Welcome to NACK’s Webinar

Introduction to Nanofabrication: Top Down to Bottom Up

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Outline

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

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  – Deposition (or film growth)
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  – Etching (or removal of material)
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• 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
  – A light sensitive material called photoresist is applied to the substrate
  – 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

• 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
Top-Down Approach

- Patterning Process: Photolithography
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  - The substrate is exposed to UV light
  - The exposed photoresist is developed
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
• This is an example of positive tone photoresist – “what shows, goes!”
Top-Down Approach

Ultraviolet Light

Mask

Photoresist

Film

Substrate

• 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
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
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

Material being gouged way from target by ions

Plasma

Trapped electrons

Argon atoms

Target atoms

Film growth

Substrate
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

- Pressure gauge
- Gas inlet
- Three zone heating element
- Insulation
- Quartz Tube (Chamber)
- Exhaust spent gas to pump
- Internal (profile) Thermocouples
- Gas Flow
- Boat
- External Thermocouples

LPCVD
Top-Down Approaches

PECVD
Questions?
Top-Down Approach

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

• Subtractive Objects: Reactive Ion Etching
  – Use plasma to ionize gas
  – Processing gas is selected for chemical etching of substrate materials
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 placed on substrate to allow 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 placed on substrate to allow for physical etching from positively charged gas species.
  – The pressure of the 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
Top-Down Approach

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

- **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

Ion drawn to negatively charged cathode

50 Ω Impedance Match

Questions?
The Basic Steps of Top-down nanofabrication. These are used in any sequence.

Lithography

Etching

Material Modification

Depositing or Growing

Courtesy of CNEU
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
An Example of a Top-Down Nanofabrication Processing Sequence

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THIN FILM GROWTH OR DEPOSITION

Film Grown by Chemical Reaction of Ambient species with the Substrate

HEAT

Oxygen

Substrate
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
An Example of a Top-Down Nanofabrication Processing Sequence

LITHOGRAPHY
Spin on Photoresist
An Example of a Top-Down Nanofabrication Processing Sequence

LITHOGRAPHY

Spin on Photoresist
An Example of a Top-Down Nanofabrication Processing Sequence

LITHOGRAPHY

Align Photomask

Mask

Photoresist

Thin Film

Substrate
An Example of a Top-Down Nanofabrication Processing Sequence

**LITHOGRAPHY**

Expose with Light

Diagram:

- **Substrate**
- **Thin Film**
- **Photoresist**
- **Mask**
An Example of a Top-Down Nanofabrication Processing Sequence

**LITHOGRAPHY**

Expose with Light

Diagram:
- Substrate
- Thin Film
- Photoresist
- Mask

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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
An Example of a Top-Down Nanofabrication Processing Sequence

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Dissolve Exposed Photoresist in Liquid Developer
An Example of a Top-Down Nanofabrication Processing Sequence

ETCHING

[Diagram showing layers: Substrate, Thin Film, Photoresist]
An Example of a Top-Down Nanofabrication Processing Sequence

ETCHING

Substrate
Thin Film
Photoresist

(Negative Bias)
An Example of a Top-Down Nanofabrication Processing Sequence

**ETCHING**

- Chemistry
- Photoresist
- Thin Film
- Substrate
- (Negative Bias)
An Example of a Top-Down Nanofabrication Processing Sequence

**ETCHING**

**PLASMA ETCH**

- Chemistry
- + IONS
- Chemistry
- + IONS
- Chemistry
- + IONS

Layers:
- Photoresist
- Thin Film
- Substrate

(Negative Bias)
An Example of a Top-Down Nanofabrication Processing Sequence

ETCHING

PLASMA ETCH

Chemistry

Chemistry

IONS

IONS

Photoresist

Thin Film

Substrate

(Negative Bias)
An Example of a Top-Down Nanofabrication Processing Sequence

ETching

PLASMA ETCH

Chemistry

IONs

Chemistry

Chemistry

Photoresist

Thin Film

Substrate (Negative Bias)
An Example of a Top-Down Nanofabrication Processing Sequence
An Example of a Top-Down Nanofabrication Processing Sequence

SURFACE MODIFICATION

Substrate

Thin Film

Photoresist

Substrate
An Example of a Top-Down Nanofabrication Processing Sequence

SURFACE MODIFICATION

Ion Implantation

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SURFACE MODIFICATION

An Example of a Top-Down Nanofabrication Processing Sequence

Ion Implantation

Substrate

Photoresist

Thin Film

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SURFACE MODIFICATION

Ion Implantation
An Example of a Top-Down Nanofabrication Processing Sequence

SURFACE MODIFICATION

Ion Implantation

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SURFACE MODIFICATION

Ion Implantation

Substrate

Photoresist

Thin Film

Substrate
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SURFACE MODIFICATION
Ion Implantation

Substrate

Photoresist
Thin Film

Substrate

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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
Thermal Anneal

HEAT

Photoresist
Thin Film
Substrate
An Example of a Top-Down Nanofabrication Processing Sequence

SURFACE MODIFICATION

Thermal Anneal

HEAT

- Photoresist
- Thin Film
- Substrate

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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

Remove the Photoresist (Etch/Ion Implantation) Barrier
An Example of a Top-Down Nanofabrication Processing Sequence

Remove the Photoresist (Etch/Ion Implantation) Barrier
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Remove the Photoresist (Etch/Ion Implantation) Barrier
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
Outline

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• Basic bottom-up approaches in nanofabrication
  – Chemical vapor growth: vapor-solid-liquid growth
  – Self assembly: colloidal chemistry
Bottom-Up Approach

• Chemical Vapor Growth: Vapor-Liquid-Solid growth (VLS growth)
  – a catalyst is introduced to direct the growth to a specific orientation in a confined area
Bottom-Up Approach

- Chemical Vapor Growth: Vapor-Liquid-Solid growth (VLS growth)
  - 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
Bottom-Up Approach

• Chemical Vapor Growth: Vapor-Liquid-Solid growth (VLS growth)
  – 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 solid, resulting in a one dimensional growth
VLS Growth of Silicon Nanowires

Gold (Au) nanoparticles are positioned on a substrate.
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)
The Si Nanowire (SiNW) has a diameter dictated by the size of the Au nanoparticle.
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
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
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.
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

<table>
<thead>
<tr>
<th>Nano-Scale</th>
<th>Meso-Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 nm</td>
<td>10 nm</td>
</tr>
<tr>
<td>10 nm</td>
<td>100 nm</td>
</tr>
<tr>
<td>100 nm</td>
<td>1 μm</td>
</tr>
<tr>
<td>1 μm</td>
<td>10 μm</td>
</tr>
<tr>
<td>10 μm</td>
<td>100 μm</td>
</tr>
</tbody>
</table>

1000 nm = 1 μm

Proteins 100 nm
HIV Virus 100 nm
E. Coli 0.8-2 um
Red Blood Cell 6-8 um
White Blood Cell 12-15 um

All of these could be classified as colloidal particles.
1. Heat a solution of chloroauric acid (HAuCl$_4$) up to reflux (boiling). HAuCl$_4$ is a water soluble gold salt.
Example: Formation of Gold Nanoparticles

2. Add trisodium citrate, which is a reducing agent

Example: Formation of Gold Nanoparticles

3. Continue stirring and heating for about 10 minutes

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

Example: Formation of Gold Nanoparticles

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

Nucleation of Au(0) seed crystals:

Seed Crystal
10's to 100's of Atoms
Example: Formation of Gold Nanoparticles

Growth of nanoparticles:

- **Seed**
  - **Isotropic Growth** → Spherical Nanoparticles
  - **Anisotropic Growth** → Nanorods

- Surface capped with citrate anions
- Adding surfactant to growth solution caps certain crystal faces and promotes growth only in selected directions
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

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Questions?
Thank you for attending

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