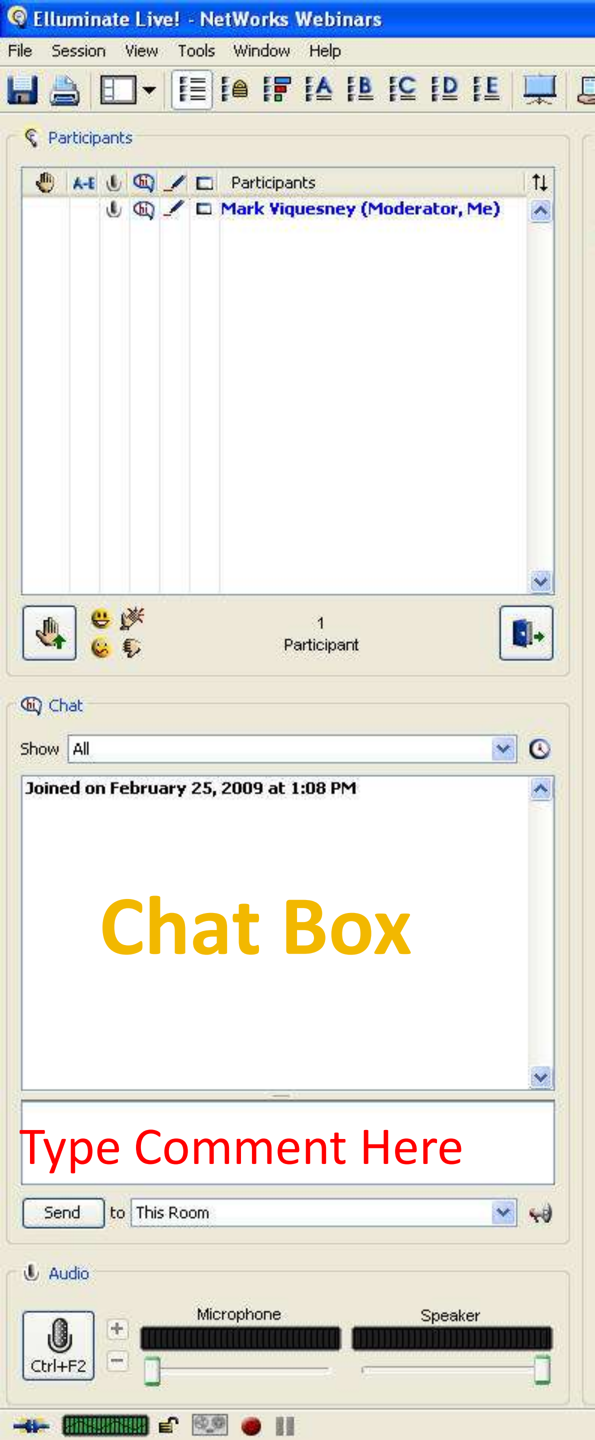

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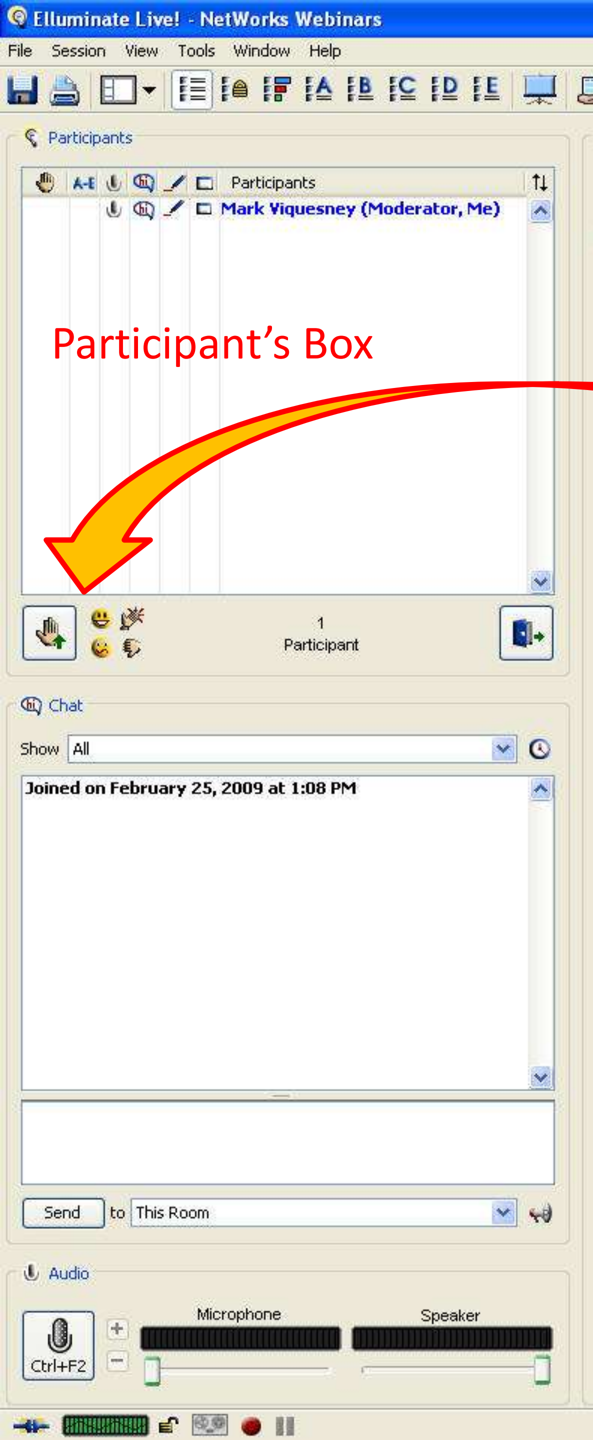

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NACK's Webinar Presenter

Presented by Dave Johnson
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Center for Nanotechnology Education and Utilization
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Outline

- Basic top-down approaches in nanofabrication
  - Pattern transfer (lithography)

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  - Deposition (or film growth)

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  - Deposition (or film growth)
  - Etching (or removal of material)



Outline

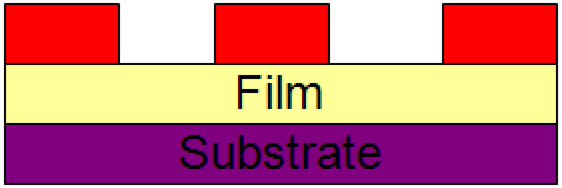
- Basic top-down approaches in nanofabrication
  - Pattern transfer (lithography)
  - Deposition (or film growth)
  - Etching (or removal of material)
- Basic bottom-up approaches in nanofabrication

Top-Down Approach

- Starts with thin films of materials supported by a substrate

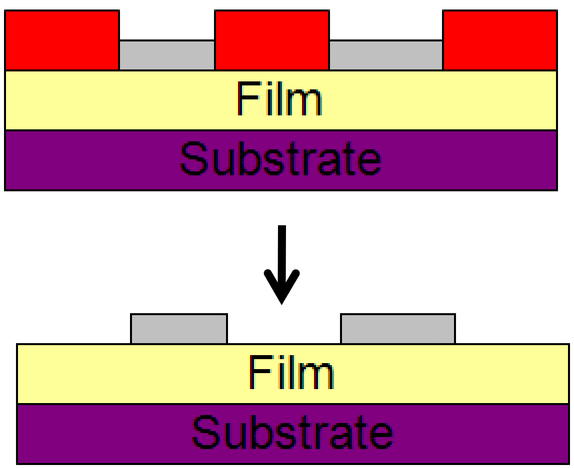
Top-Down Approach

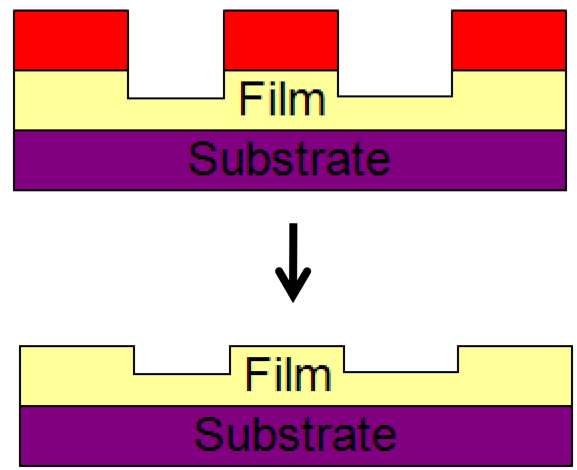
- Nanoscale features are defined through a patterning process



Top-Down Approach

- Nanoscale features from the pattern are then transferred to the substrate through additive or subtractive processes





Top-Down Approach

- These steps are performed many times to create complex nanostructures



Top-Down Approach

- Patterning Process: Photolithography
  - A light sensitive material called photoresist is applied to the substrate

Top-Down Approach

- Patterning Process: Photolithography
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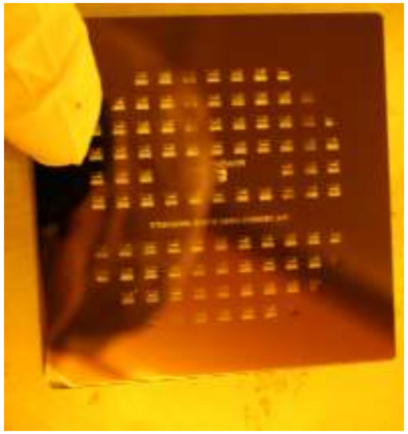
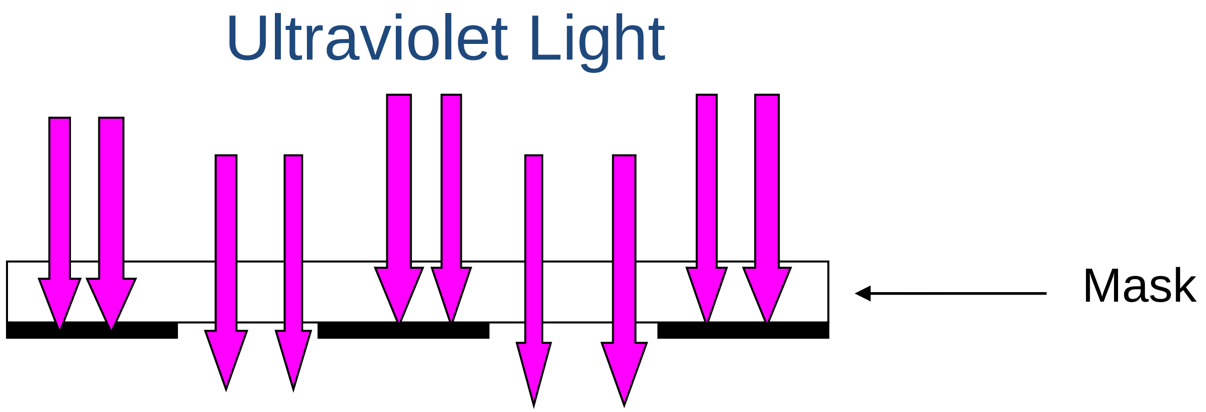
  - A photomask is aligned to the substrate



Top-Down Approach

- A photomask is used to determine which portions of the resist film are exposed to the UV light.
  - Made of glass or quartz with a chrome pattern
  - Even the mask needs to be made with lithography!





Top-Down Approach

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Top-Down Approach

- Patterning Process: Photolithography
  - A light sensitive material called photoresist is applied to the substrate
  - A photomask is aligned to the substrate
  - The substrate is exposed to UV light
  - The exposed photoresist is developed
  - The pattern is checked for quality



Top-Down Approach

- There are two general types of UV sensitive photoresists
  - Positive resists
  - Negative resists

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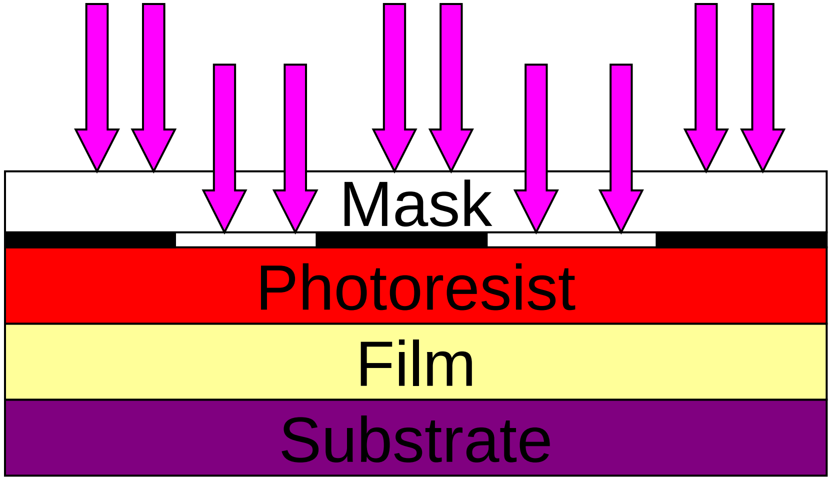
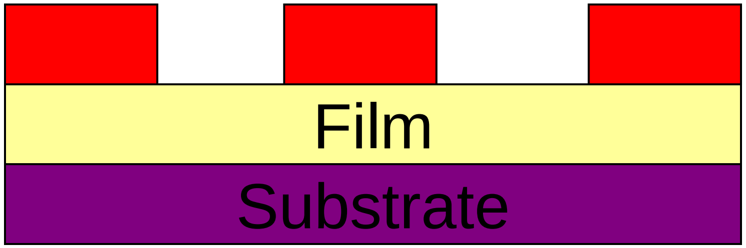
Top-Down Approach

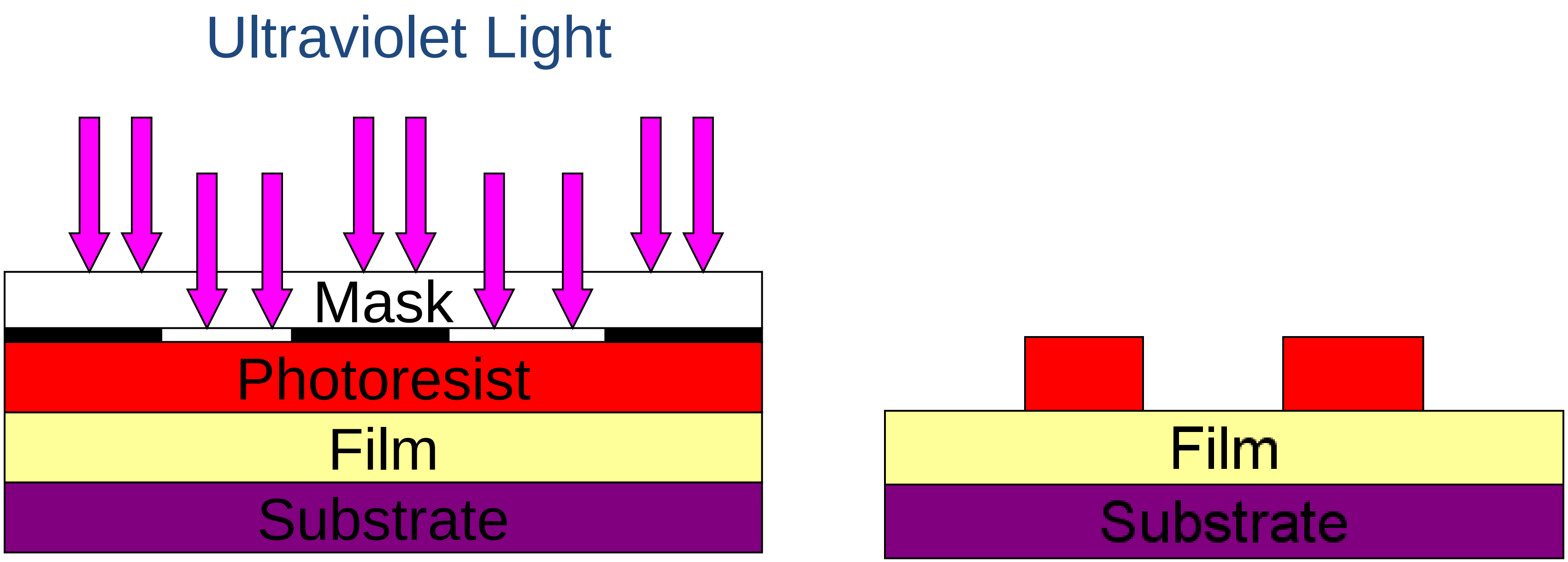
Ultraviolet Light





- This is an example of positive tone photoresist – “what shows, goes!”

Top-Down Approach



- This is an example of negative tone photoresist – “what shows, stays!”

Questions?

Top-Down Approach

- Additive Processes: Deposition, Growth & Implantation
  - Deposition
    - Typically requires energy to perform the process

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Top-Down Approach

- Additive Processes: Deposition, Growth & Implantation
  - Deposition
    - Typically requires energy to perform the process
  - Growth typically means there is consumption of the substrate to create a new material
    - Typically requires high heat and chemical reactions
  - Implantation
    - Used to modify the optical, mechanical, electrical, or etch characteristics of a material
    - Typically requires a heating step to anneal the sample

Top-Down Approaches

- Physical Vapor Deposition
  - Evaporation

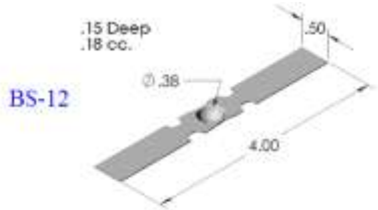
Top-Down Approaches

- Evaporation
  - Create a vacuum



Top-Down Approaches

- Evaporation
  - Create a vacuum
  - Melt metal pellets
    - Alloys and insulators are difficult to evaporate

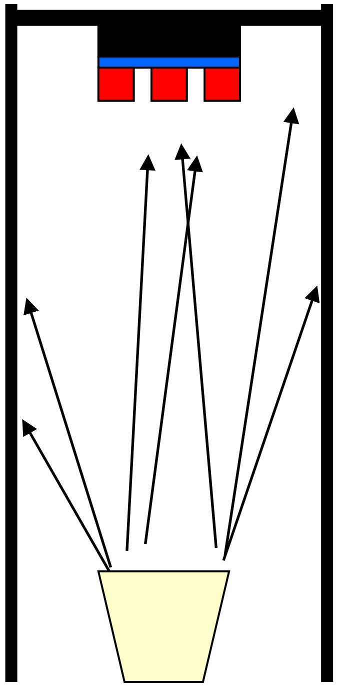


Top-Down Approaches

- Evaporation
  - Increase temperature so that molten metal evaporates

Top-Down Approaches

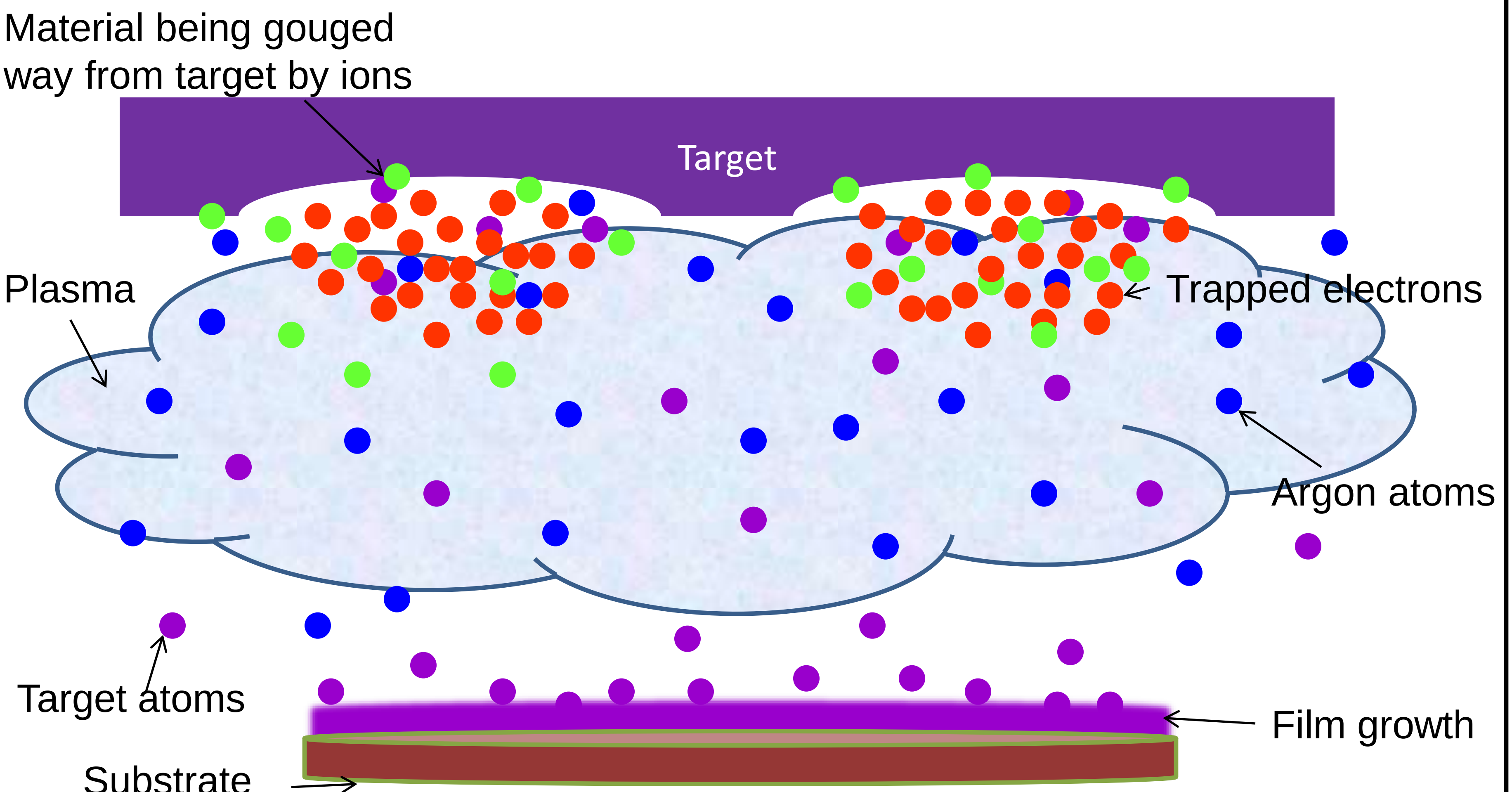
- Evaporation
  - Metal vapor condenses onto your sample



Top-Down Approaches

- Physical Vapor Deposition
  - Sputtering

Top-Down Approaches



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Questions?

Top-Down Approaches

- Chemical Vapor Deposition:
  - Low Pressure Chemical Vapor Deposition

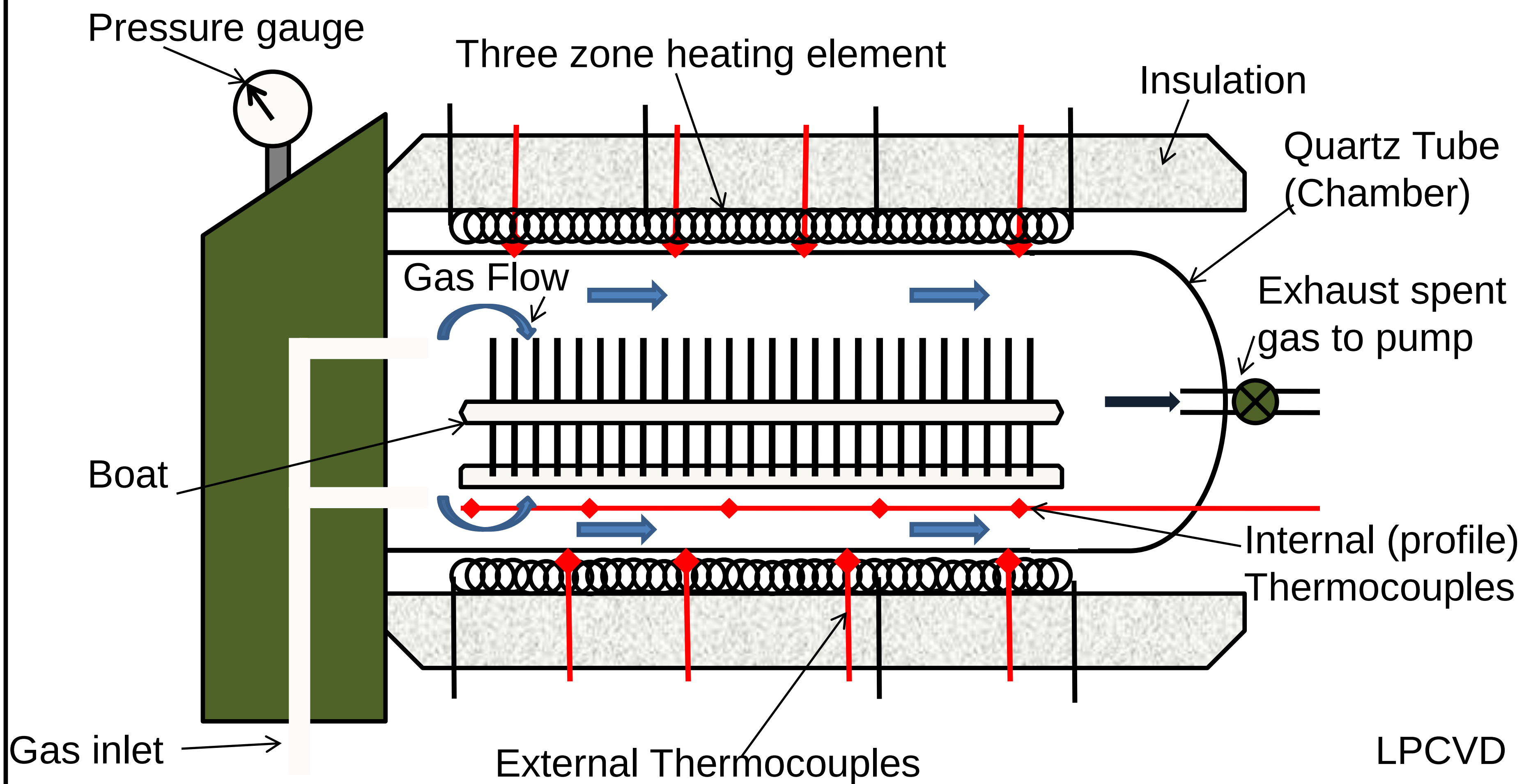


Top-Down Approaches

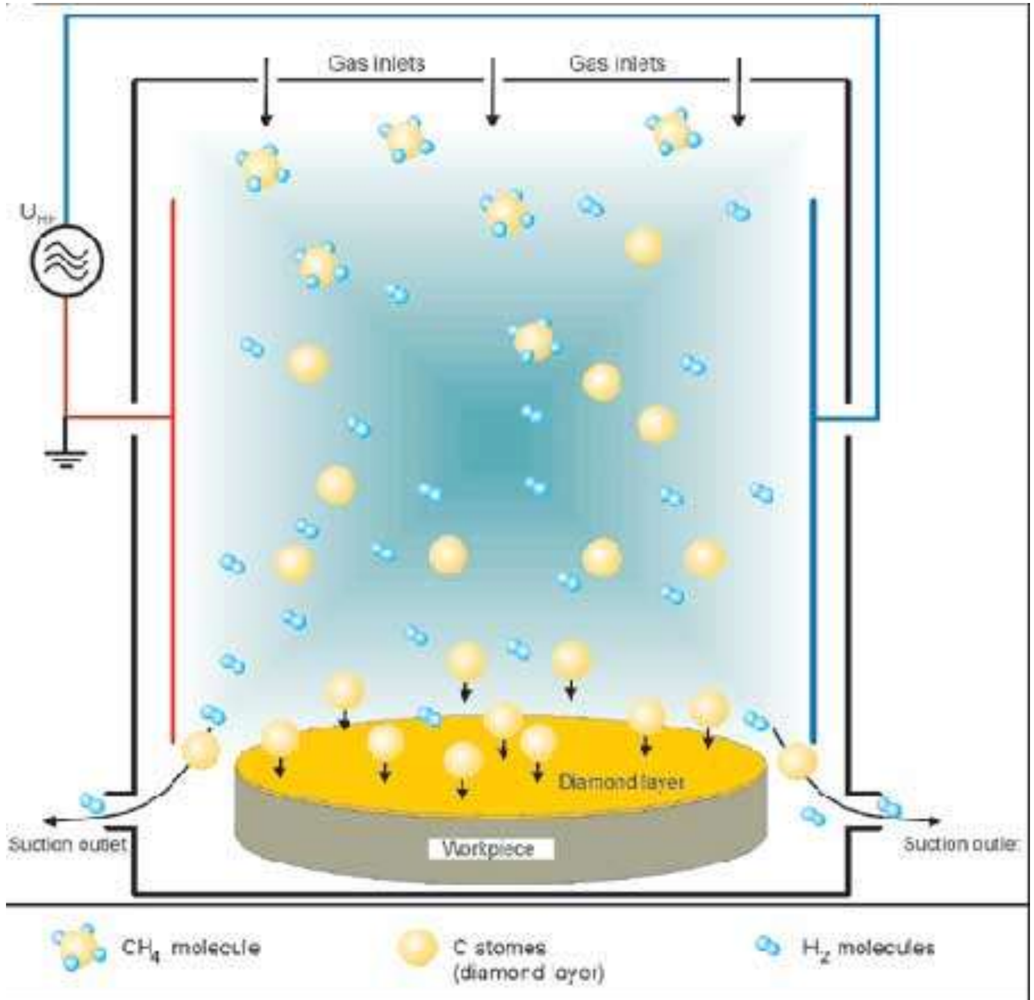
- Chemical Vapor Deposition:
  - Low Pressure Chemical Vapor Deposition
  - Plasma Enhanced Chemical Vapor Deposition



Top-Down Approaches



Top-Down Approaches



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Questions?

Top-Down Approach

- Subtractive Objects: Wet Etching
  - Uses liquid chemistry to chemical react with substrate materials

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  - For patterned amorphous materials wet etchants produce isotropic etch profiles

Top-Down Approach

- Subtractive Objects: Wet Etching
  - Uses liquid chemistry to chemical react with substrate materials
  - For patterned amorphous materials wet etchants produce isotropic etch profiles
  - Isotropic features are just as wide as they are deep

Top-Down Approaches

- Subtractive Objects: Reactive Ion Etching
  - Use plasma to ionize gas

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  - A negative bias is place on substrate to allows for physical etching from positively charged gas species.



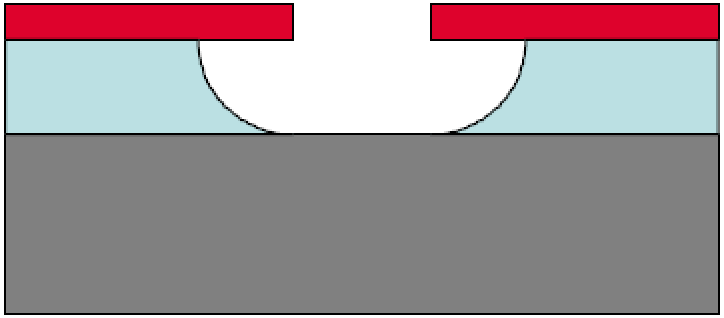
Top-Down Approaches

- Subtractive Objects: Reactive Ion Etching
  - Use plasma to ionize gas
  - Processing gas is selected for chemical etching of substrate materials
  - A negative bias is place on substrate to allows for physical etching from positively charged gas species.
  - The pressure of they system determines the etch profile of the sample



Top-Down Approach

- High pressure etching (100s mT)
  - Creates a small Mean Free Path
  - Promotes a chemical etch
  - Creates isotropic etch profiles



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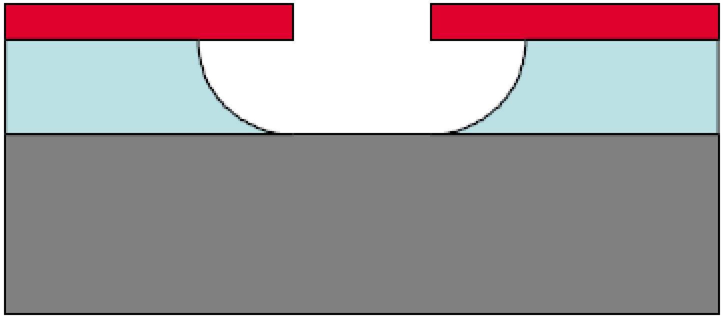
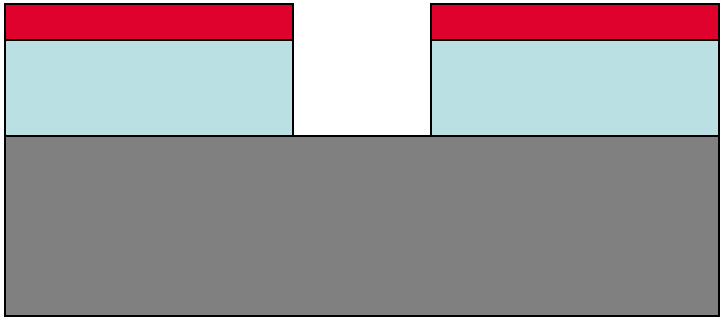
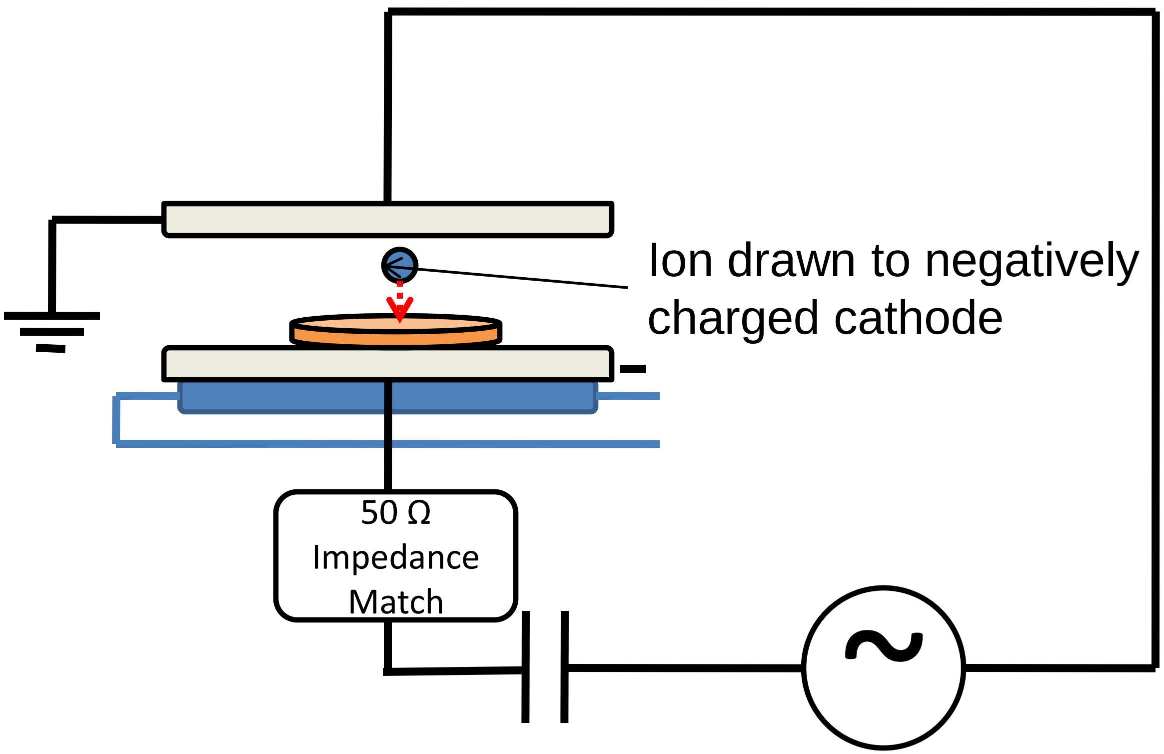


- Low pressure etching (10s mT)
  - Creates a larger Mean Free Path
  - Promotes a physical etch
  - Creates anisotropic etch profiles



Top-Down Approach

Reactive Ion Etching



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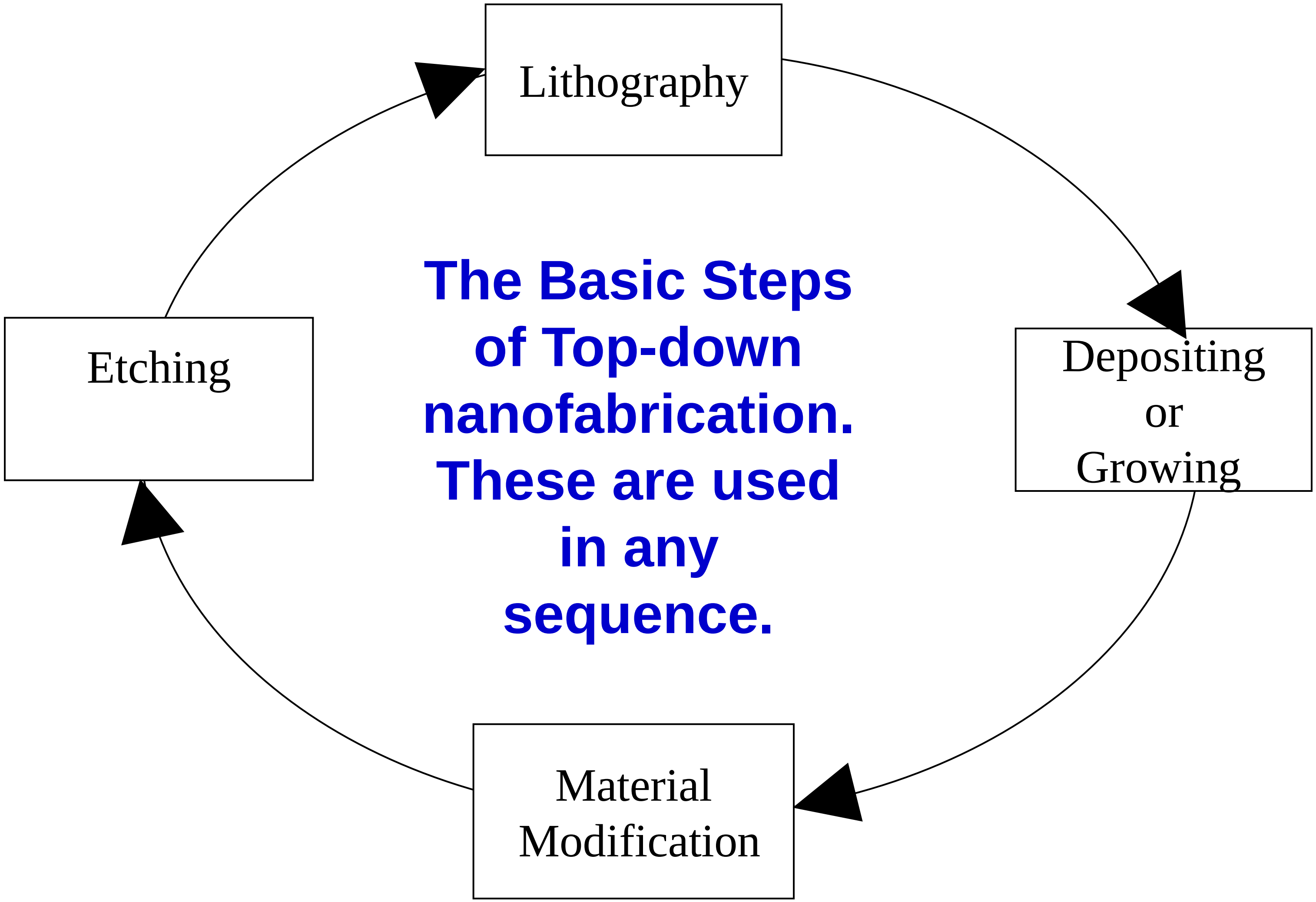

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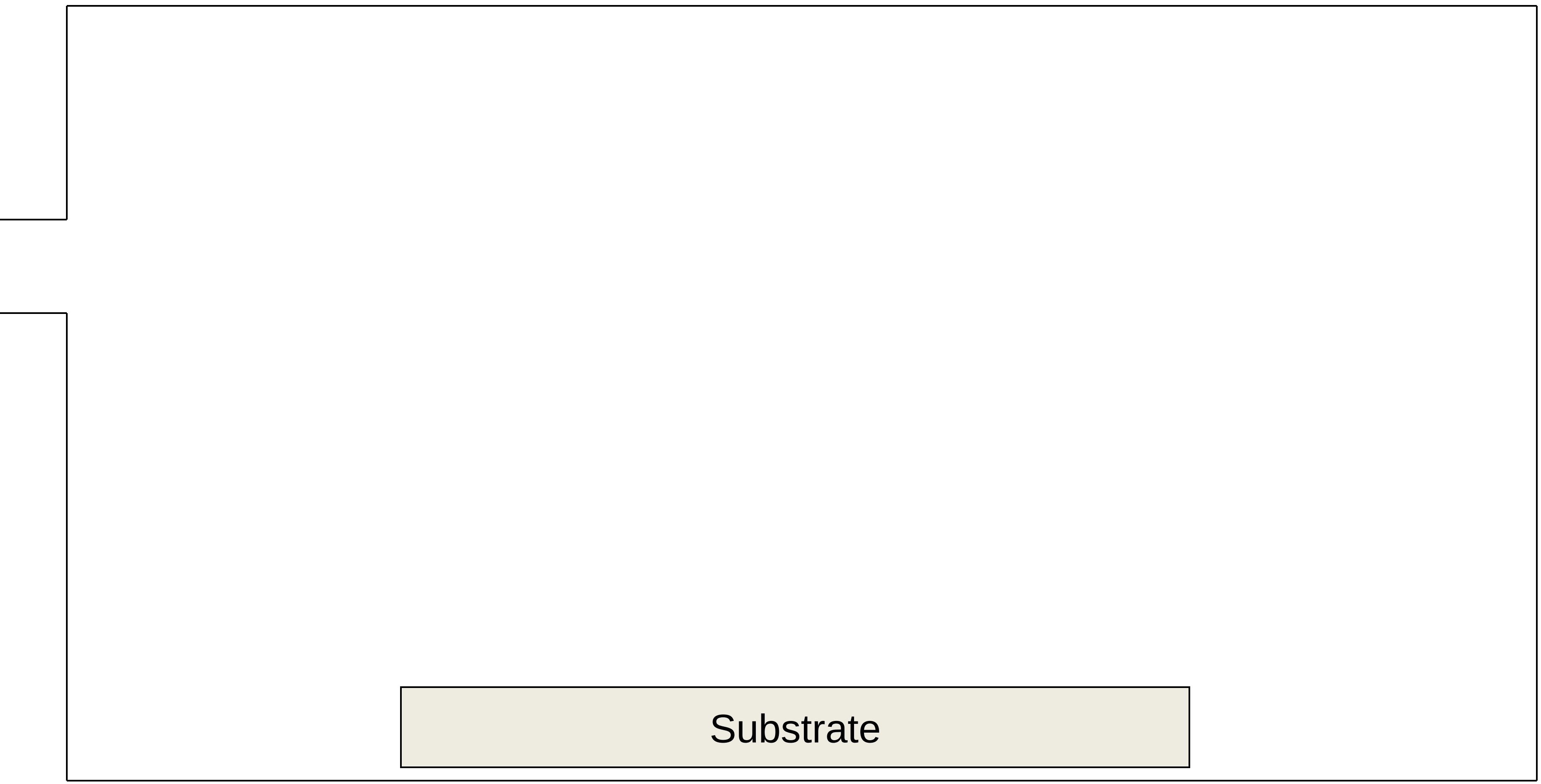
An Example of a Top-Down Nanofabrication Processing Sequence

THIN FILM GROWTH OR DEPOSITION

Film Grown by Chemical Reaction of Ambient species with the Substrate



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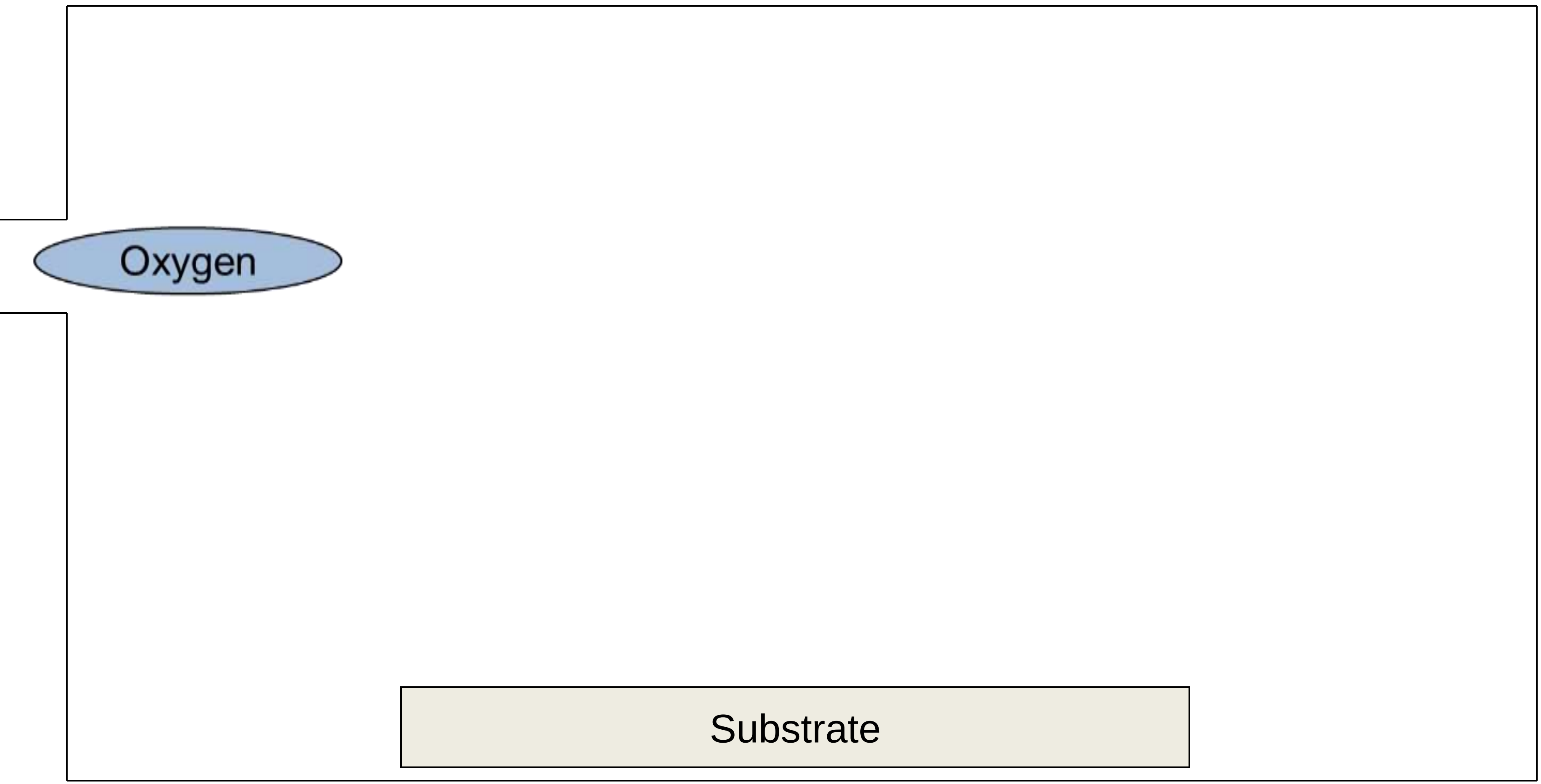

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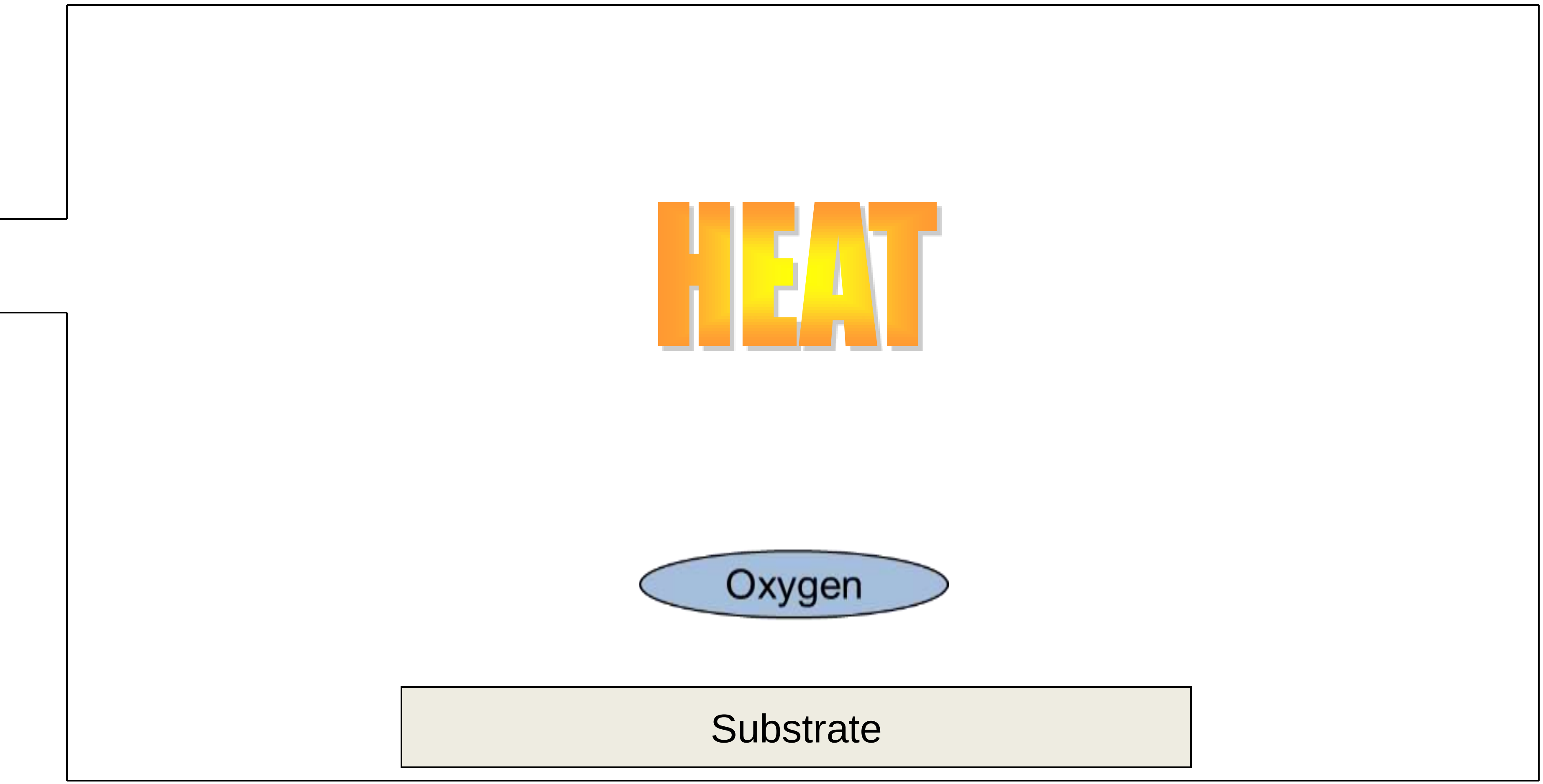

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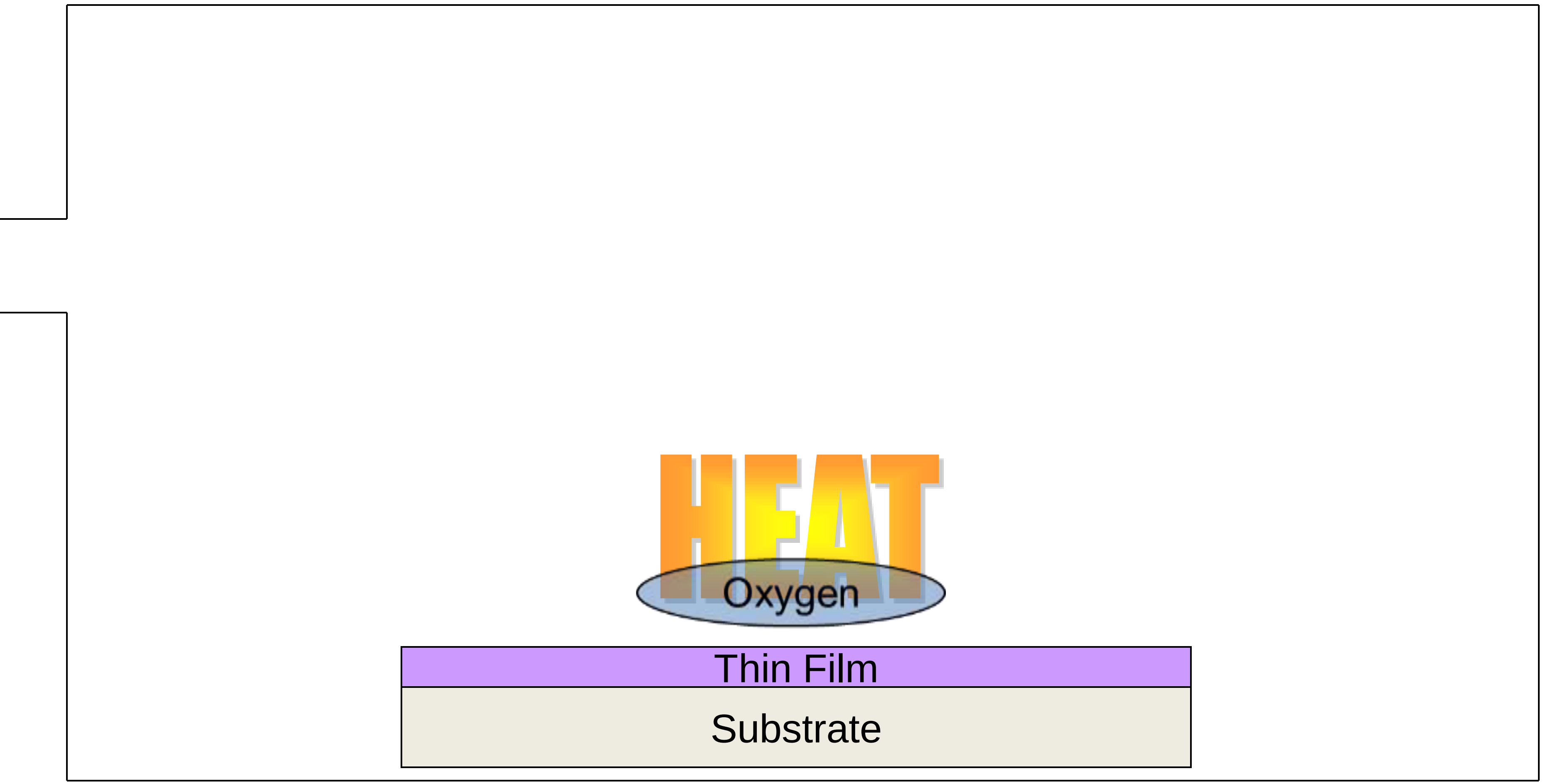

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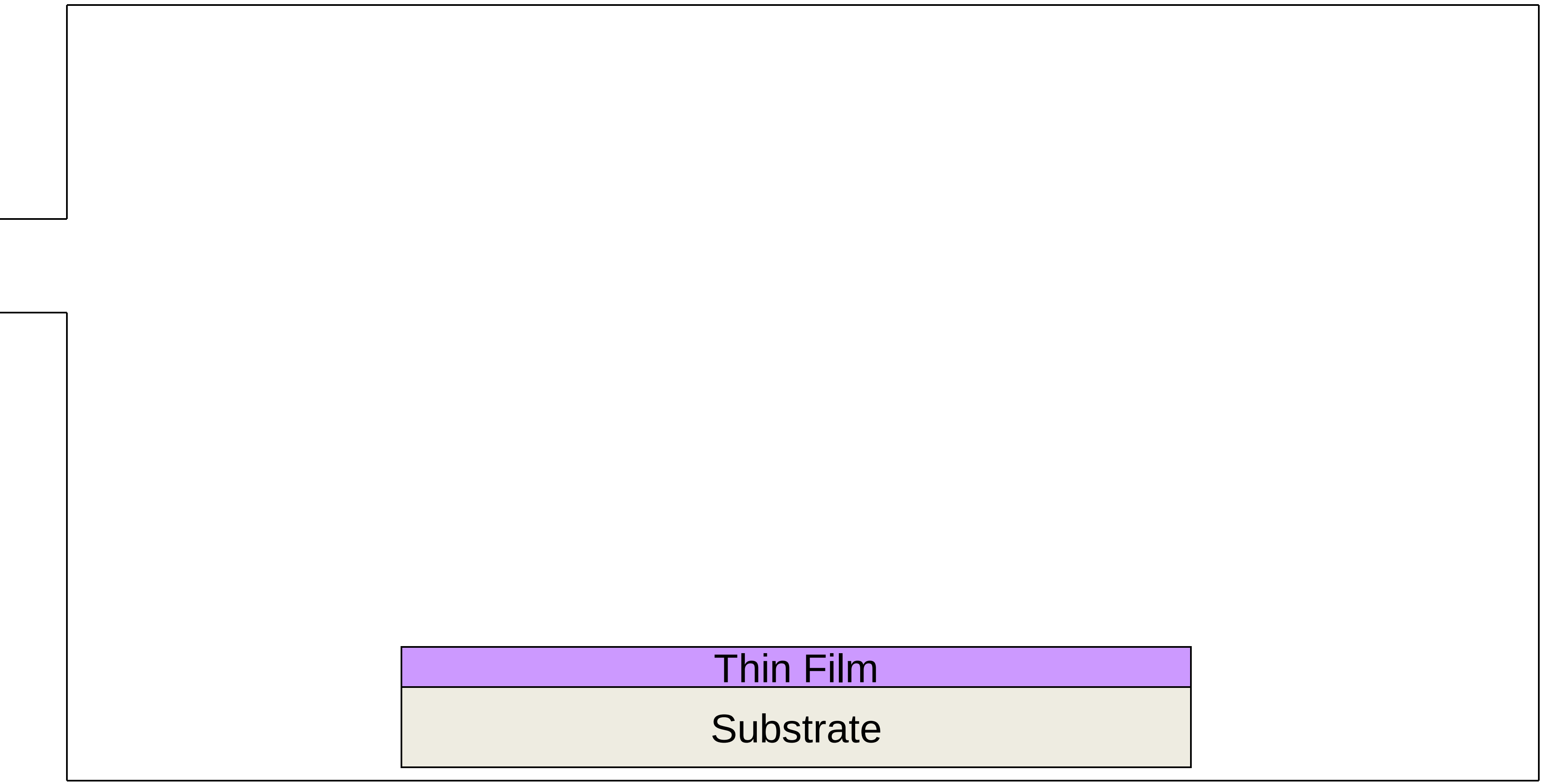
LITHOGRAPHY

Spin on Photoresist



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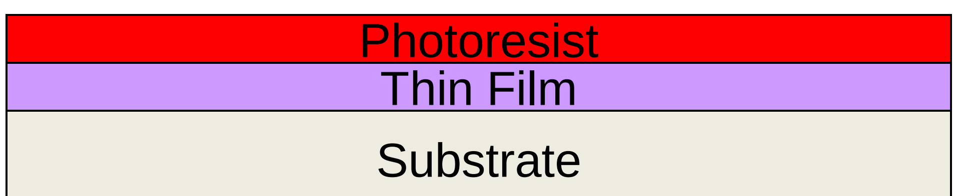

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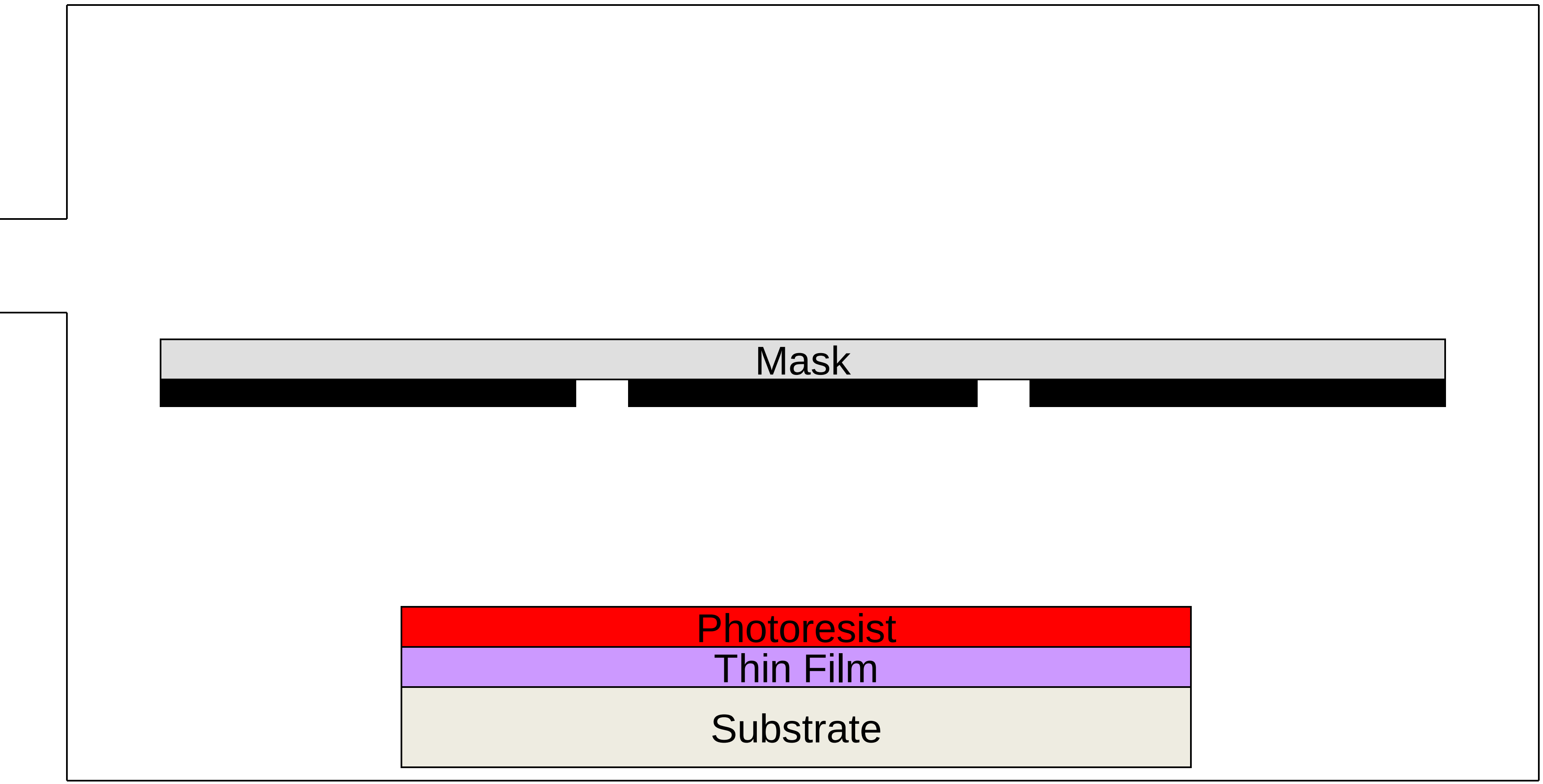
LITHOGRAPHY

Align Photomask



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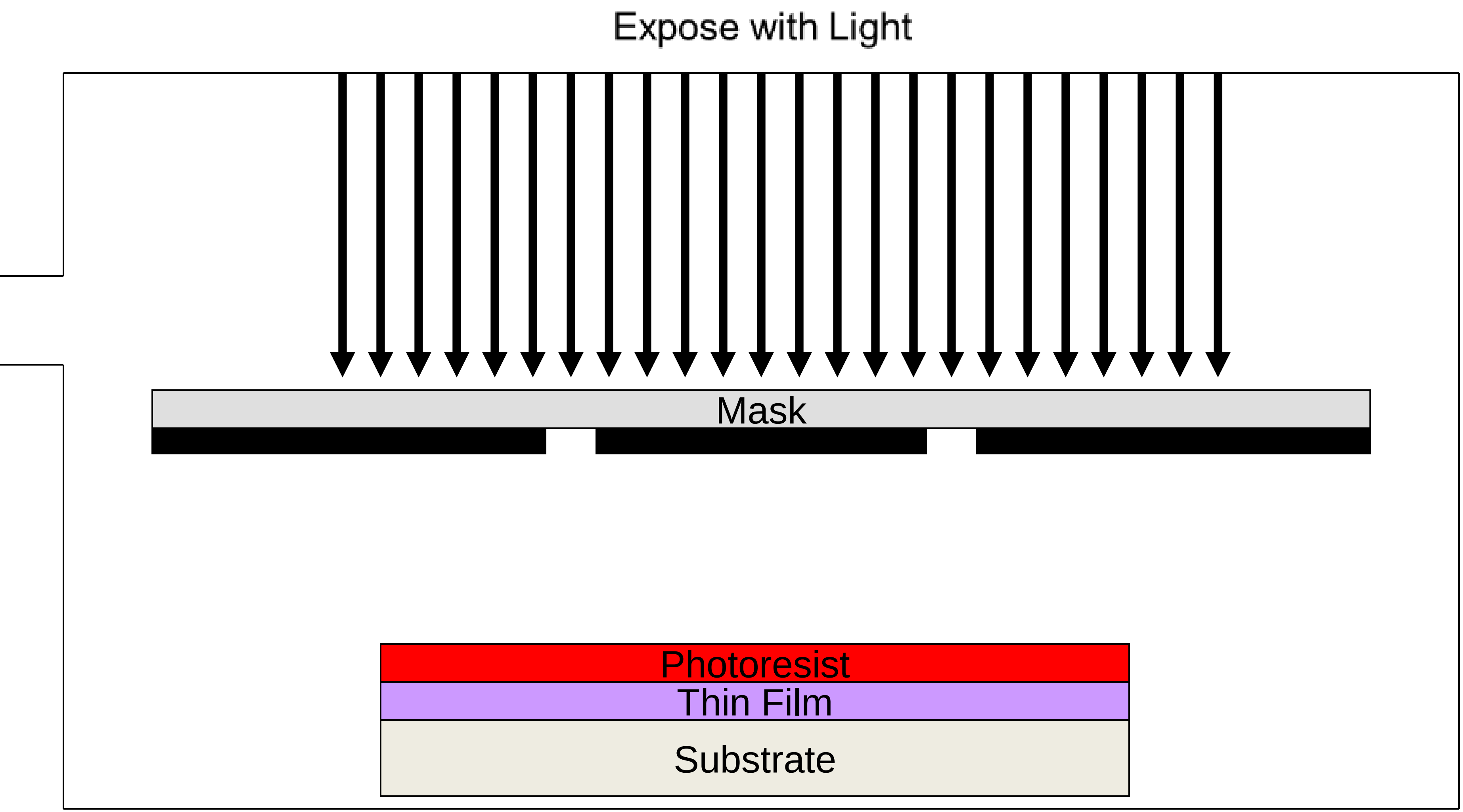

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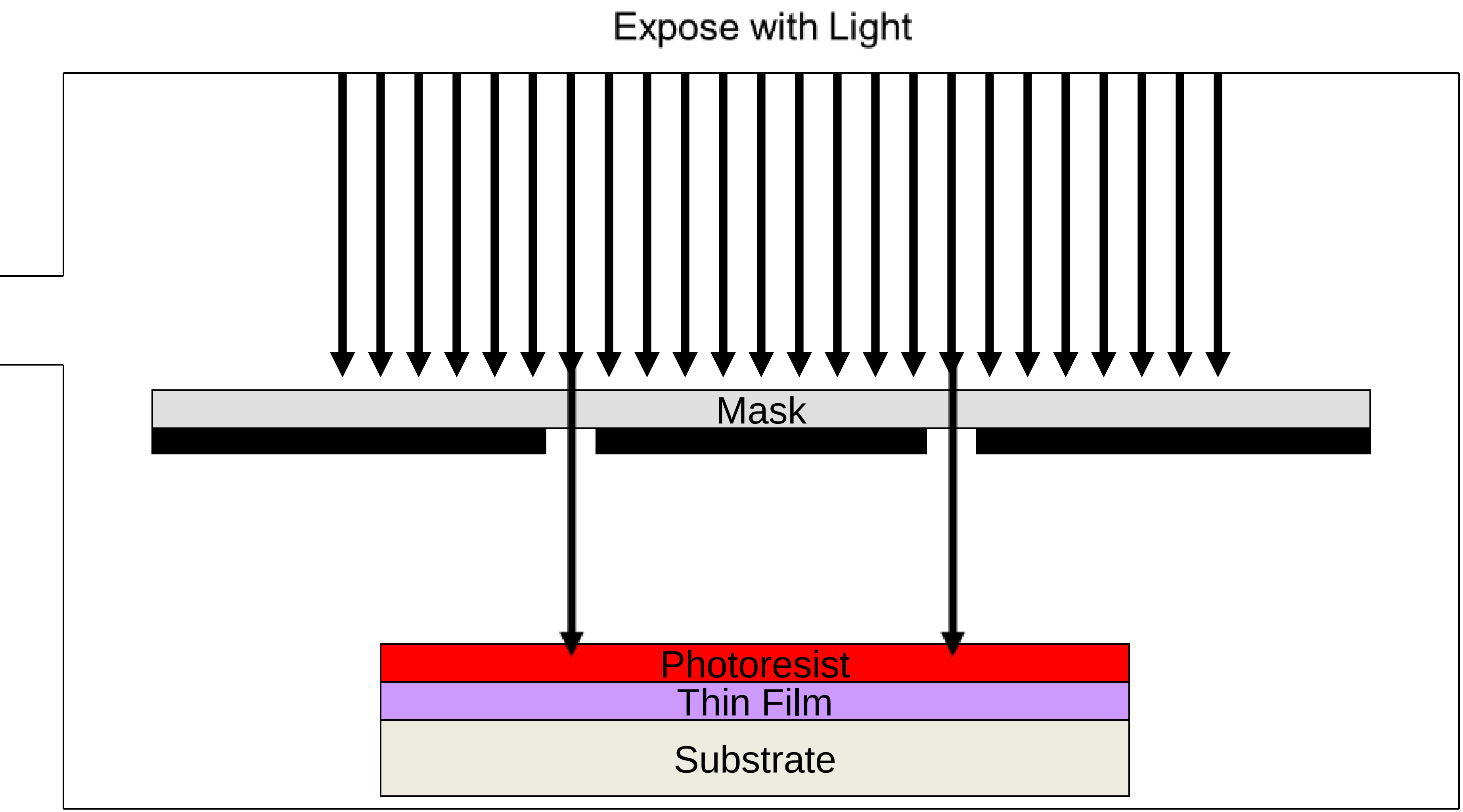
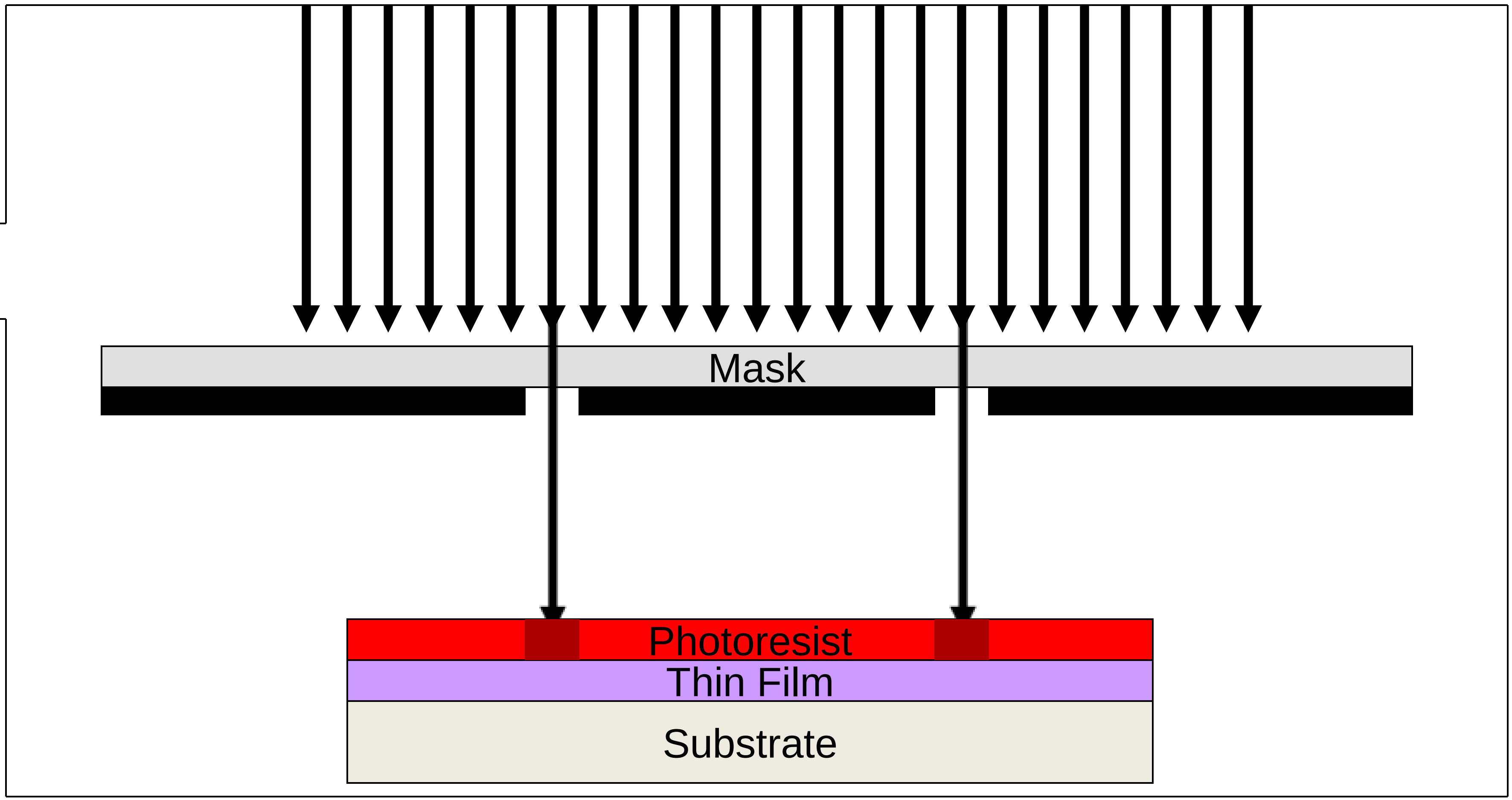


An Example of a Top-Down Nanofabrication Processing Sequence

LITHOGRAPHY

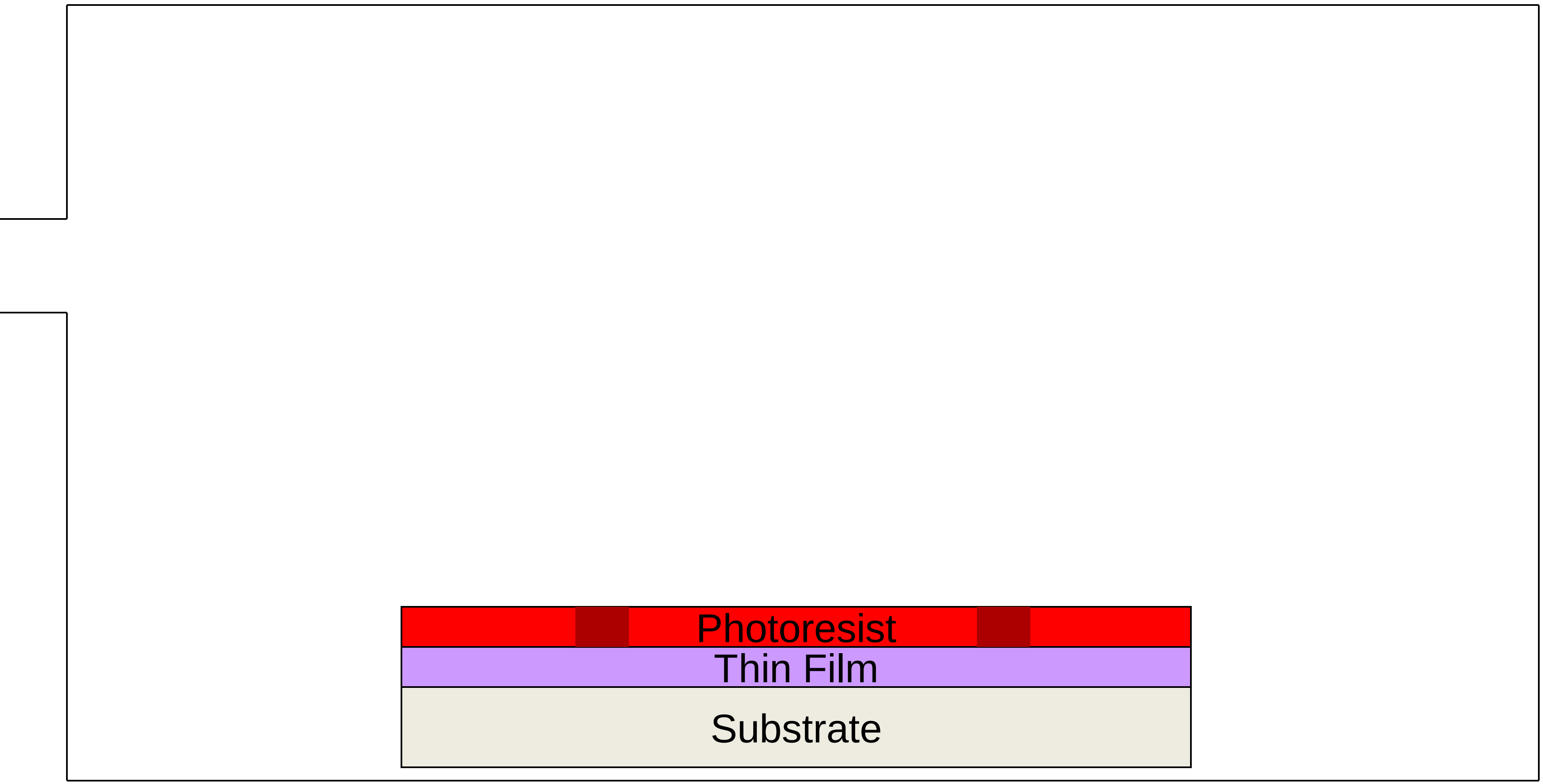
Chemical Bonds are Altered in Exposed Areas



An Example of a Top-Down Nanofabrication Processing Sequence

LITHOGRAPHY

Dissolve Exposed Photoresist in Liquid Developer



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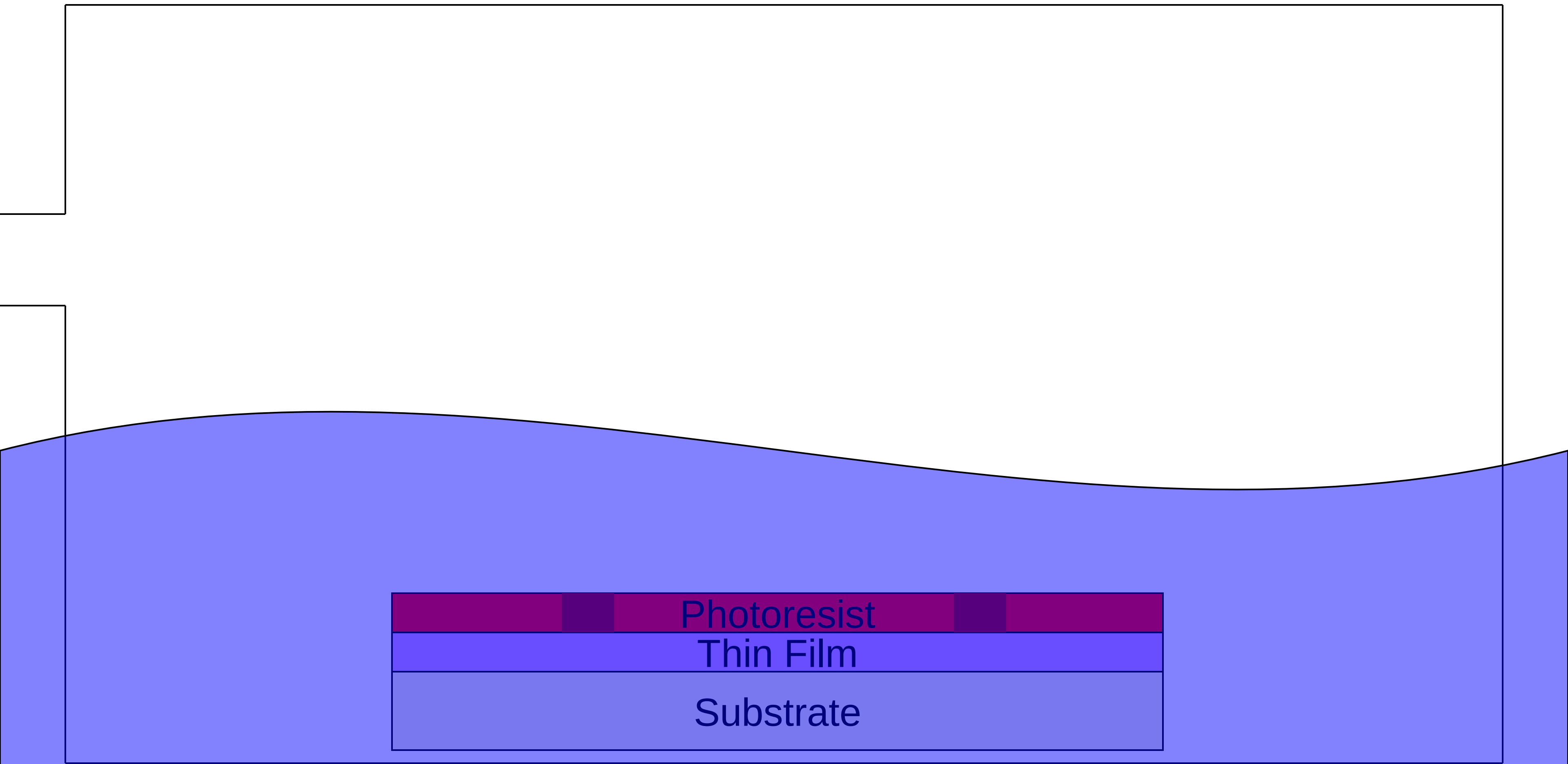

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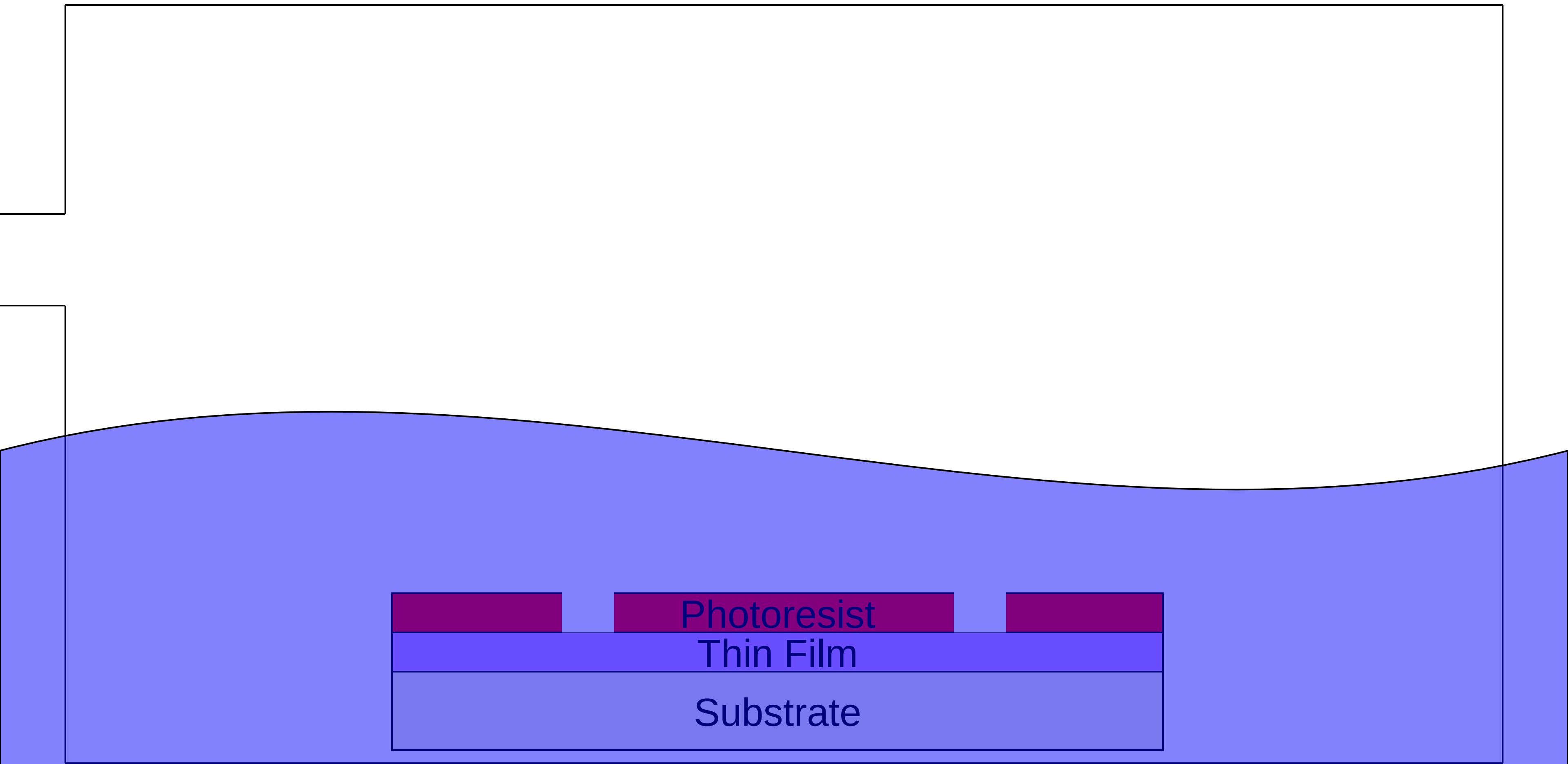

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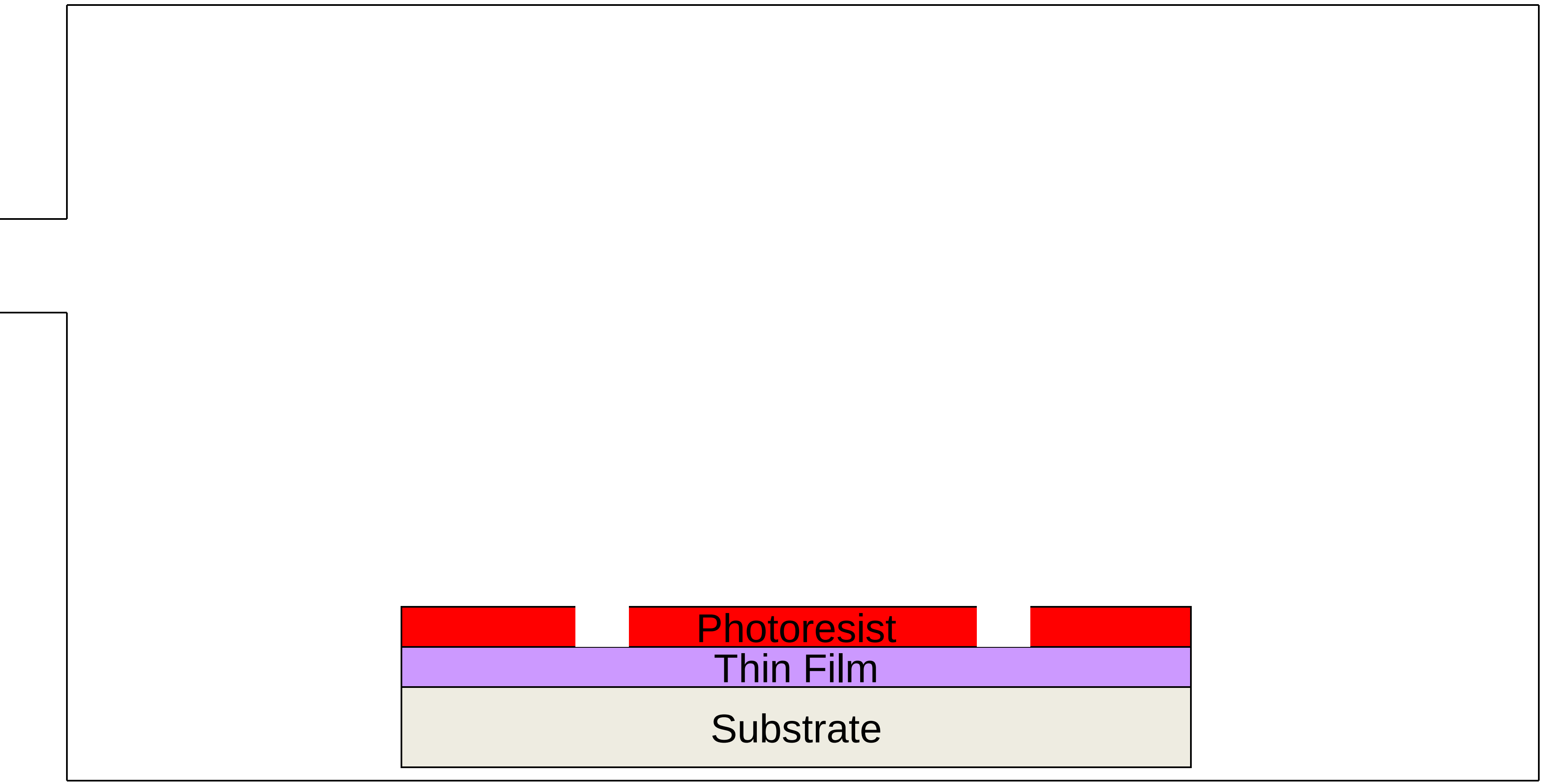

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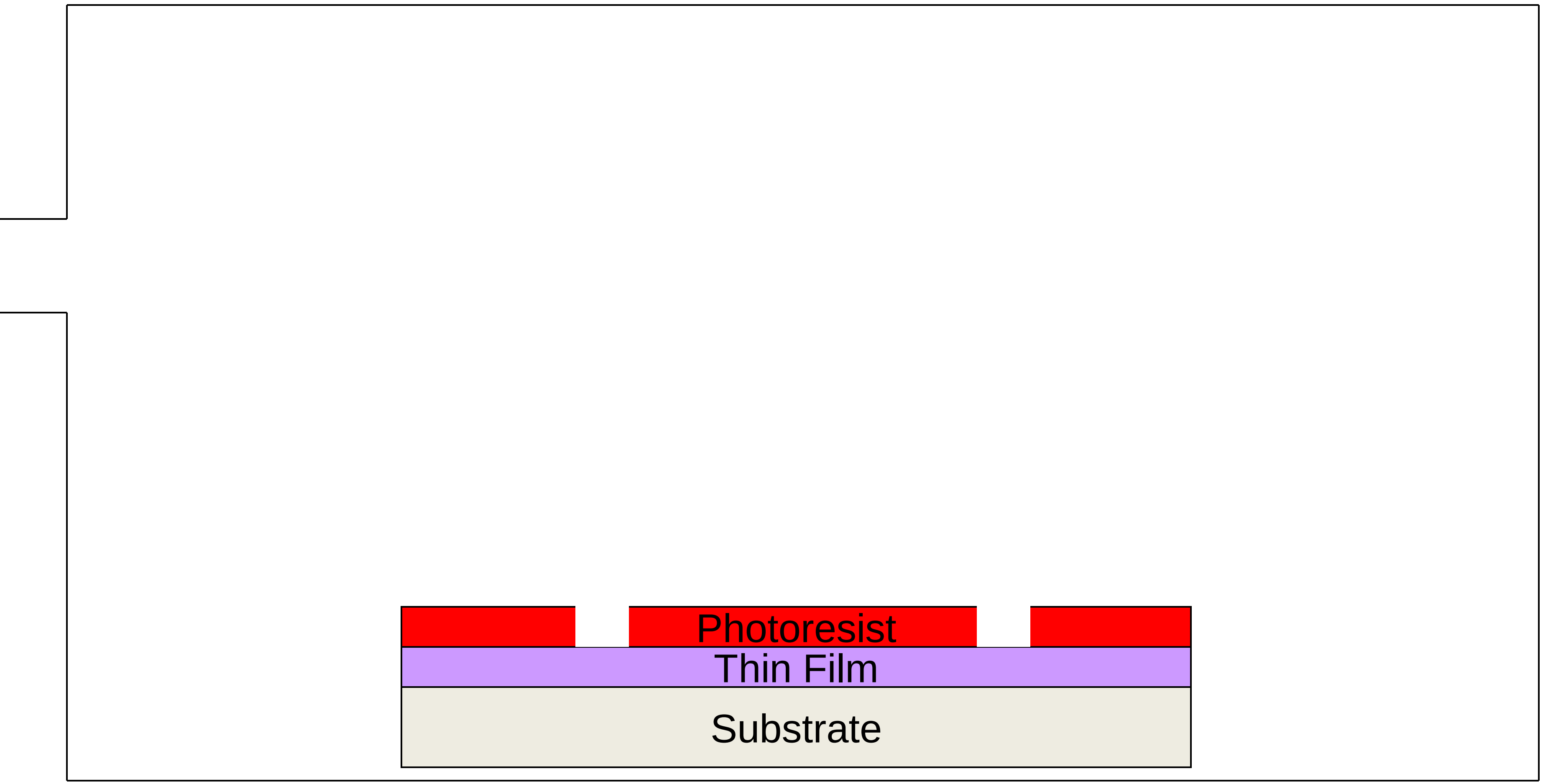
ETCHING



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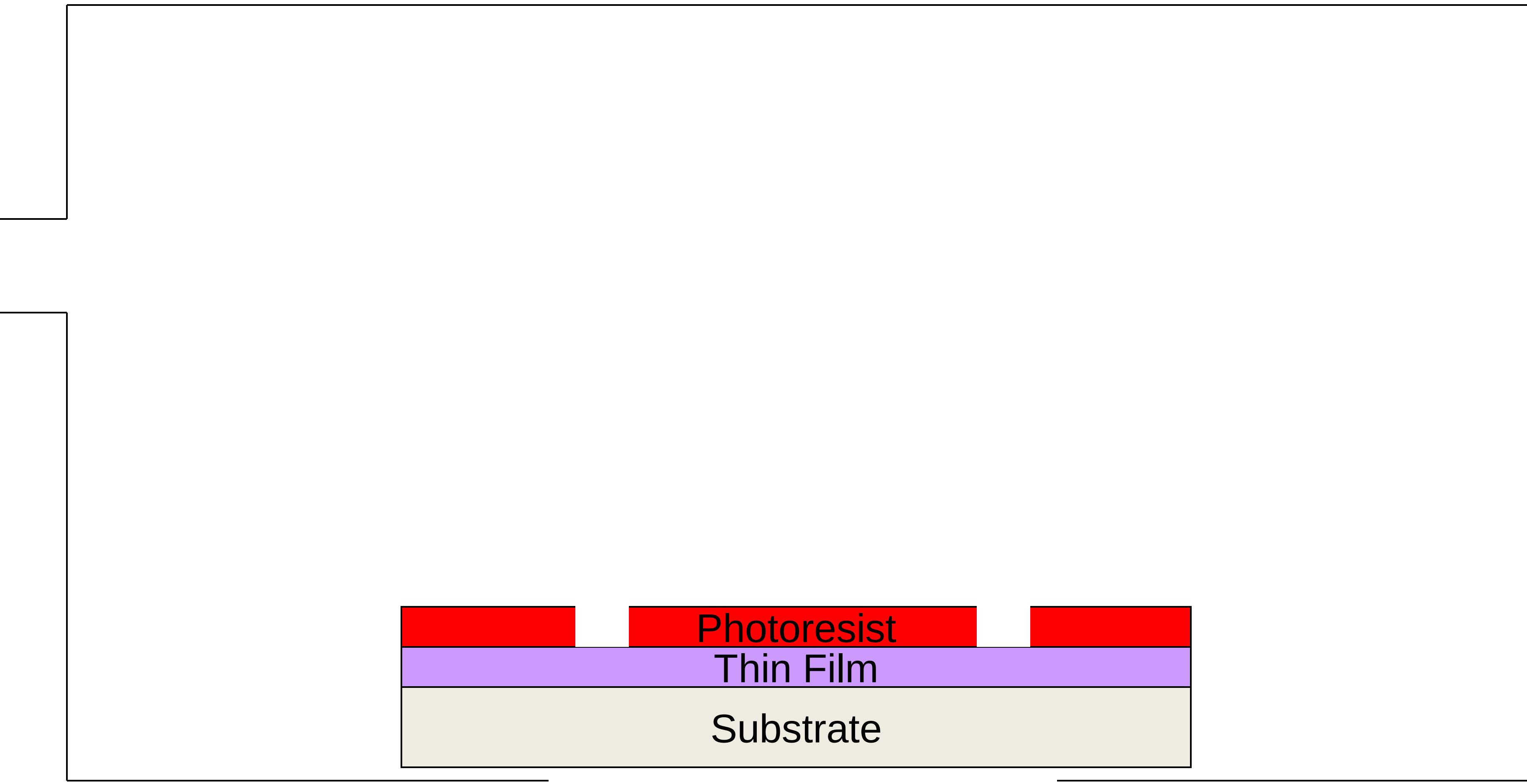

(Negative Bias)

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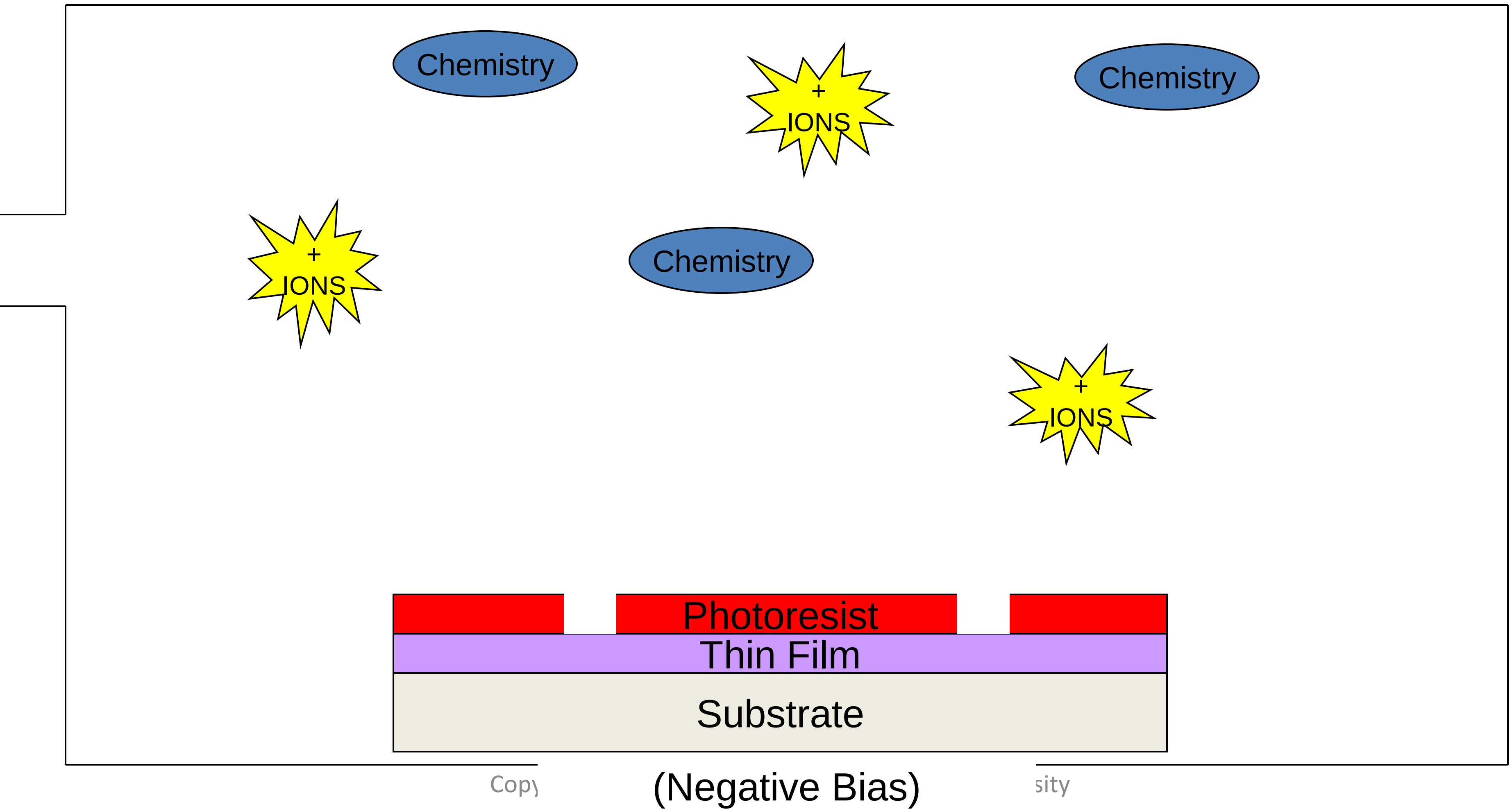
ETCHING



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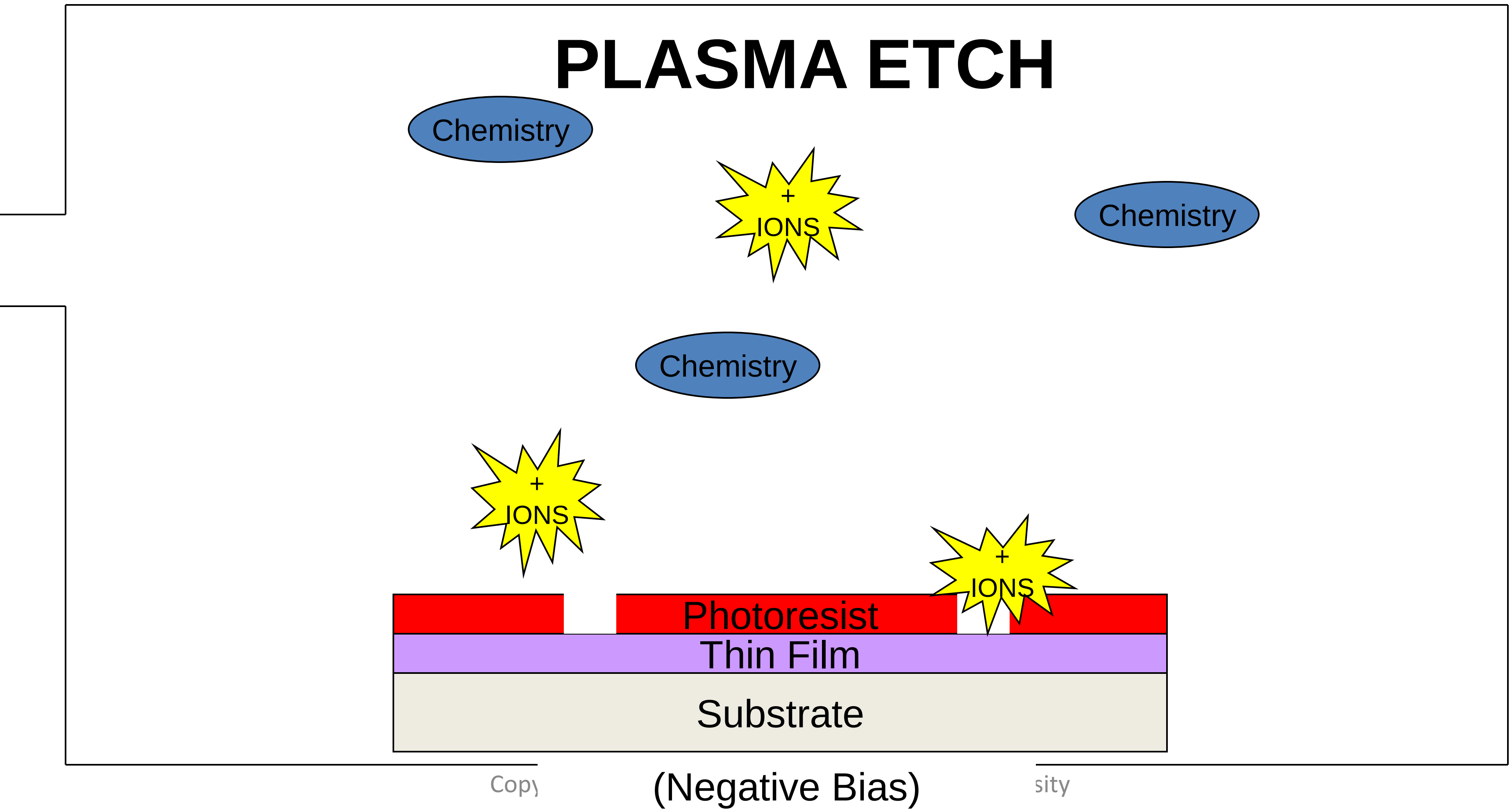

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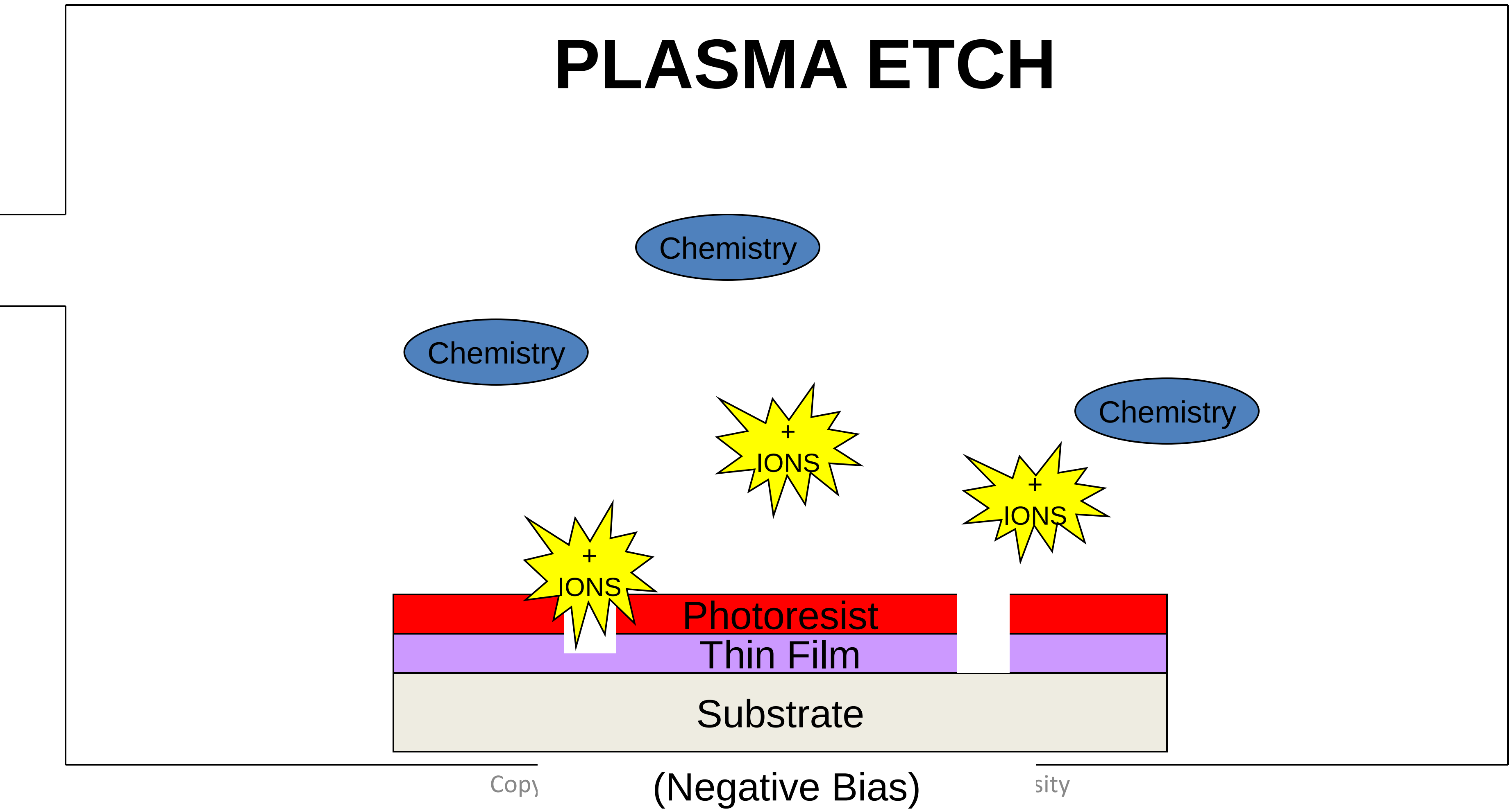

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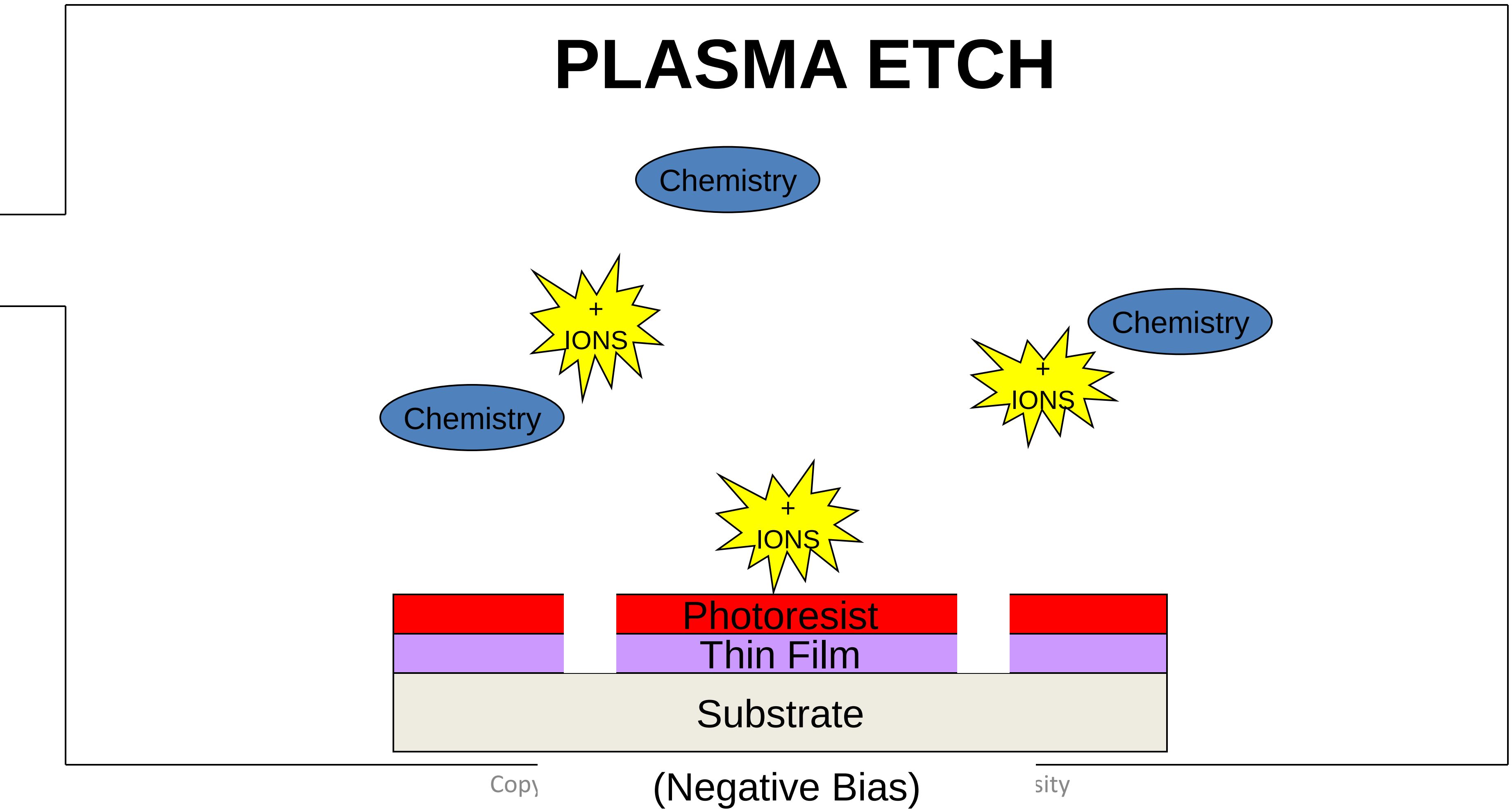

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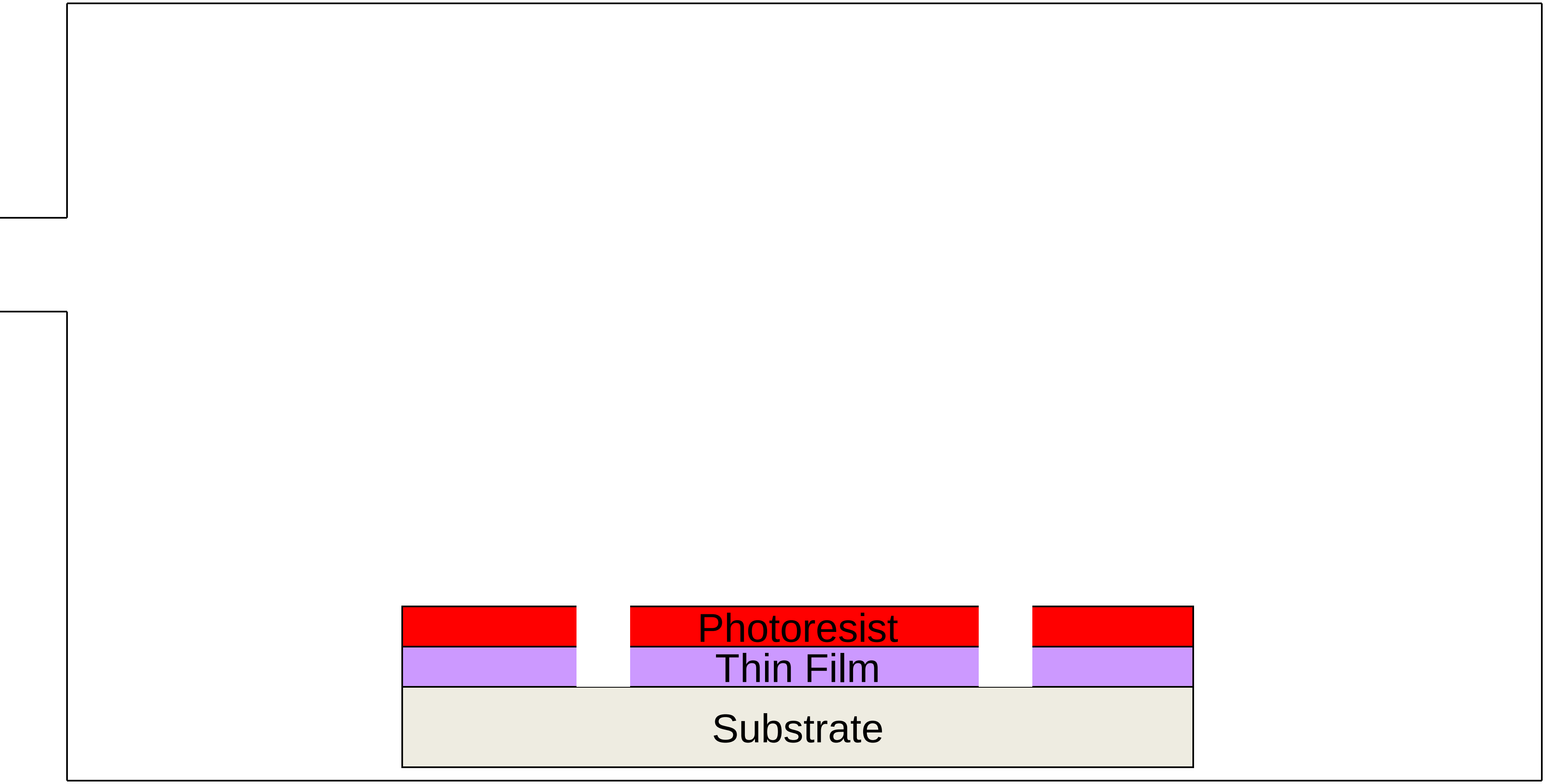
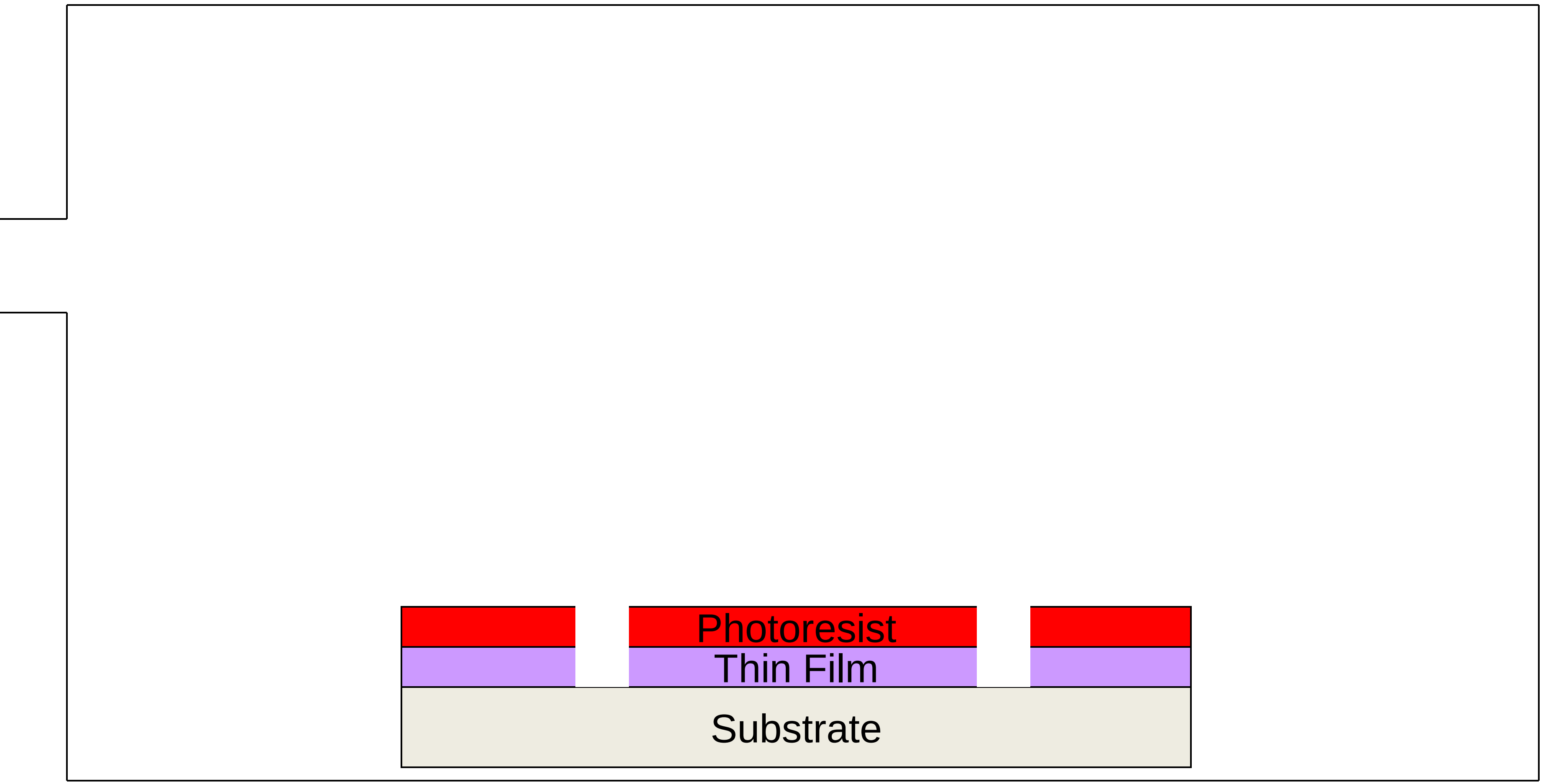


An Example of a Top-Down Nanofabrication Processing Sequence

SURFACE MODIFICATION



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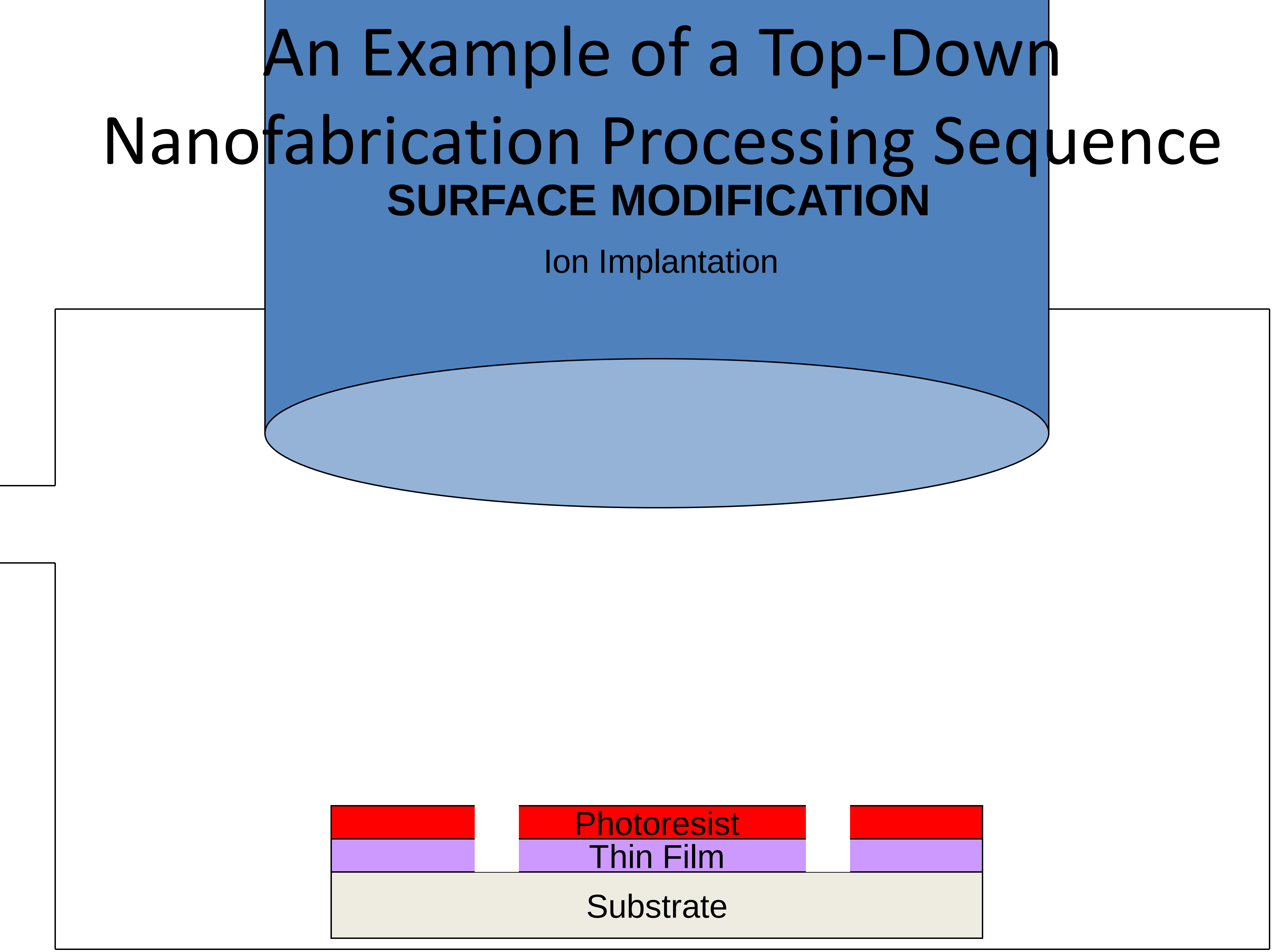

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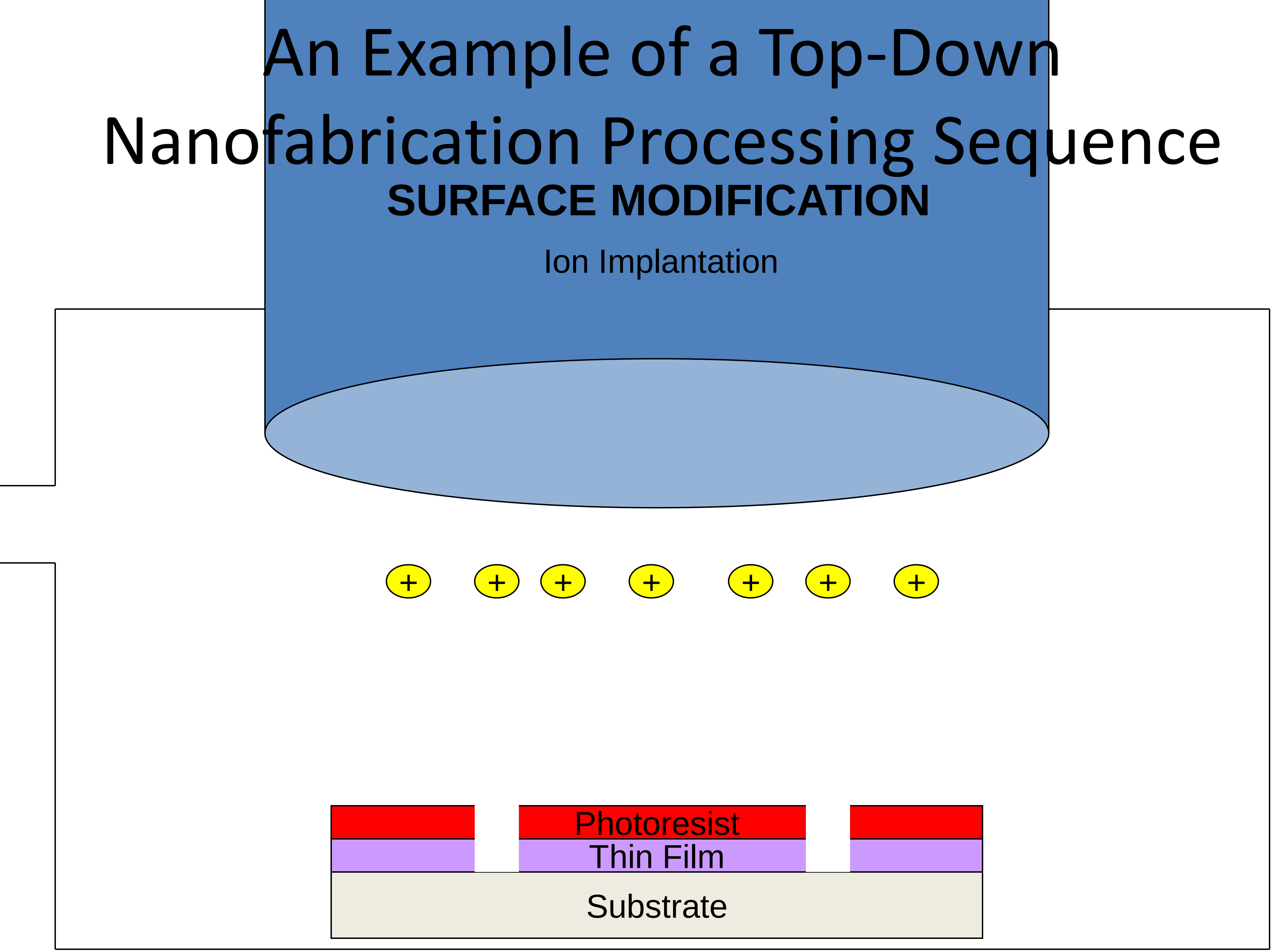

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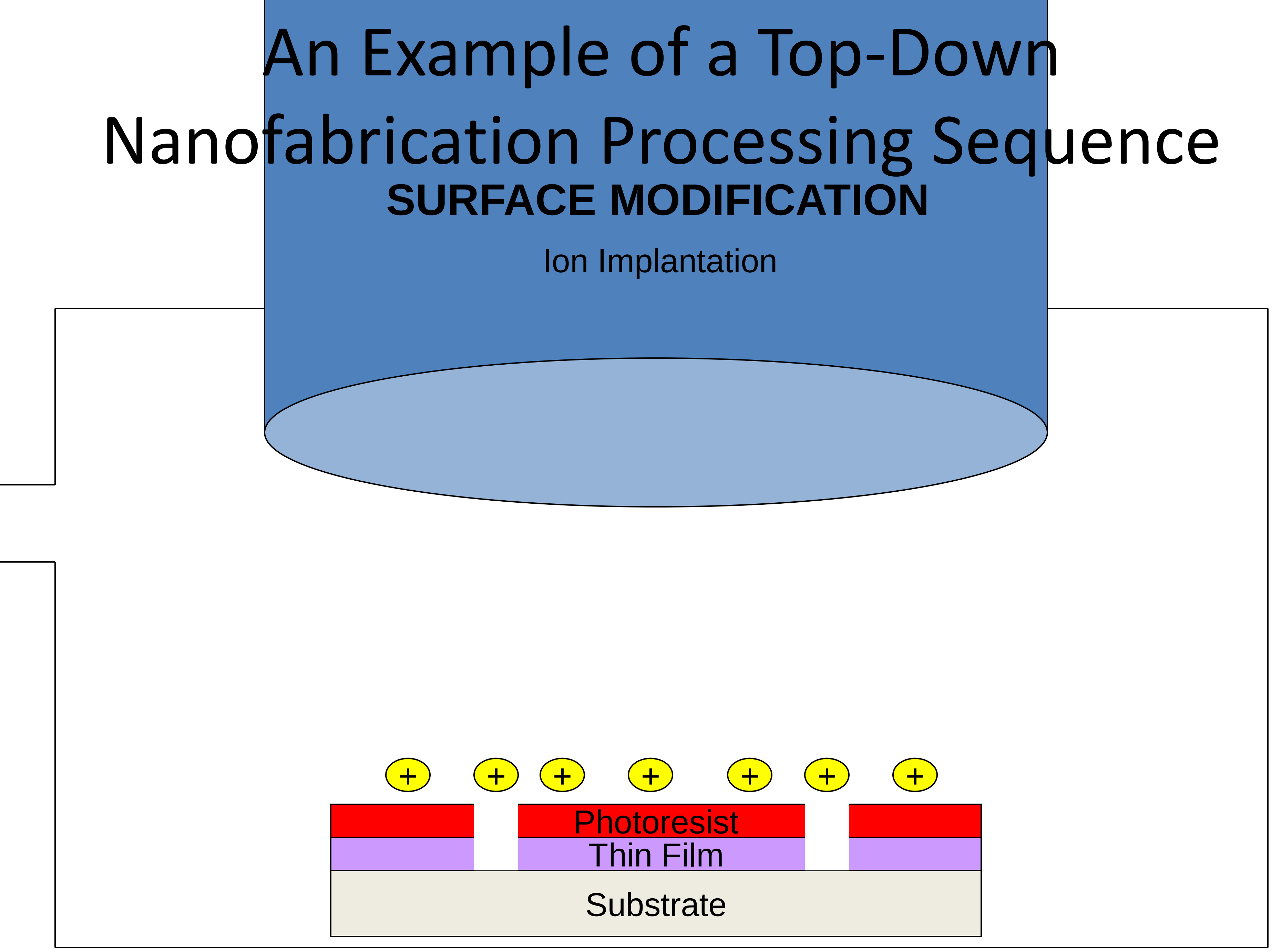

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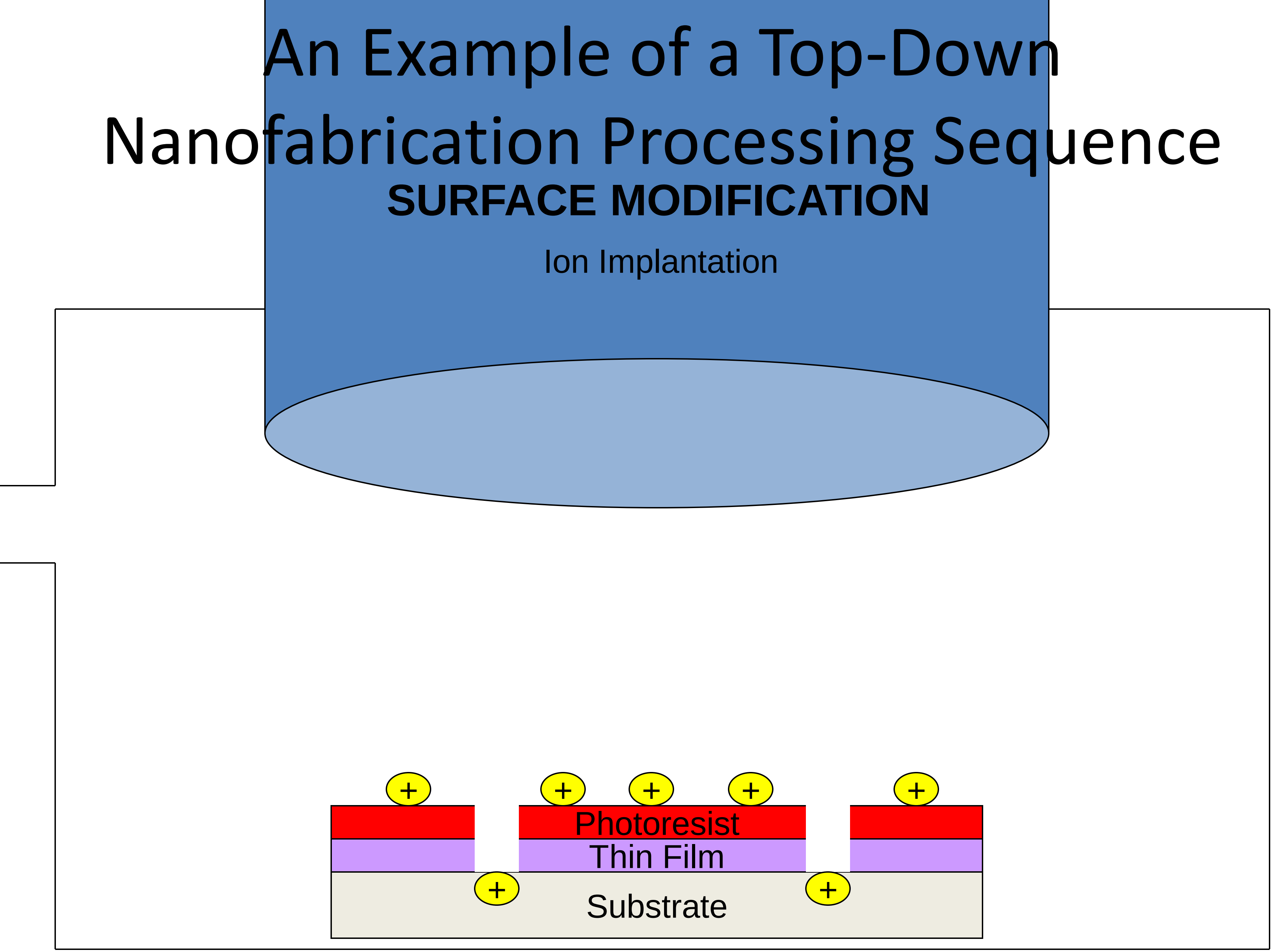

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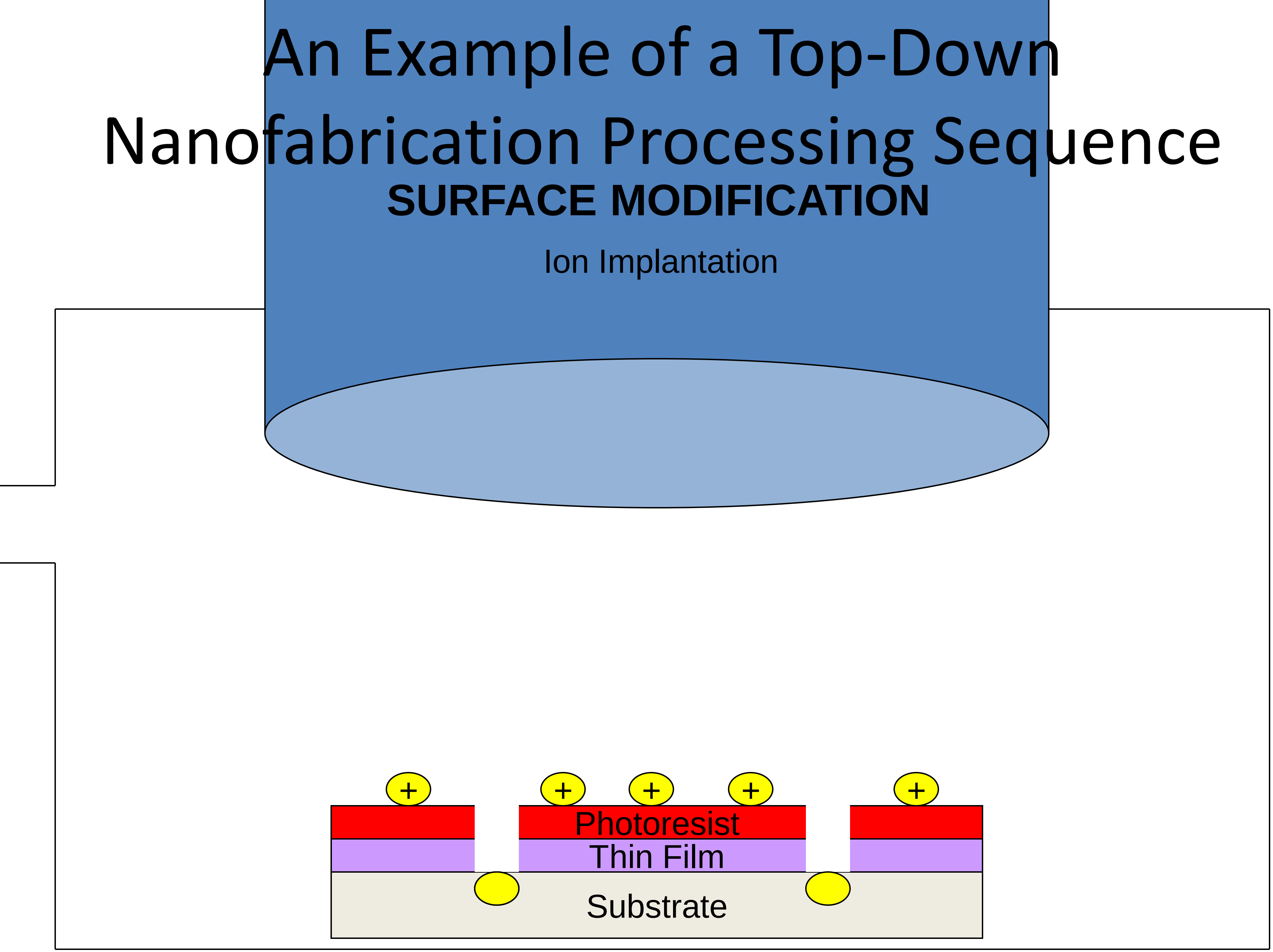

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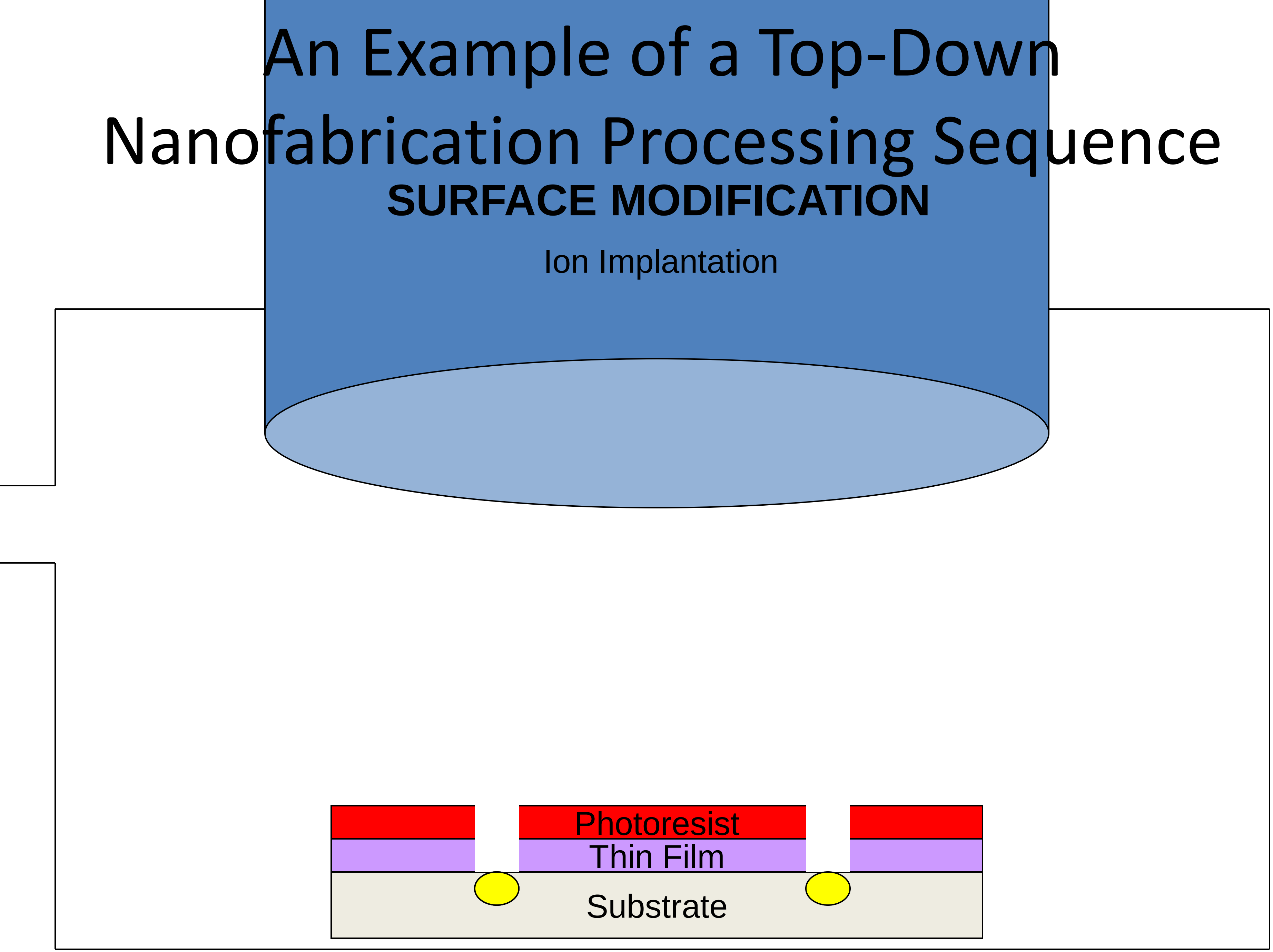
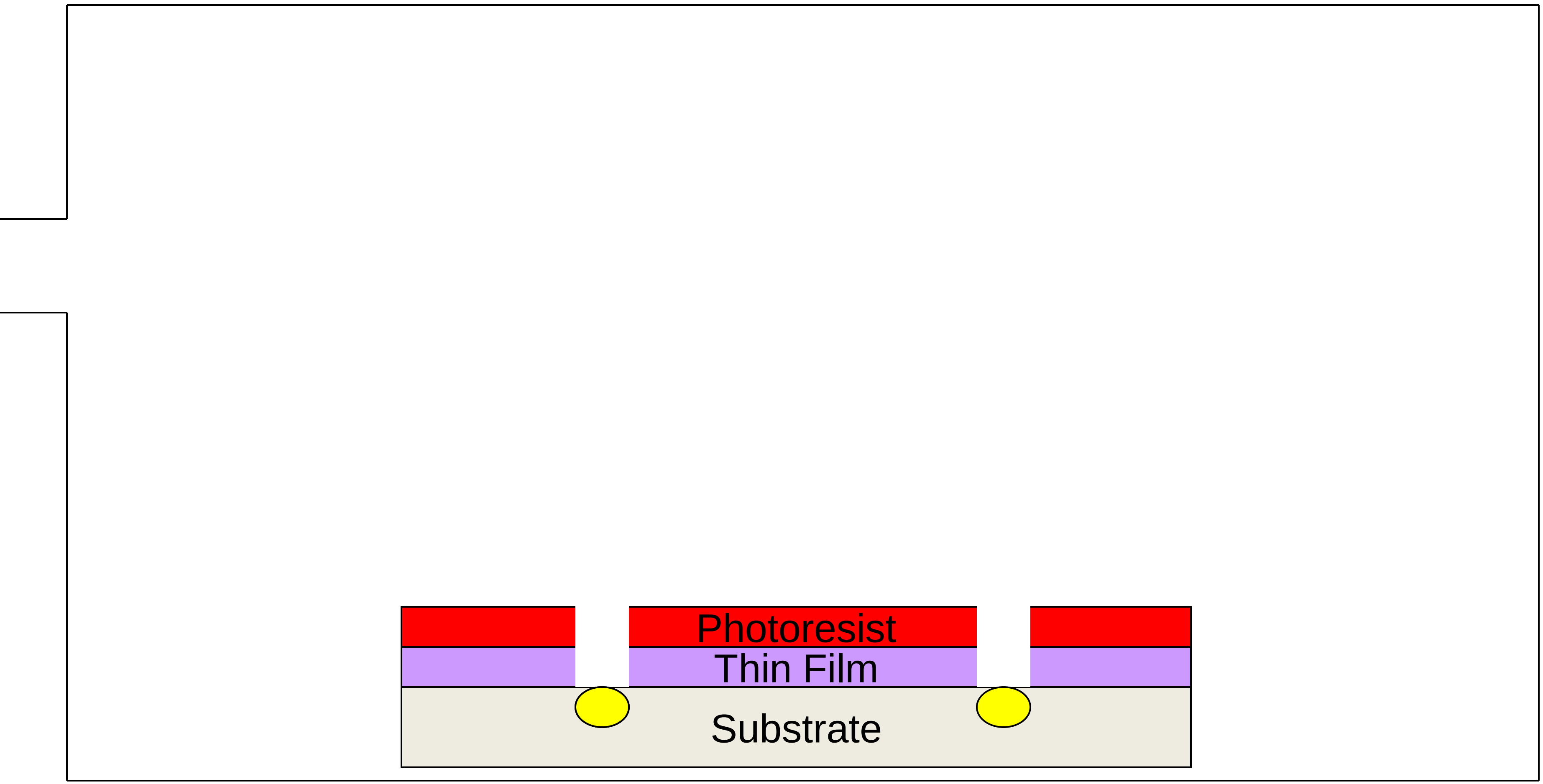


An Example of a Top-Down Nanofabrication Processing Sequence

SURFACE MODIFICATION

Thermal Anneal



An Example of a Top-Down Nanofabrication Processing Sequence

SURFACE MODIFICATION

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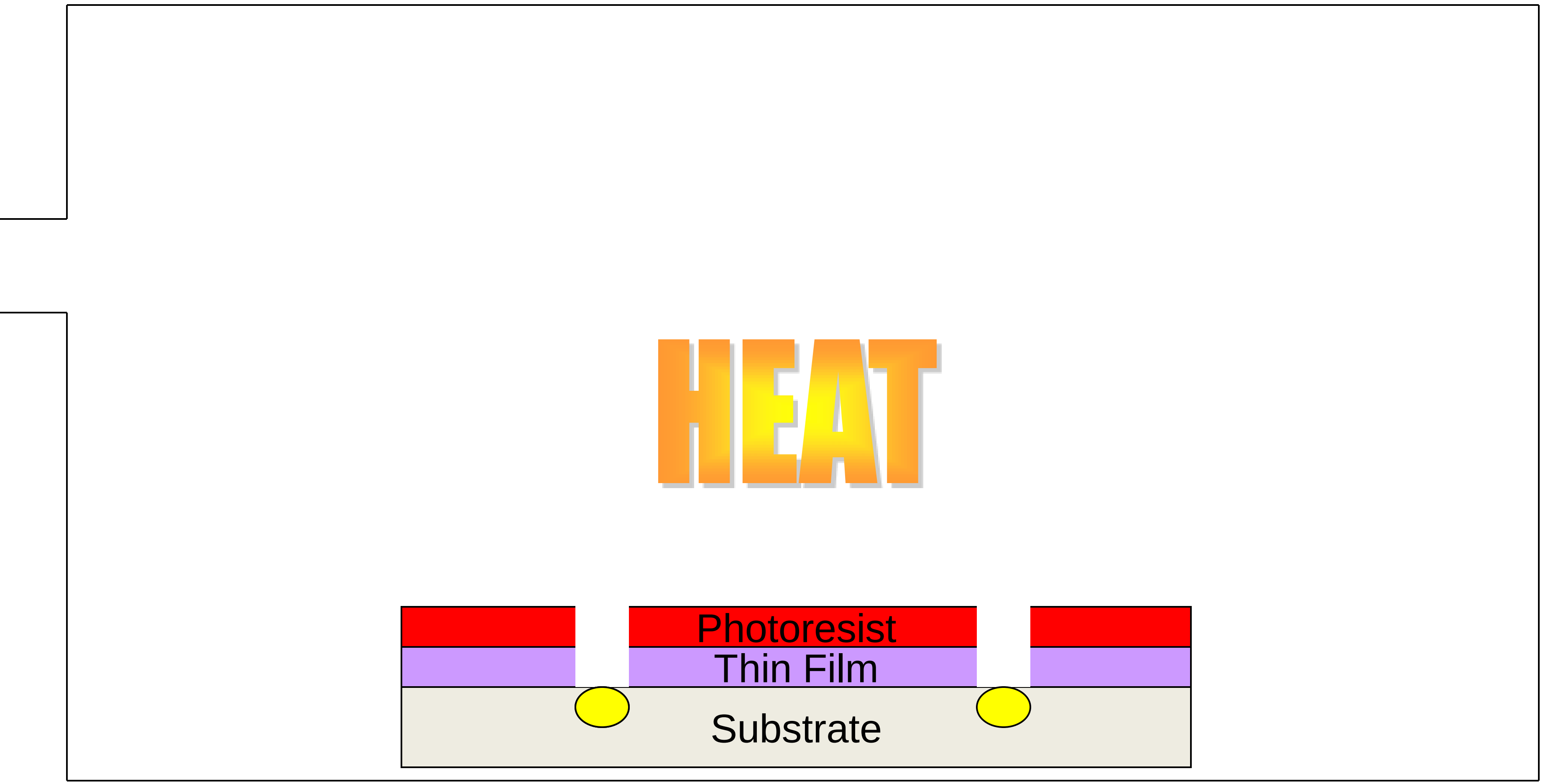

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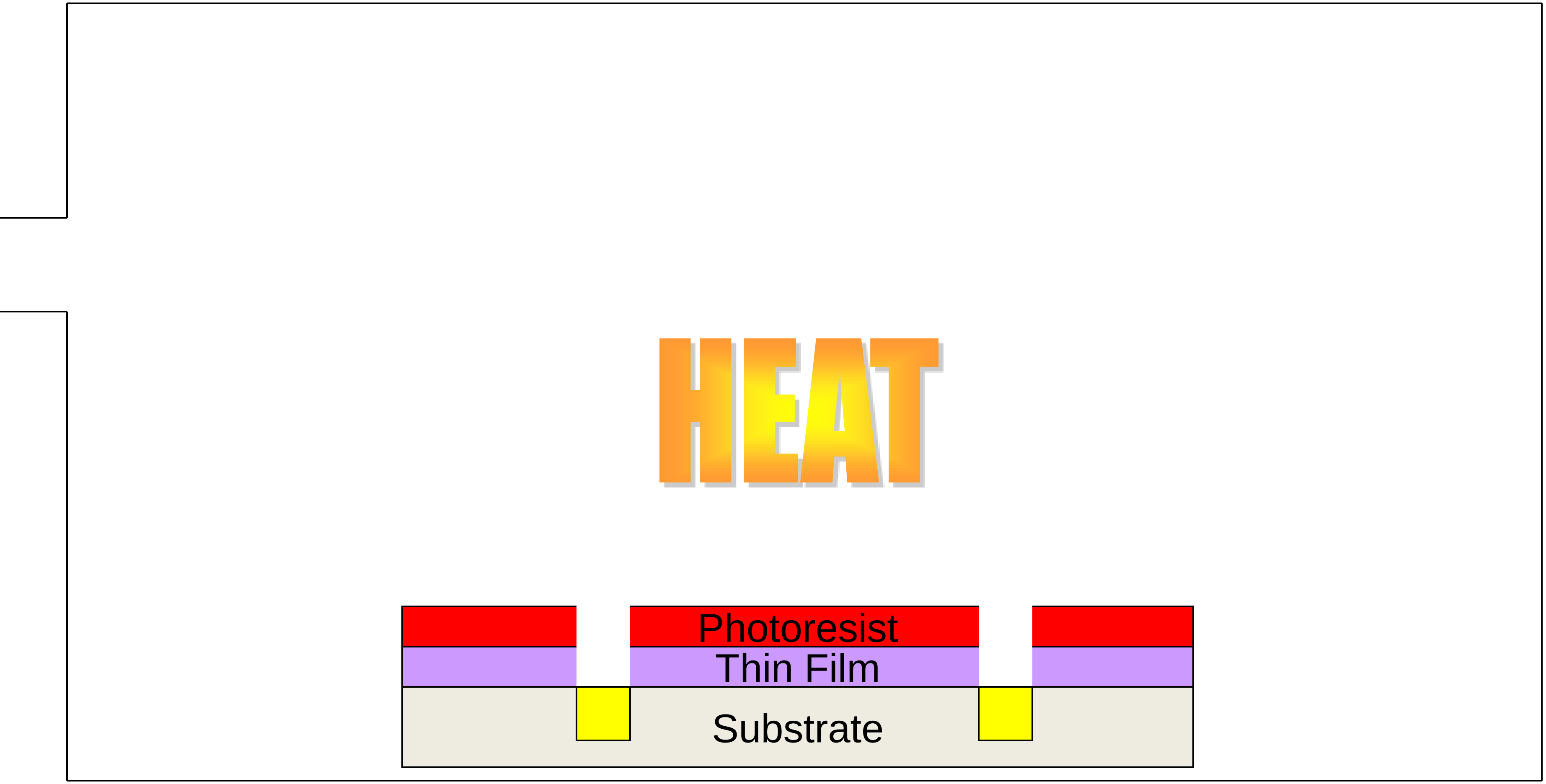

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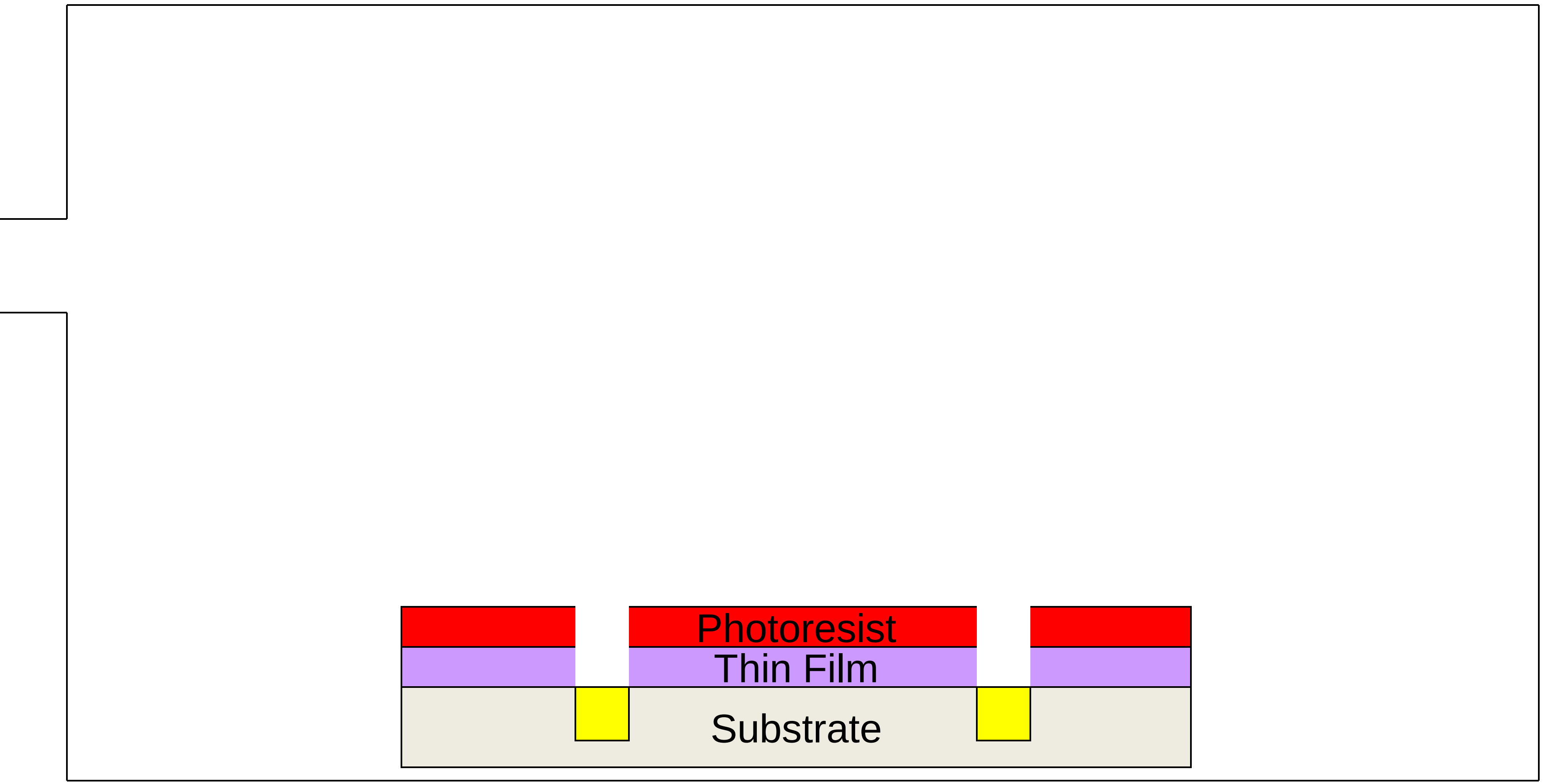
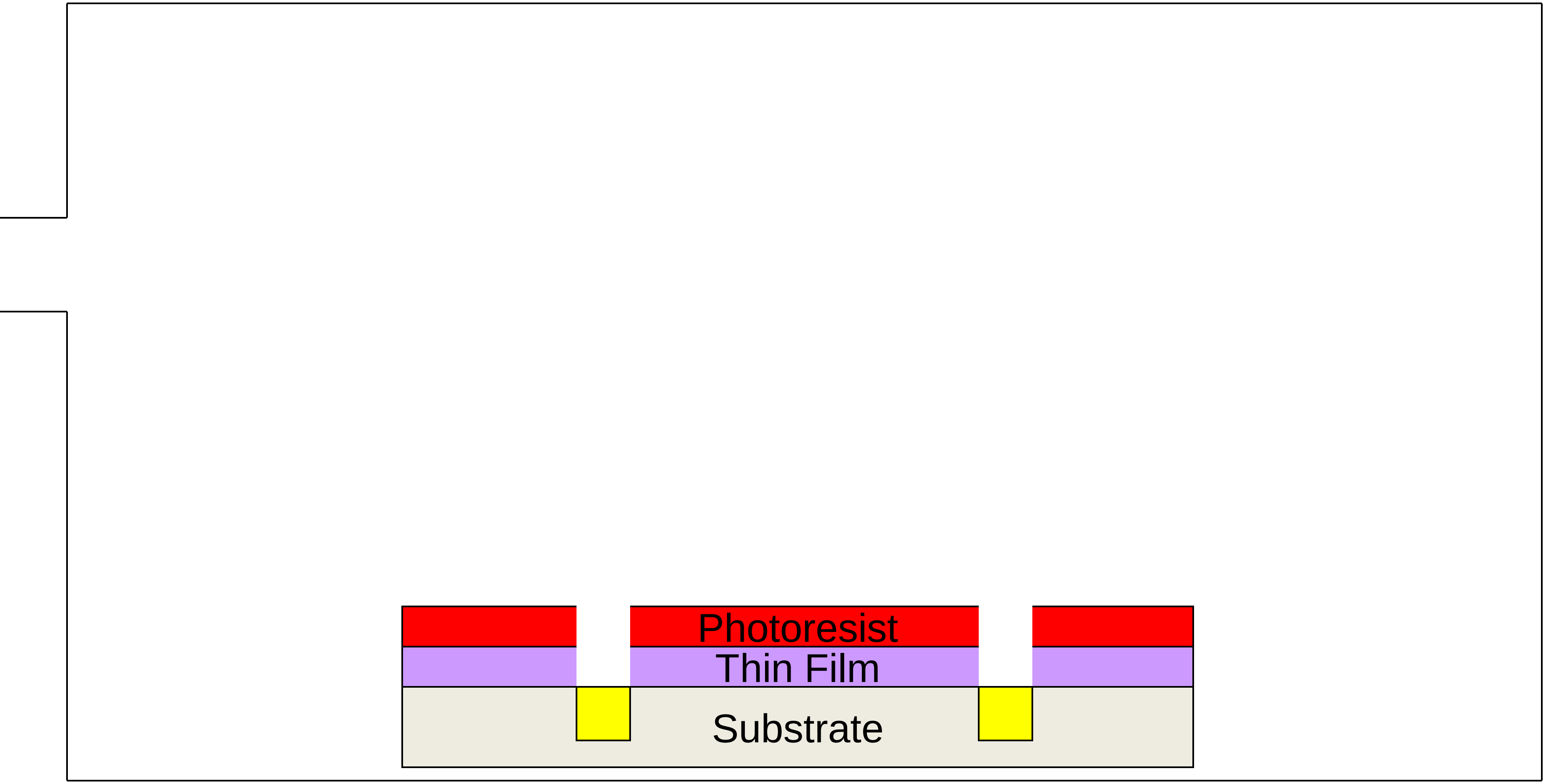


An Example of a Top-Down Nanofabrication Processing Sequence

Remove the Photoresist (Etch/Ion Implantation) Barrier



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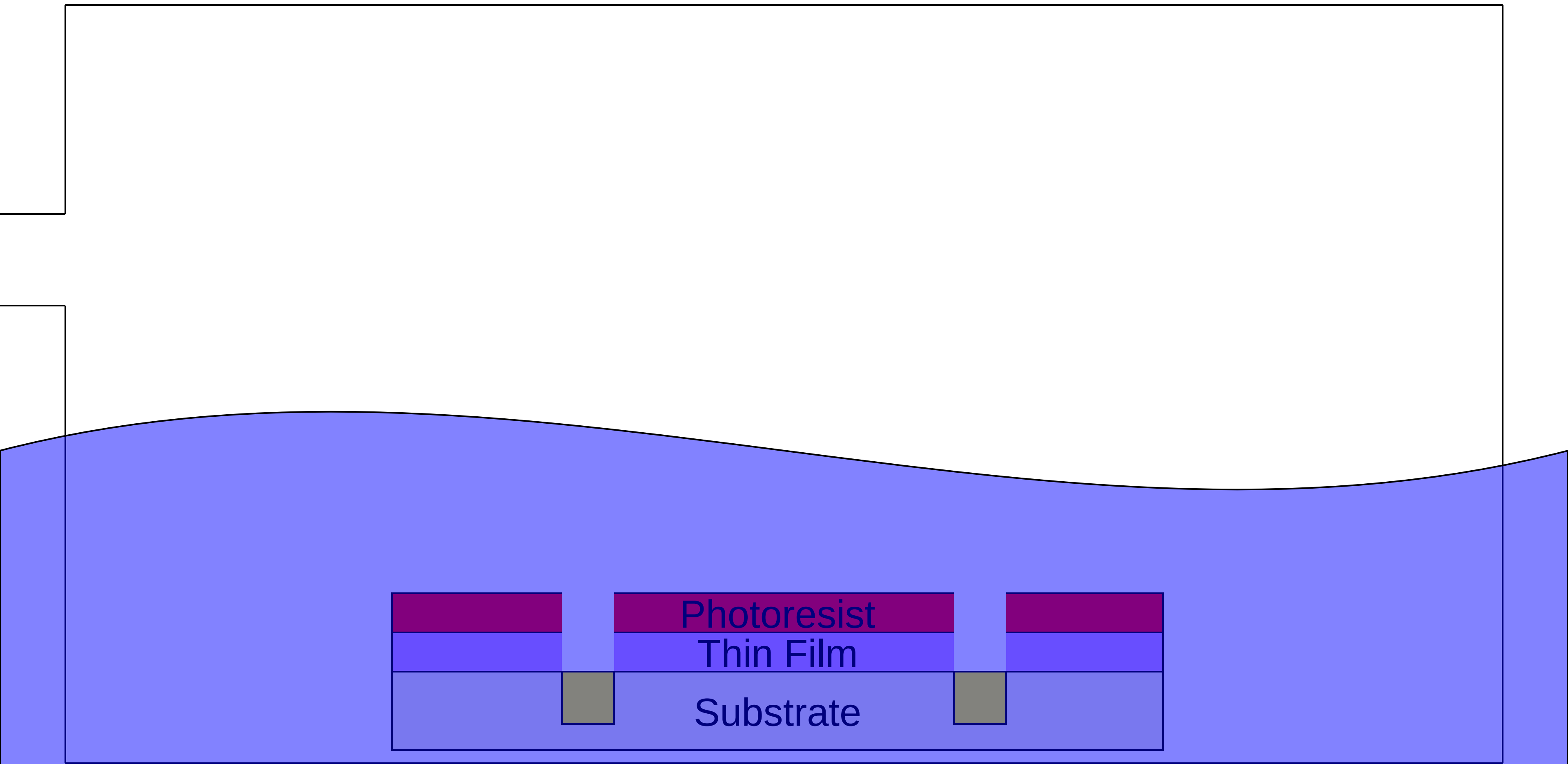

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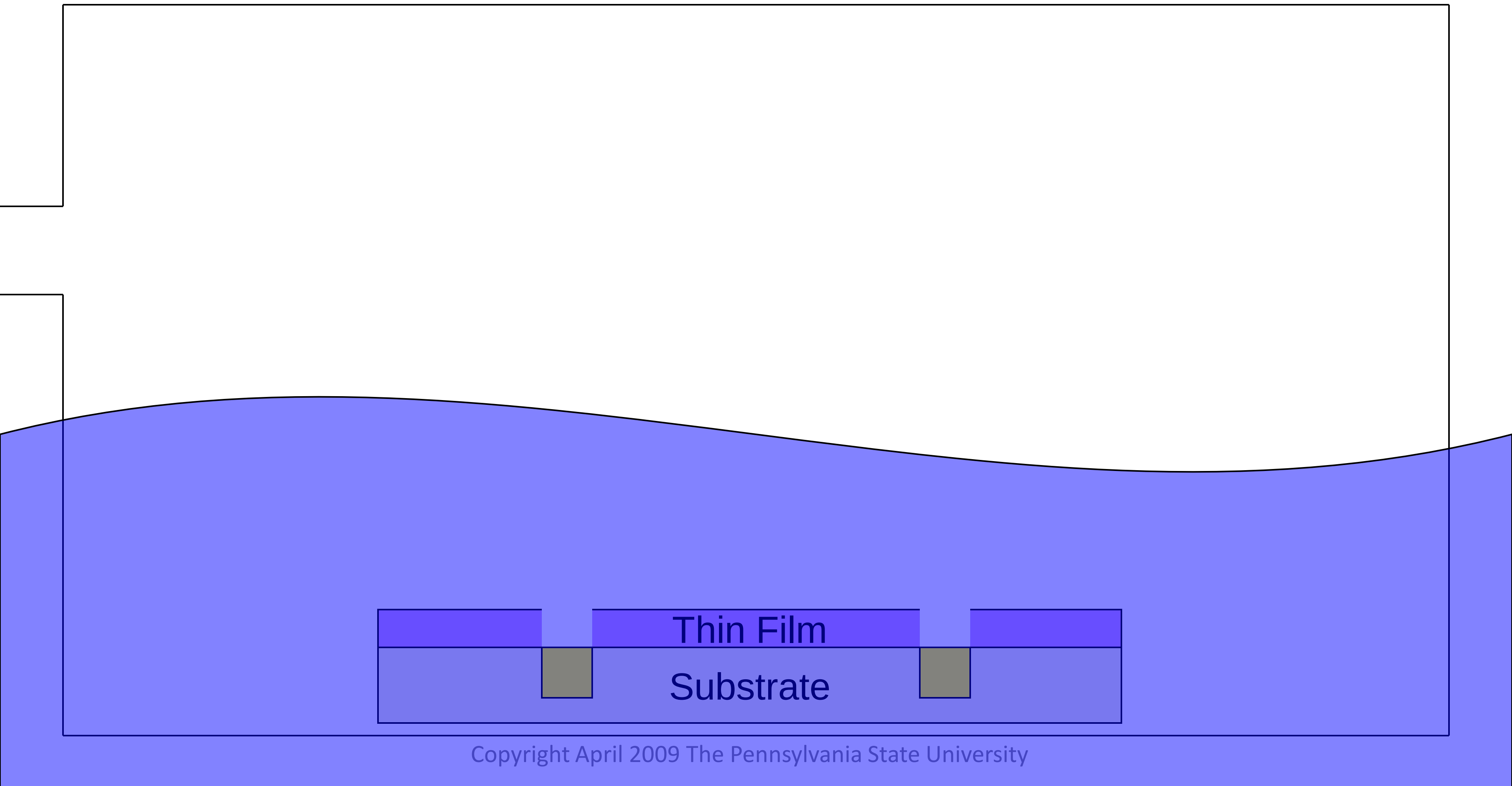

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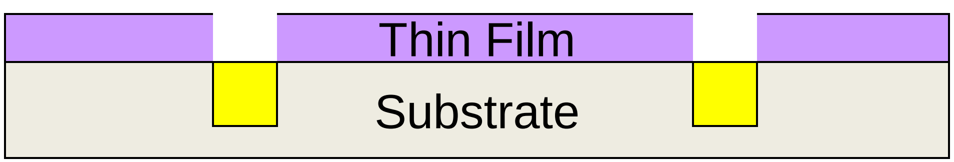
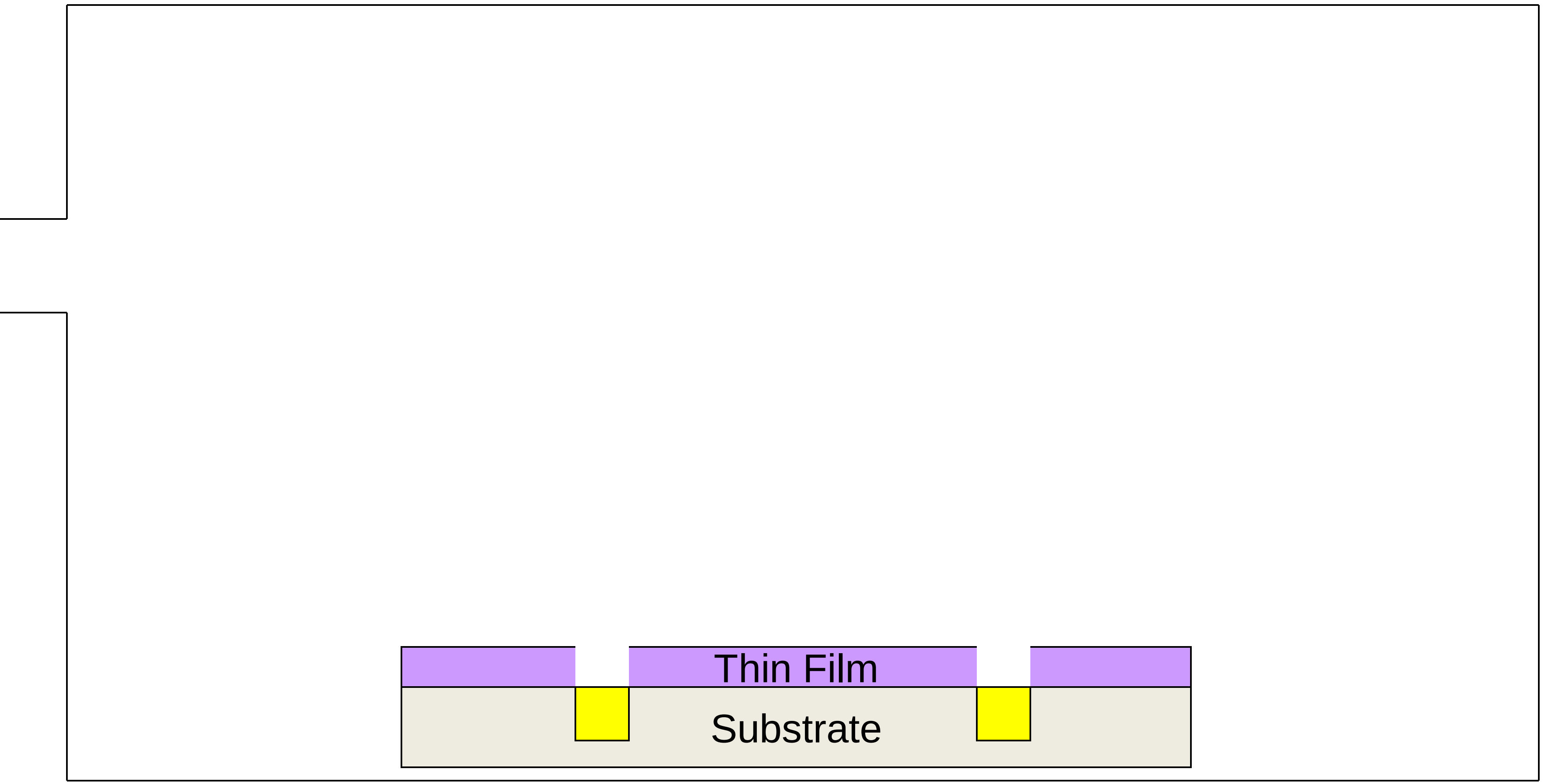


An Example of a Top-Down Nanofabrication Processing Sequence

Pattern Transfer and Substrate Modification Complete



Questions?

Outline

- Basic top-down approaches in nanofabrication
  - Pattern transfer (lithography)
  - Deposition (or film growth)
  - Etching (or removal of material)
- Basic bottom-up approaches in nanofabrication
  - Chemical vapor growth: vapor-solid-liquid growth



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  - Self assembly: colloidal chemistry



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  – a catalyst is introduced to direct the growth to a specific orientation in a confined area

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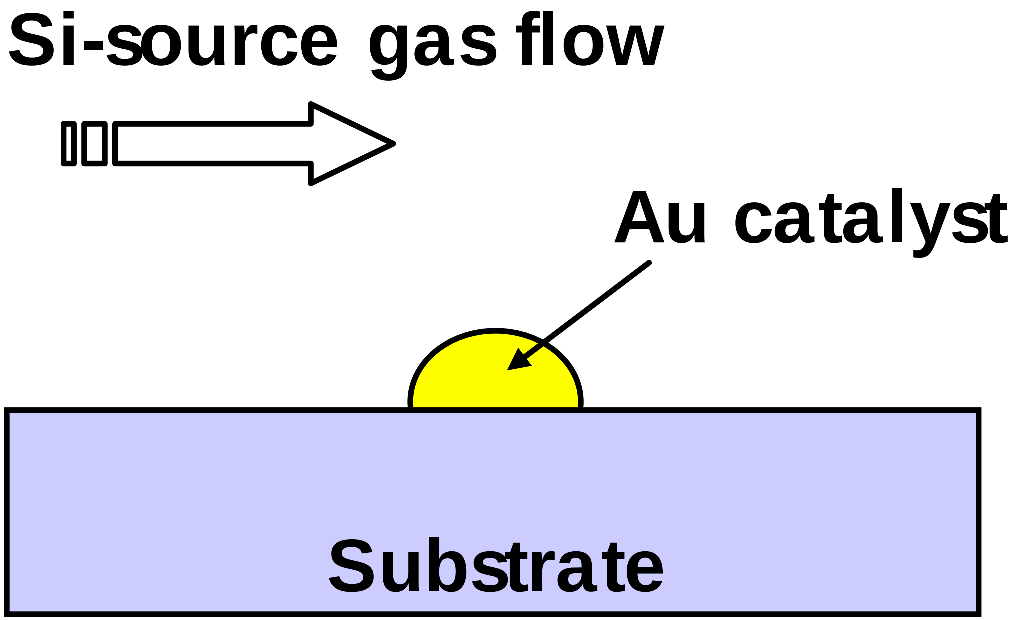
  - a catalyst is introduced to direct the growth to a specific orientation in a confined area
  - The catalyst forms a liquid droplet that acts as a nucleation site for the growth species
  - Saturation of the catalyst results in precipitation of a sold, resulting in a one dimensional growth



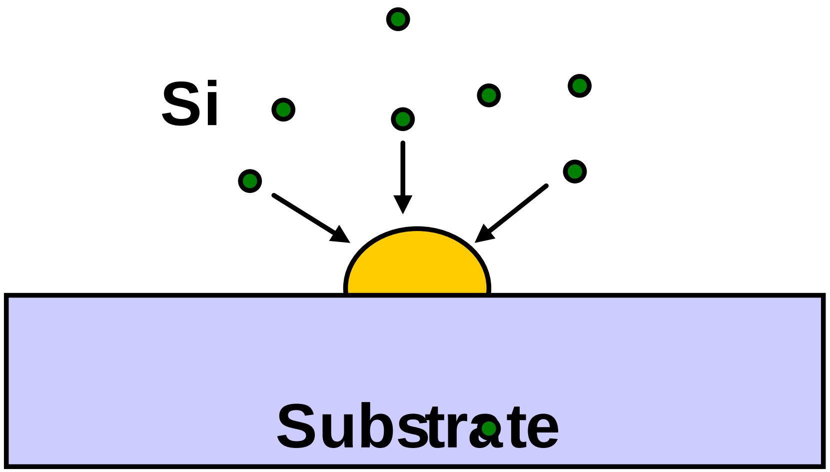
VLS Growth of Silicon Nanowires



Gold (Au) nanoparticles are positioned on a substrate

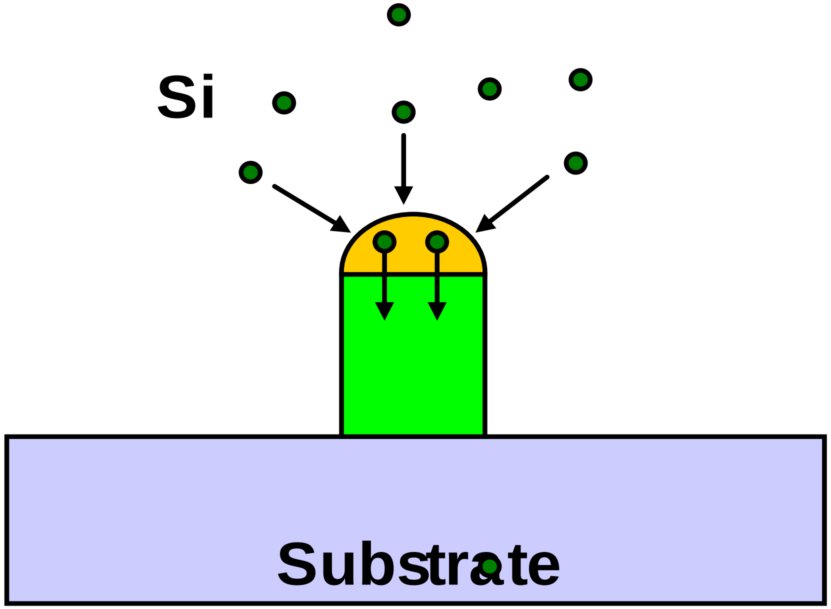
Courtesy of CNEU

VLS Growth of Silicon Nanowires



Nanoparticles act as a catalyst releasing silicon (Si) from its precursor (source). Si then dissolves into the gold

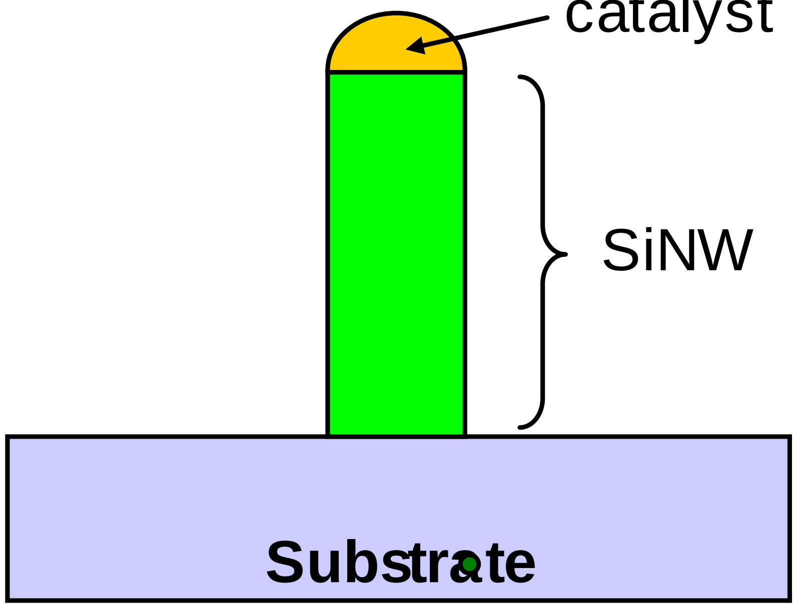
VLS Growth of Silicon Nanowires



Gold nanoparticle becomes supersaturated with Si which then precipitates out as a solid nanowire. (shown in green)



VLS Growth of Silicon Nanowires



The Si Nanowire (SiNW) has a diameter dictated by the size of the Au nanoparticle



Courtesy of CNEU

Questions?

Bottom-Up Approach

- Self assembly: colloidal chemistry
  - Starts with nanoparticles or molecules that aggregate via chemical and physical interactions into the desired nanoscale feature



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Bottom-Up Approach

- Self assembly: colloidal chemistry
  - Starts with nanoparticles or molecules that aggregate via chemical and physical interactions into the desired nanoscale feature
  - The resulting nanostructures may reside in a solution, on a substrate, or in an object
  - There is no use of the lithography or etching steps involved.

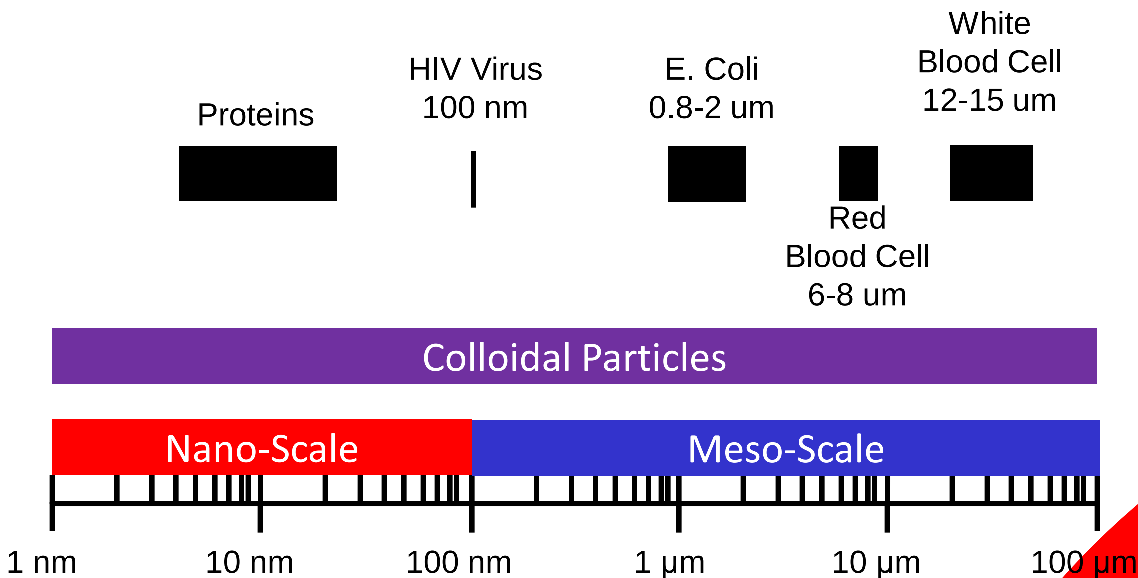
Bottom-Up Approach

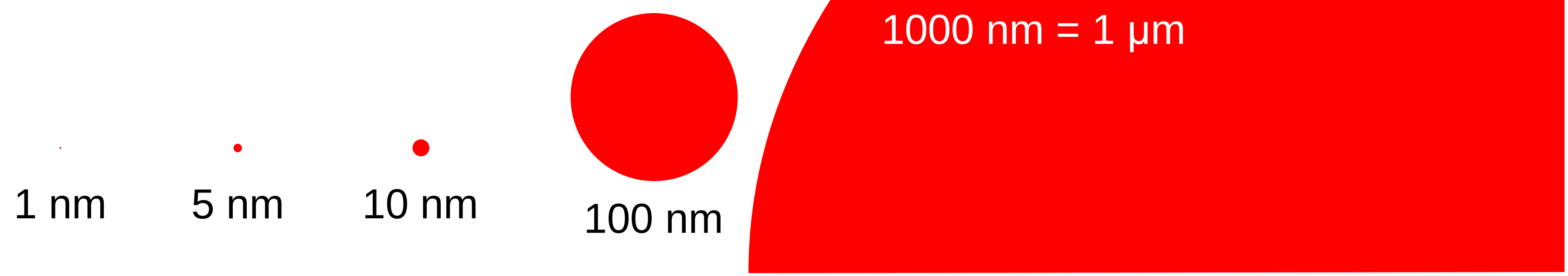
- Colloid: refers to a state of subdivision
  - Implies that the molecules or particles dispersed in a medium have at least one dimension roughly between 1 nm and 1 µm.
  - Whipped cream
  - Milk
  - Fog
  - Smoke



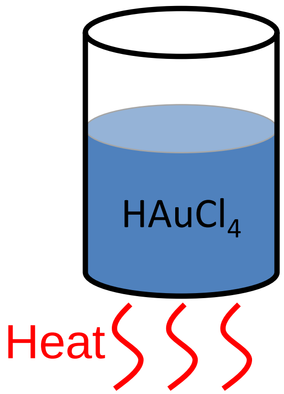
Comparative Size Scale

All of these could be classified as colloidal particles





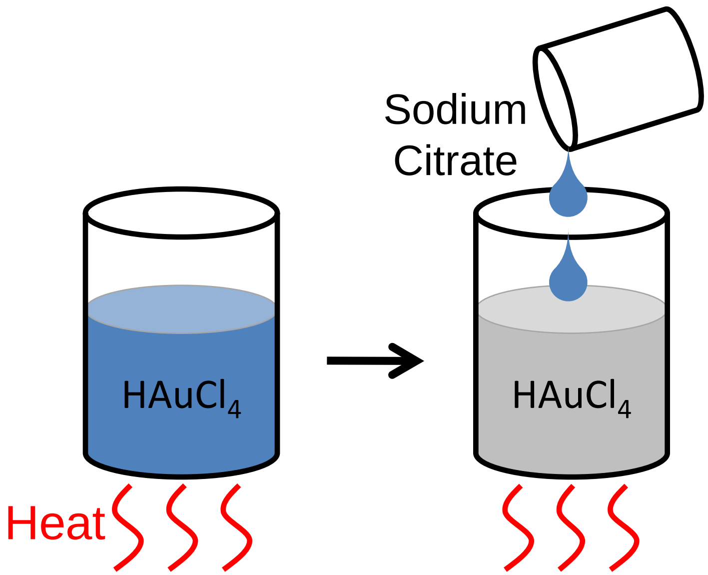
Example: Formation of Gold Nanoparticles



1. Heat a solution of chloroauric acid ($HAuCl_4$) up to reflux (boiling). $HAuCl_4$ is a water soluble gold salt

http://mrsec.wisc.edu/Edetc/nanolab/gold/index.html
J. Chem. Ed. 2004, 81, 544A.

Example: Formation of Gold Nanoparticles



2. Add trisodium citrate, which is a reducing agent

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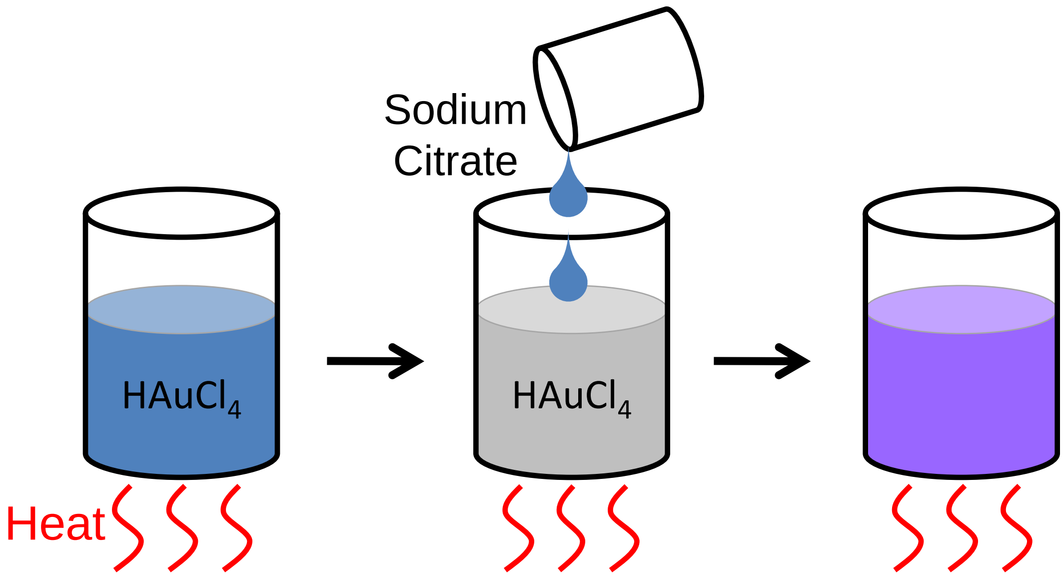

3. Continue stirring and heating for about 10 minutes

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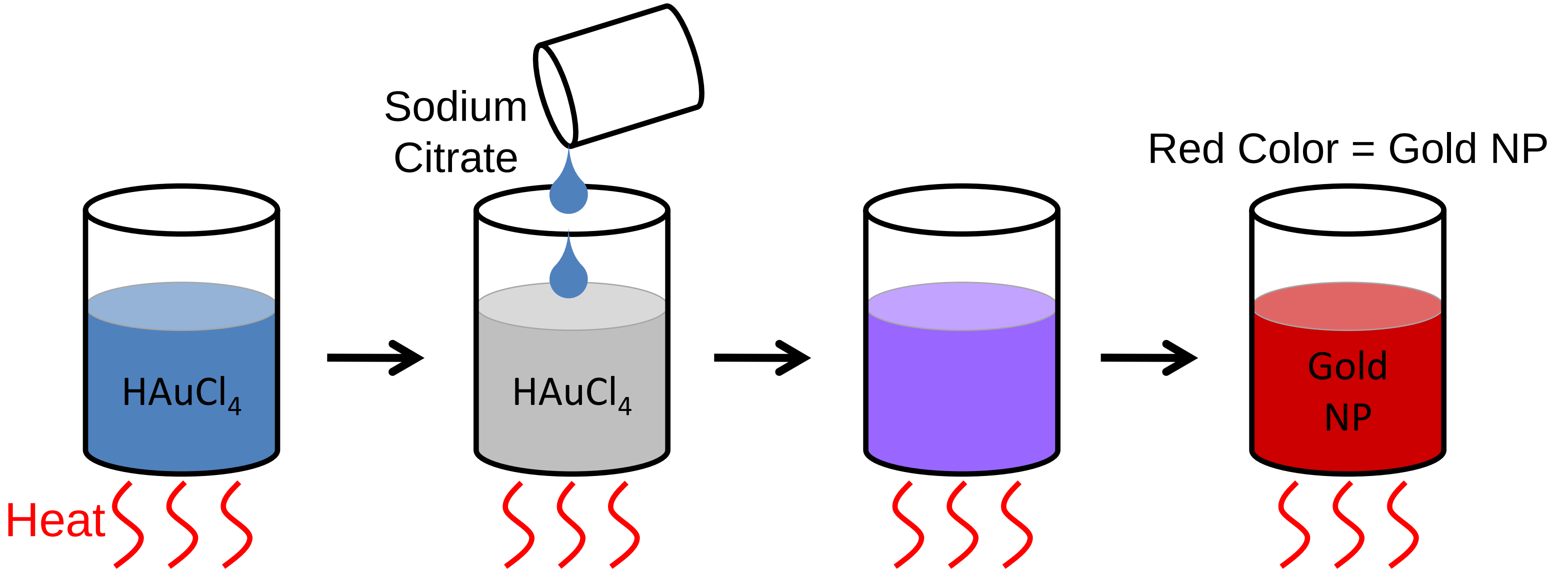
Example: Formation of Gold Nanoparticles



3. Continue stirring and heating for about 10 minutes
   - During this time, the sodium citrate reduces the gold salt (Au^{3+}) to metallic gold (Au^0)
   - The neutral gold atoms aggregate into seed crystals
   - The seed crystals continue to grow and eventually form gold nanoparticles

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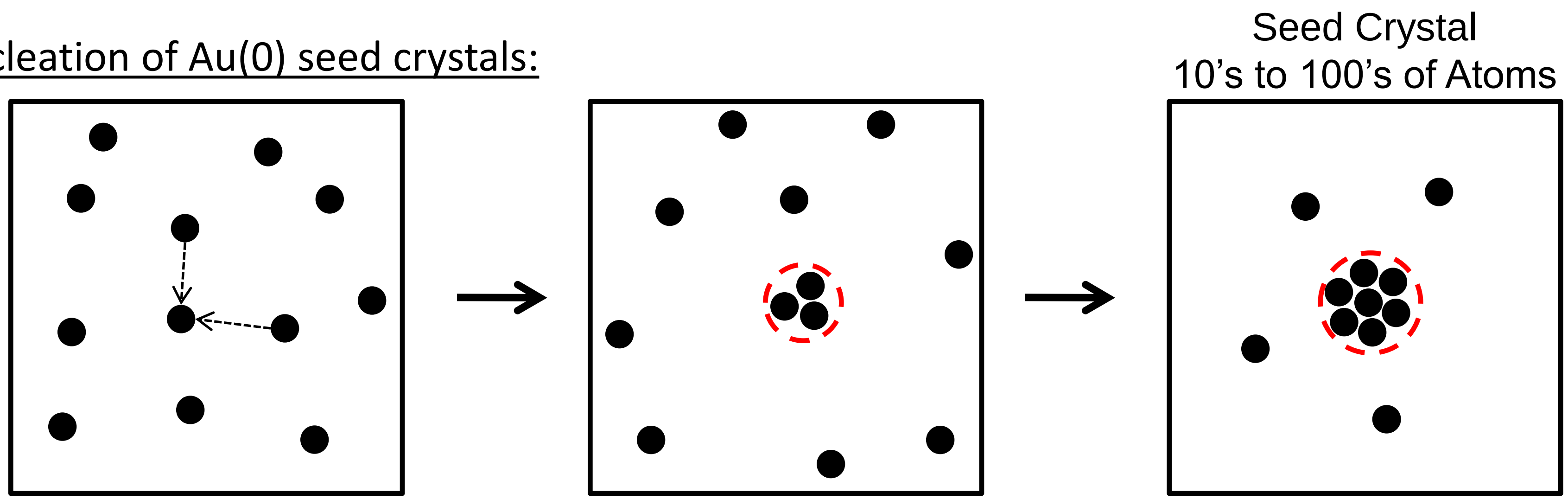
Example: Formation of Gold Nanoparticles

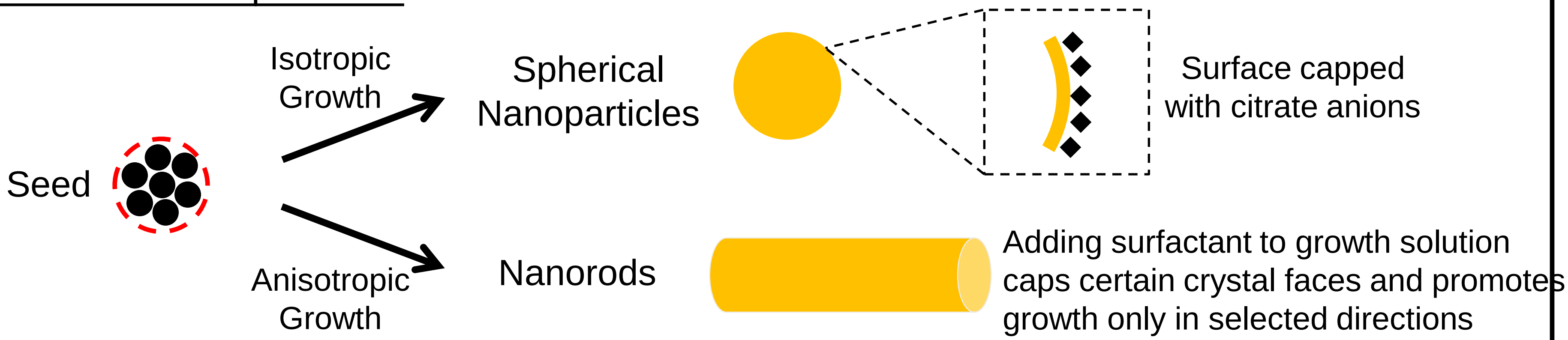
Reduction of gold ions: $Au(III) + 3e^{-} \rightarrow Au(0)$

Nucleation of Au(0) seed crystals:



Example: Formation of Gold Nanoparticles

Growth of nanoparticles:





Questions?

Nano4me.org applications:

Introduction of Nanofabrication:
Top Down to Bottom Up
for the classroom maybe found at:

Module 6: How Do You Make Things So Small: An Introduction to Nanofabrication

You may find additional resources and free curriculum for nanotechnology at www.nano4me.org and click Educators.

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Questions?

Thank you for attending

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