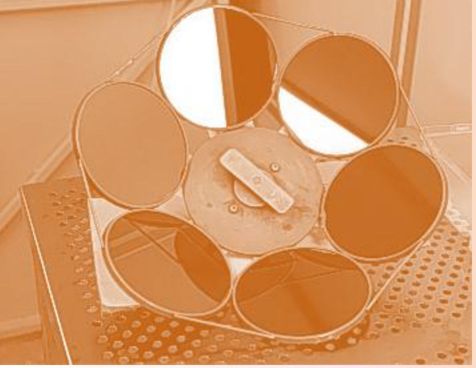


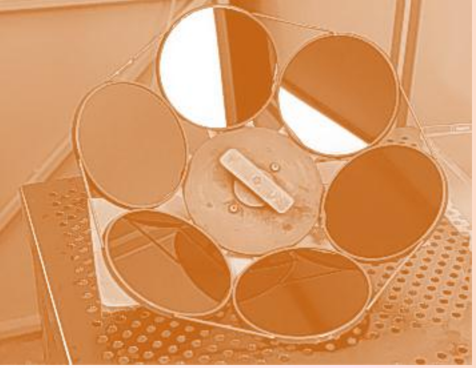
Microsystem Processes – Part I Deposition

Presented by

Southwest Center for Microsystems Education

-SCME-

September 2012

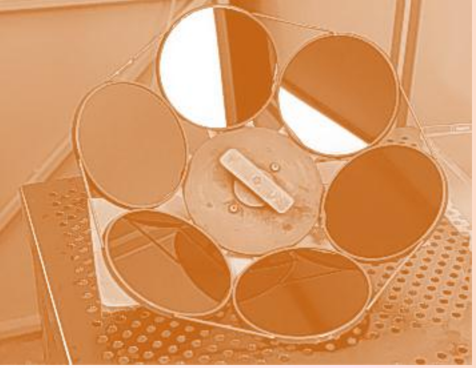


SCME
Southwest Center for Microsystems Education

SCME is a National Science Foundation Advanced Technological Education (ATE) Program at the University of New Mexico.

We offer professional development and educational materials to excite and engage high school, community college and university students in the field of Microsystems (MEMS) technology.

Support for this work was provided by the National Science Foundation's Advanced Technological Education (ATE) Program through Grants #DUE 0992411.



Our Presenters

Barb Lopez

Research Engineer, University of New Mexico and Instructional Designer, SCME

Mary Jane (MJ) Willis

Instructional Designer, SCME and retired Chair for the Manufacturing Technology Program – Central New Mexico Community College

Southwest Center for Microsystems Education

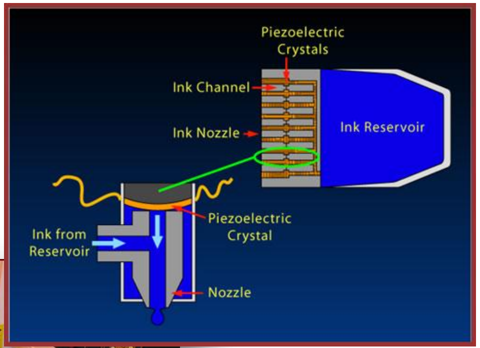
Today's Topics

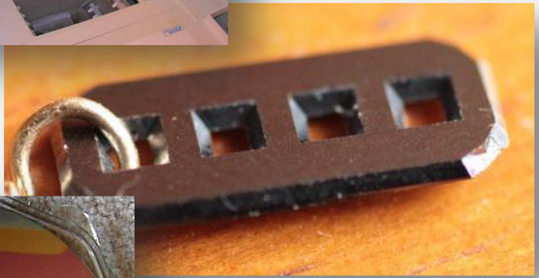
- Brief overview of what SCME can do for you
- What is deposition?
- Thin Films
- Deposition and microsystems
- Types of Deposition

Educational Materials

To date SCME offers

- 150 Shareable Content Objects (SCOs)
  - Informational Units / lessons
  - Supporting activities
  - Supporting assessments
- 37 Learning Modules in the areas of
  - Safety
  - Microsystems Introduction
  - Microsystems Applications
  - Bio MEMS
  - Microsystems Fabrication
- 11 Instructional Kits
- All are available @ scme-nm.org



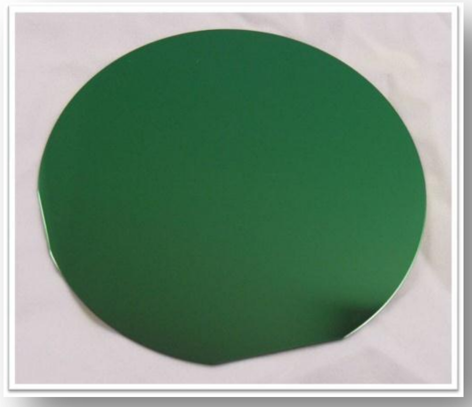


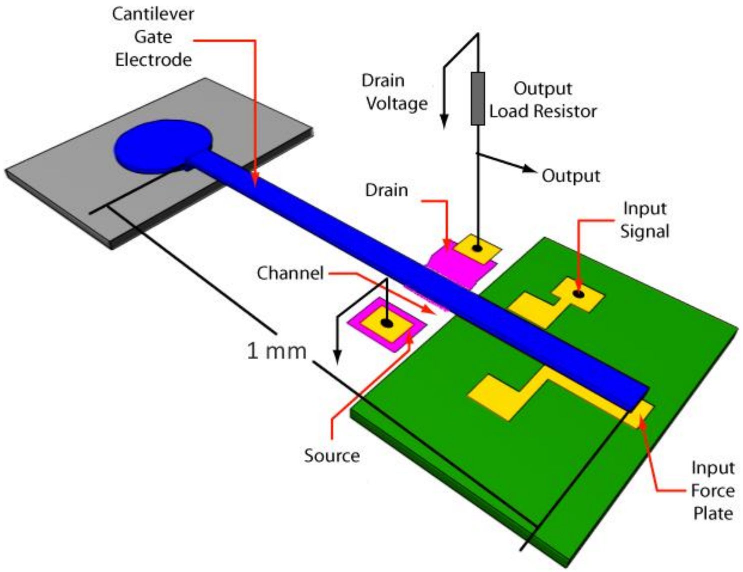
Professional Development

- 4 to 5-day workshops
- 2-day workshops
- 1-day workshop
- Conferences and conference workshops
- Create hubs at other colleges to teach our workshops
- Webinars

What is Deposition?

- Deposition is any process that deposits a thin film of material onto an object.
- Deposition provides the ability to deposit thin film layers as thick as 100 micrometers and as thin as a few nanometers.
- Deposition is one of the primary processes in the construction of microsystems.

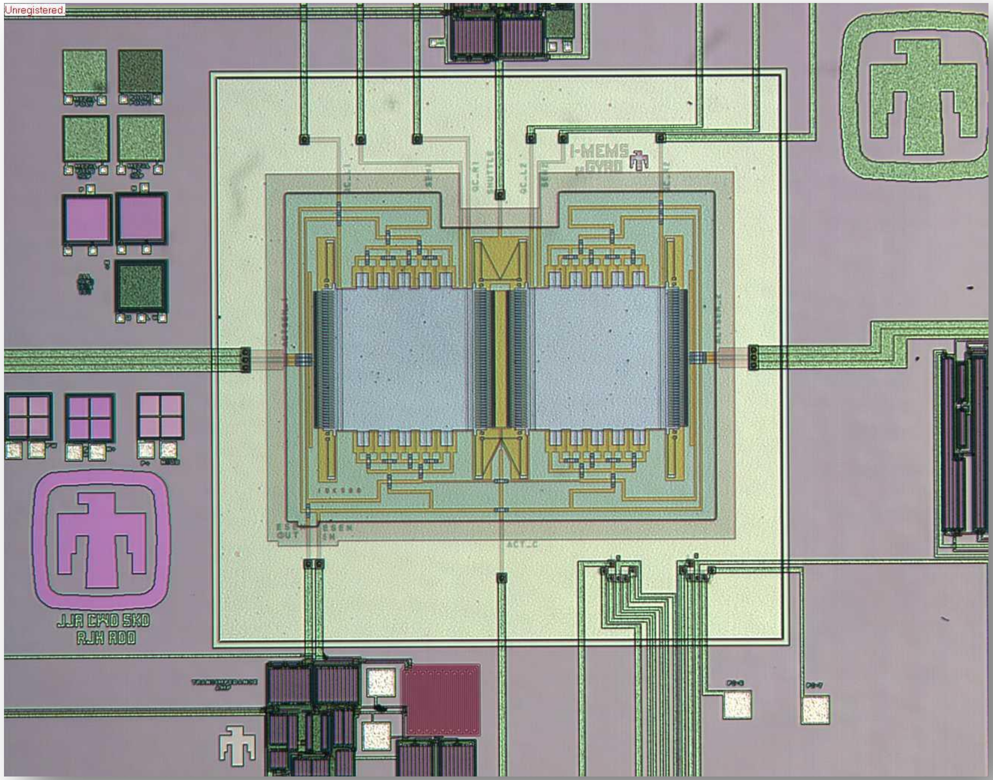




Microsystems Processes

Microsystems are constructed using many of the same processes found in integrated circuit manufacturing:

- Photolithography
- Wet and dry etch
- Diffusion
- Planarization
- Deposition



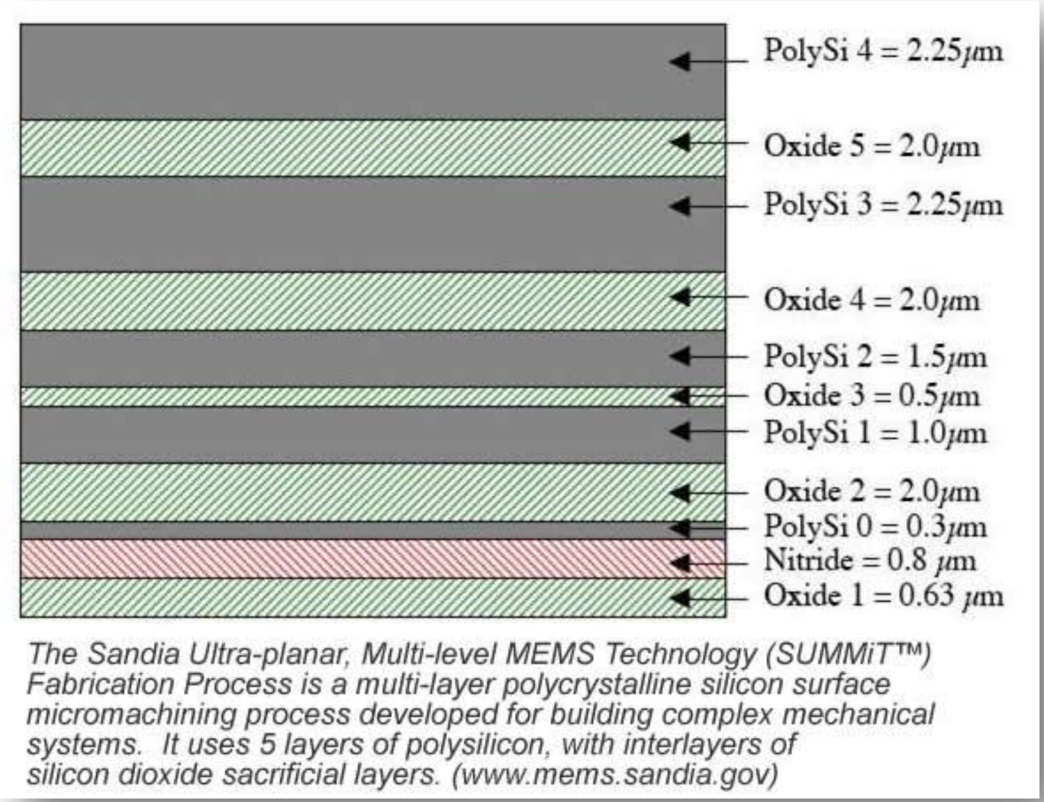
Vibrating Gyroscope
[Graphic courtesy of Sandia National Laboratories]

When is Deposition used?

Prior to the photolithography and etch processes, a solid, thin film of material is deposited on the wafer.

Common thin films:

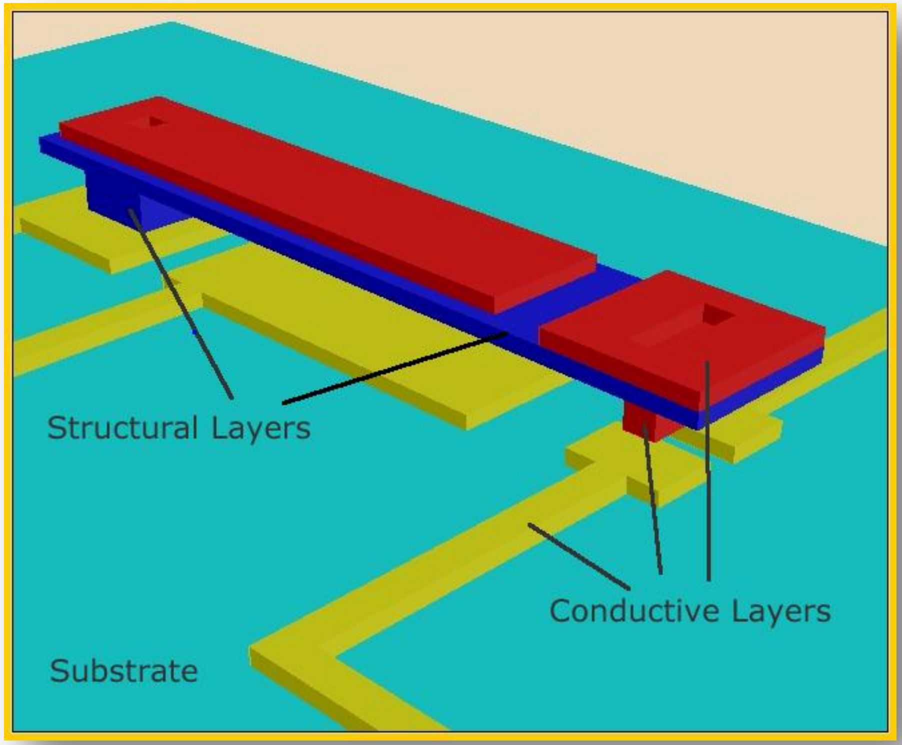
- polysilicon (poly)
- silicon dioxide (oxide)
- silicon nitride
- Metals (gold, copper, aluminum)



Thickness of deposited layers used in the SUMMIT™ Fabrication Process developed at Sandia National Laboratories (SNL). [Image courtesy of SNL]

What is the Purpose of a Deposited Layer?

- Structural layer
- Sacrificial layer
- Conductive layer
- Insulating layer
- Protective layer
- Etch stop layer
- Etch mask layer



Different Layers for building a MEMS
[Khalil Najafi, University of Michigan]

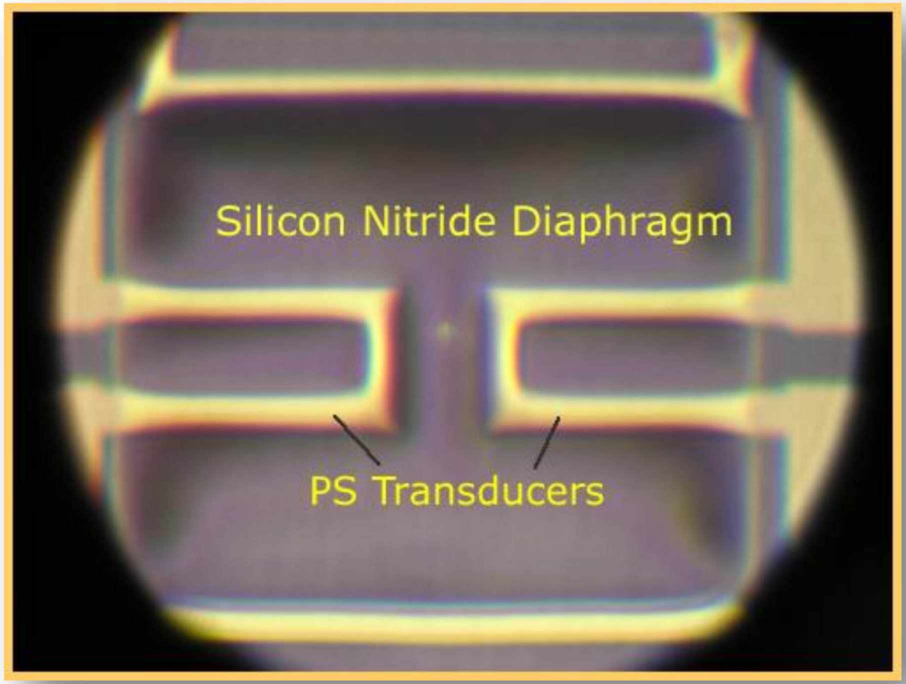
Type of Film vs. Application

Type of Thin Film	Applications
Silicon Dioxide	Sacrificial
	Masking
Polysilicon	Structural
	Piezoresistive
Silicon Nitride	Electrical Isolation
	Masking
Phosphosilicate Glass (PSG)	Structural anchor to substrate
	Sacrificial
Metals	Conductors
	Reflective
Spin-on Glass (SOG)	Final Layer
Zinc Oxide	Piezoelectric
	Sacrificial
Photoresist	Masking

Thin Films in Microsystems

Thin films are used for
- mechanical components
- electrical components
- sensor coatings

The figure shows a thin film of silicon nitride being used as the diaphragm for a MEMS pressure sensor.

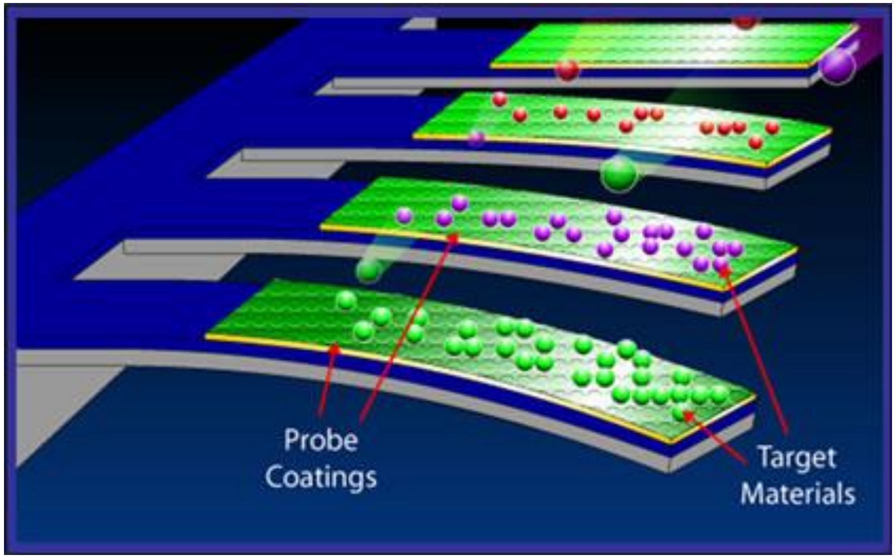


MEMS Pressure Sensor [University of New Mexico, MTTC]

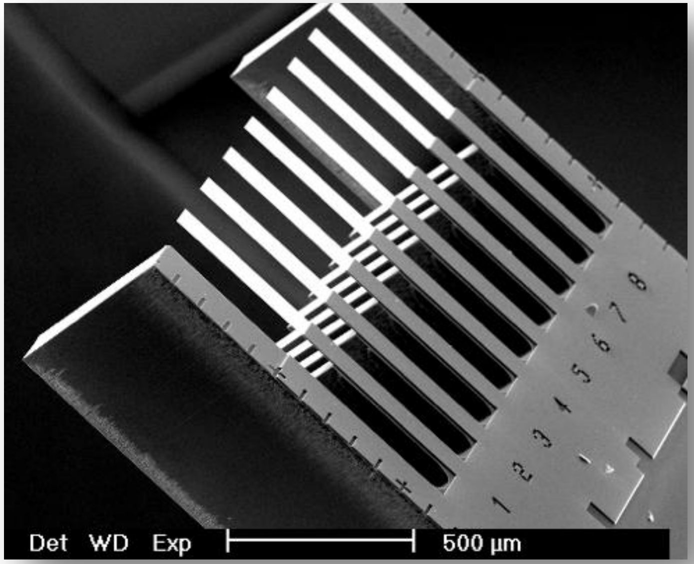
Thin Films in Microsystems

Thin films are used for

- mechanical components
- electrical components
- sensor coatings



The figure shows a cantilever sensor array used to detect target molecules such as specific gases or biomolecules.



Cantilever Array

[Image courtesy of Dr. Christoph Gerber, Institute of Physics, University of Basel]

Question - Poll

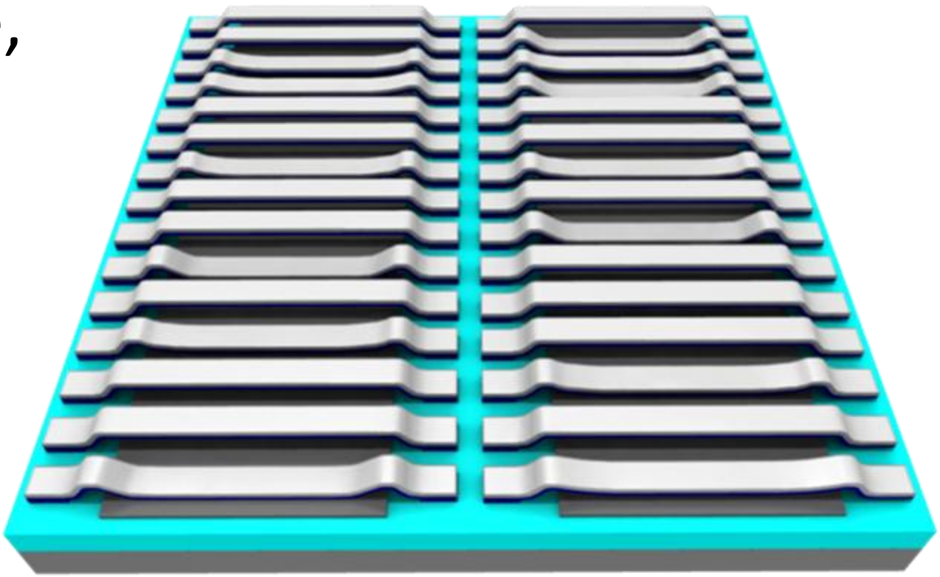
Based on what is shown here, how many thin film layers were required to construct this area?

A. 4

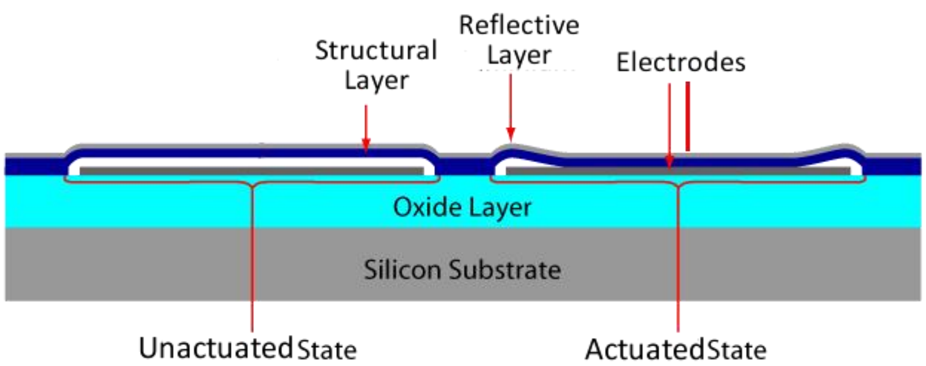
B. 5

C. 6

D. 7



Cross-section of GLV fabrication and actuation



Question - Poll

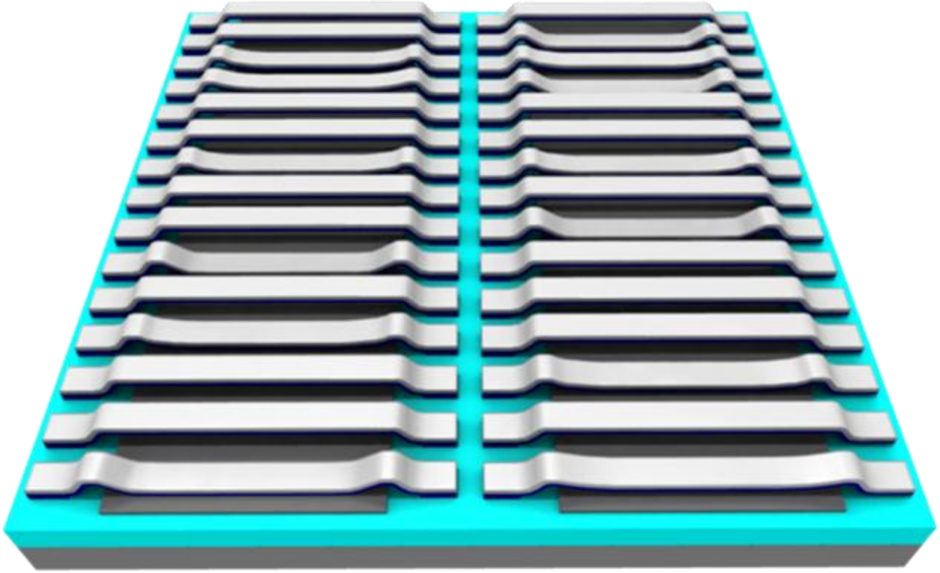
How many thin film layers required in this grating light valve as shown?

A. 4

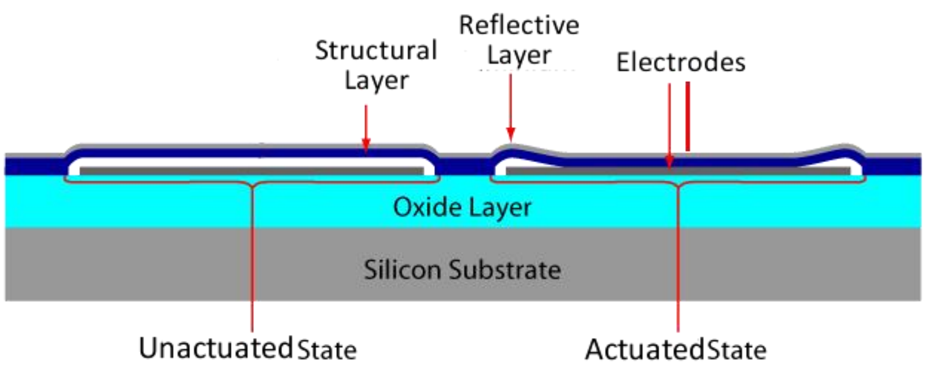
B. 5 (answer)

C. 6

D. 7

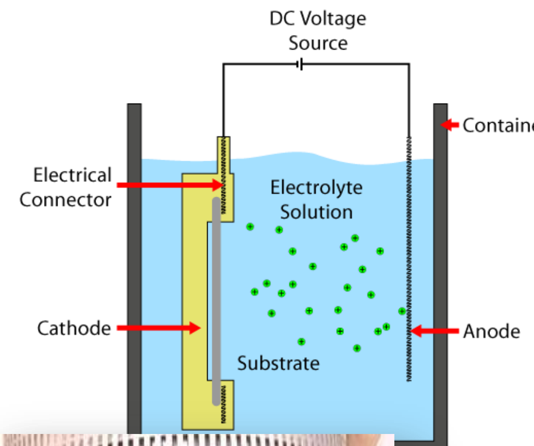


Cross-section of GLV fabrication and actuation



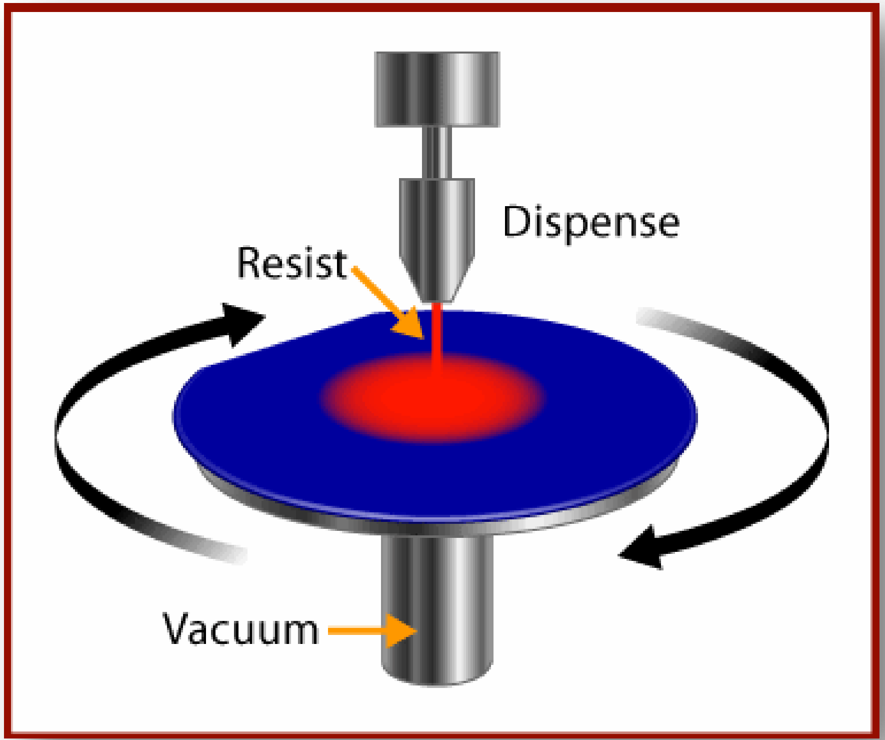
Types of Deposition

Thin films can have different thicknesses, purposes, and composition; so different deposition processes are required for different films.



Spin-on Films

- Spin-on deposition is the process of literally spinning a liquid onto the wafer surface.
- Spin-on deposition is primarily used for photoresist and spin-on glass (SOG).



Spin-on Photoresist

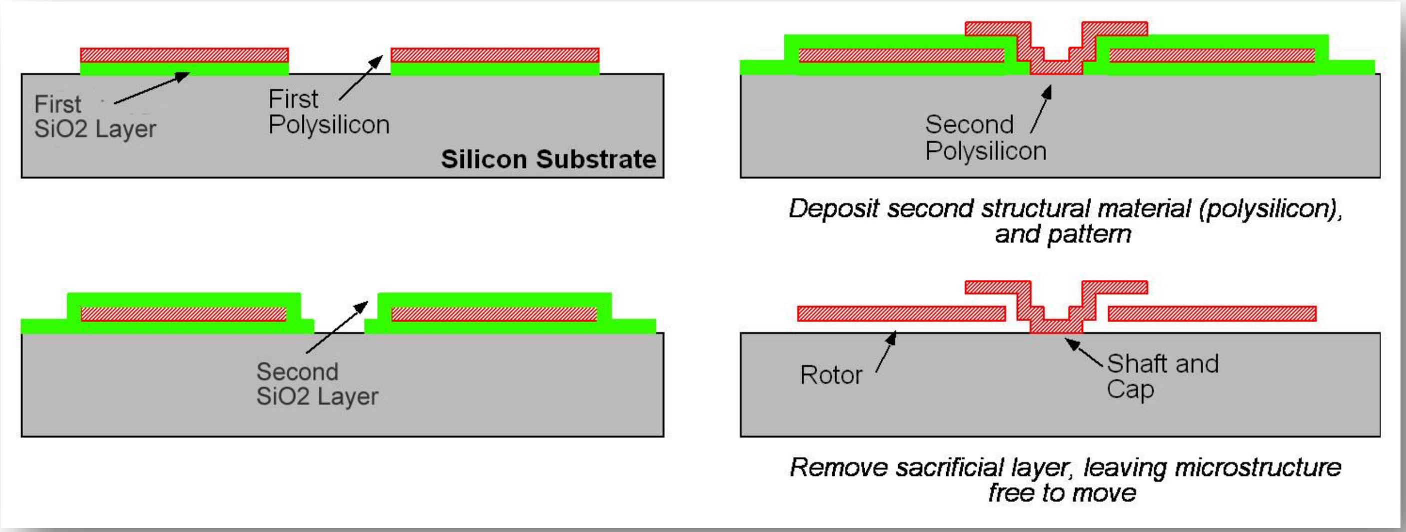
Thermal Oxidation

- Thermal oxidation is the process used to grow a uniform, high quality layer of silicon dioxide (SiO_2) on the surface of a silicon substrate.

- This SiO_2 layer literally grows **into** the silicon substrate consuming silicon.

- Other types of deposition "deposit" the layer on the substrate surface with little if any reaction with the surface molecules.

Silicon Dioxide



Silicon Dioxide as Sacrificial Layers

When exposed to oxygen, silicon oxidizes to form silicon dioxide (SiO_2). SiO_2 is used for a variety of purposes:

- Barrier material or hard mask
- Electrical isolation
- Device component
- Sacrificial layer or scaffold for microsystems devices.

Thermal Oxidation

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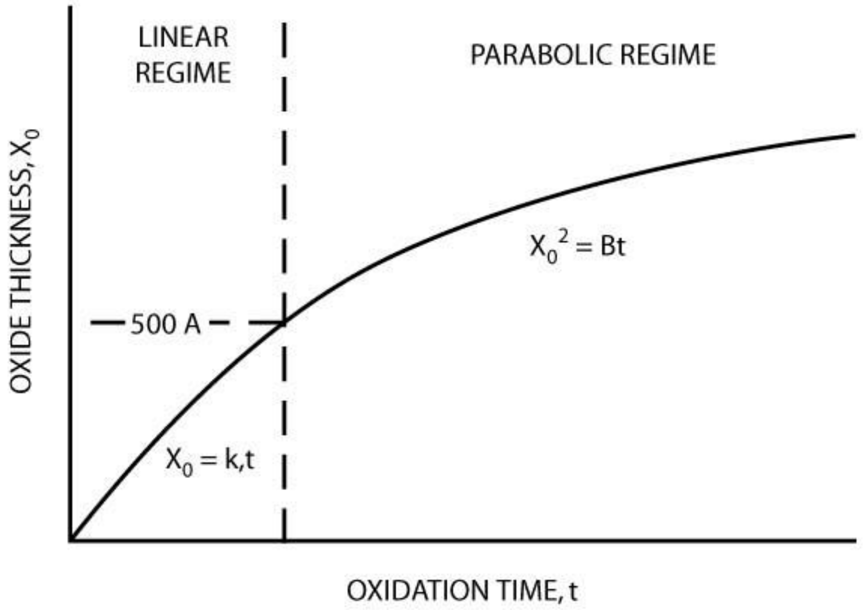
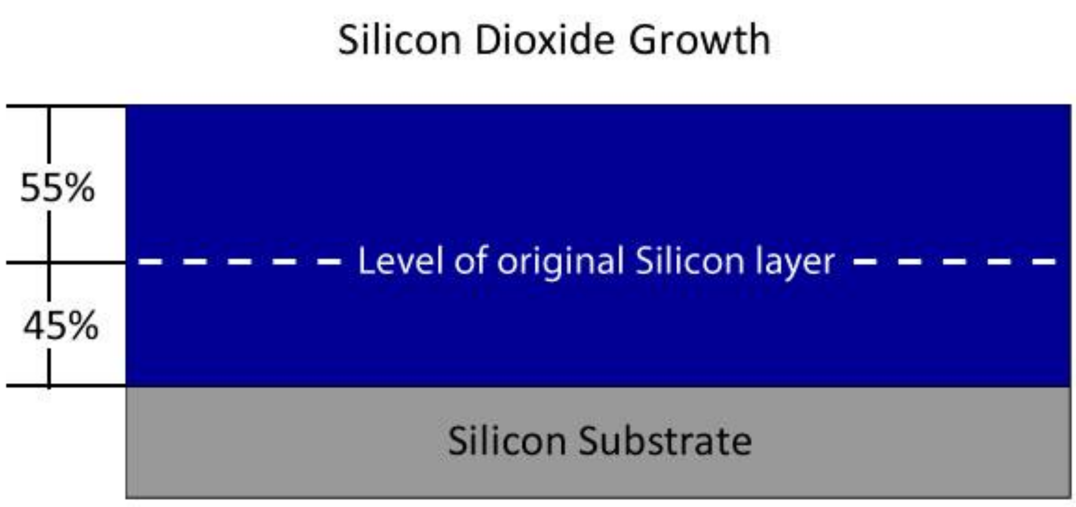
- This SiO_2 layer literally grows **into** the silicon substrate consuming silicon.

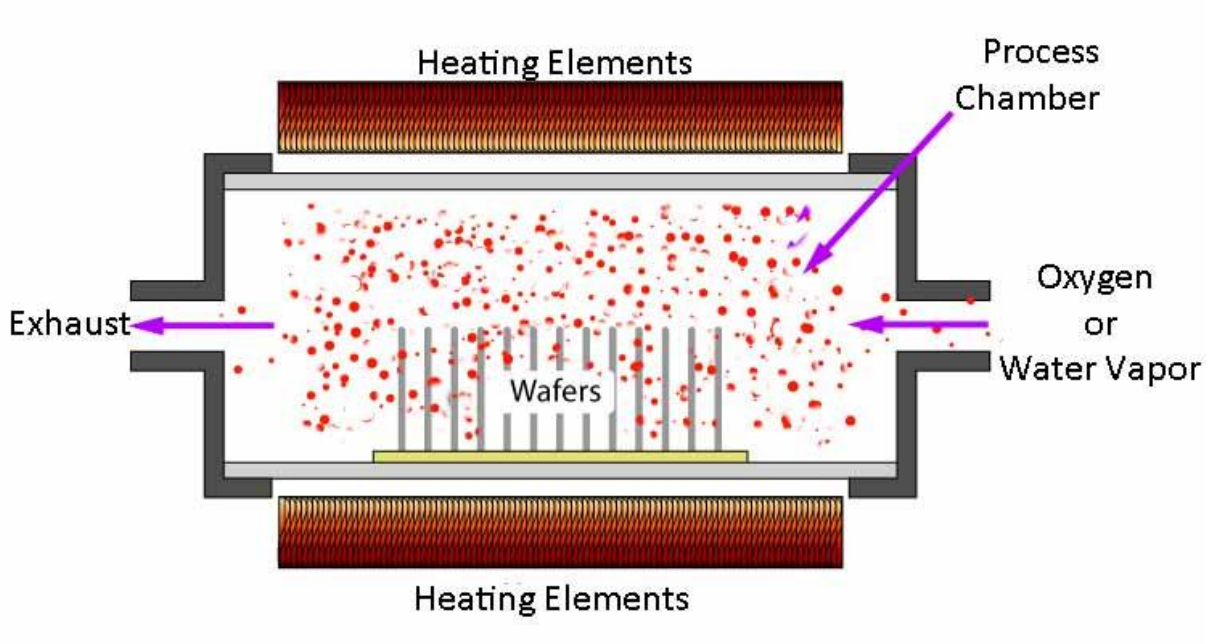




Thermal Oxidation Process

Three basic steps:

- Silicon wafers are placed in a heated vacuum chamber (typically 900 – 1200 degrees C).
- An oxygen source (gas or vapor) is pumped into the chamber.
- Oxygen molecules react with the silicon to grow silicon dioxide (SiO_2).



Dry Oxidation

In dry oxidation, dry oxygen is pumped into a heated process chamber.

The oxygen reacts with the silicon to form silicon dioxide.

$$Si\ (solid) + O_2\ (gas) \rightarrow SiO_2\ (solid)$$

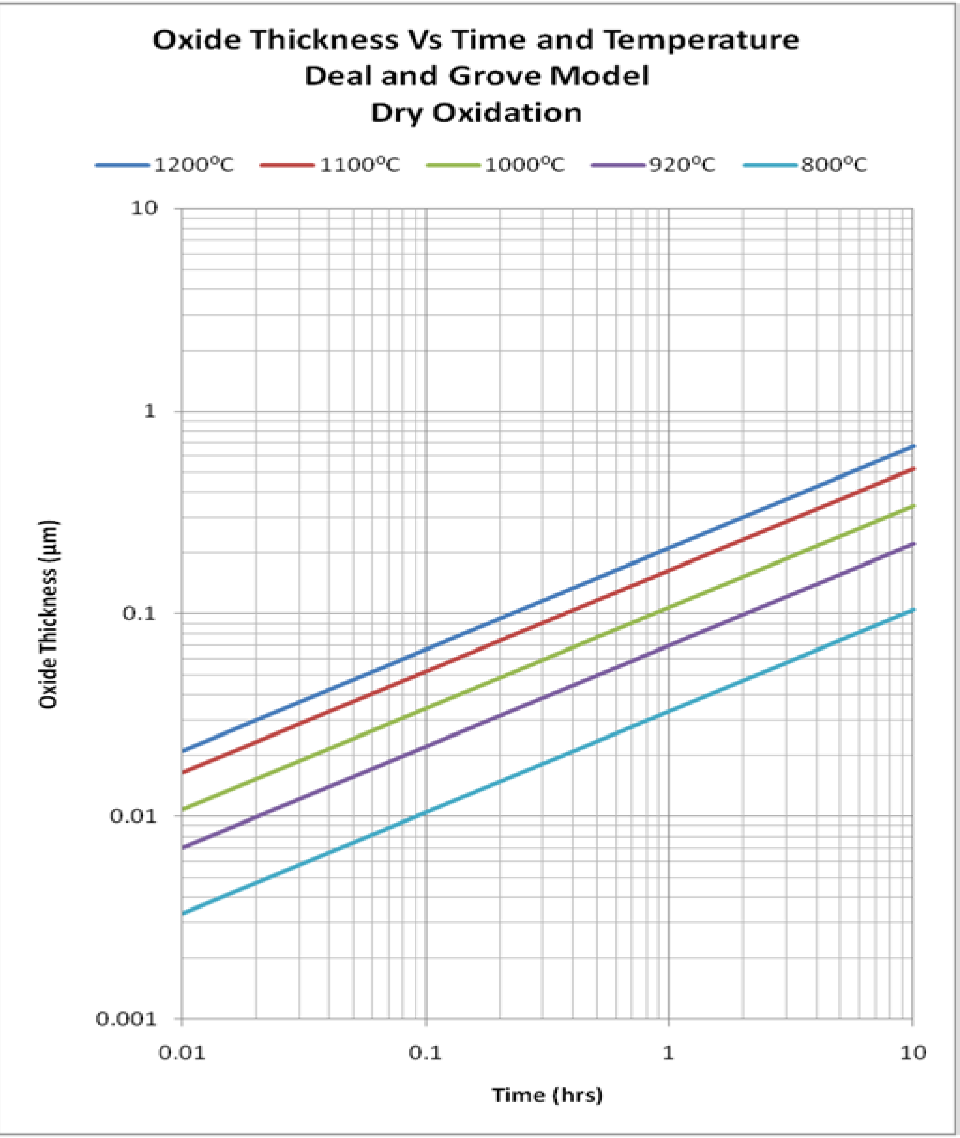
Wet Oxidation

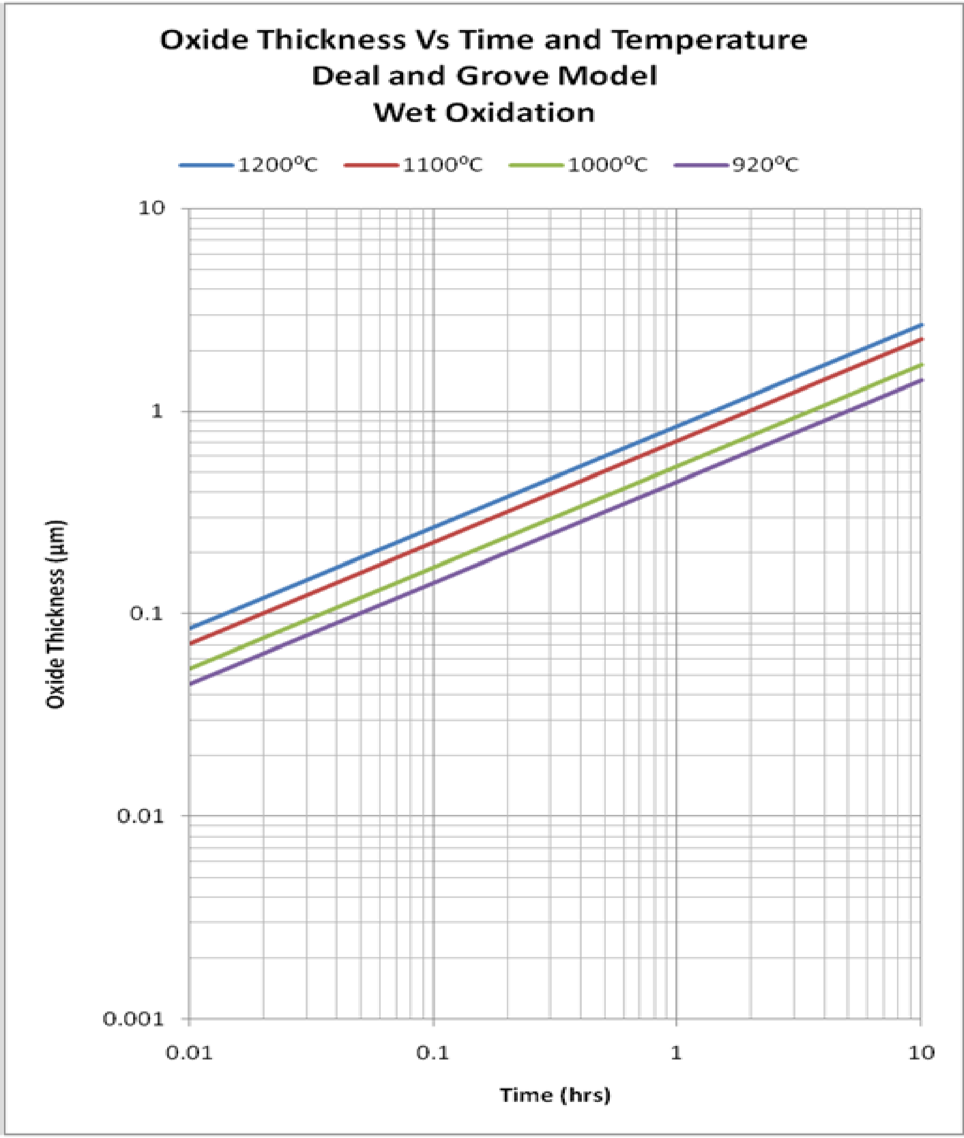
- Oxygen saturated with water vapor or steam is used in place of dry oxygen.

Si (solid) + 2H$_2$O (vapor) → SiO$_2$ (solid) + 2H$_2$ (gas)

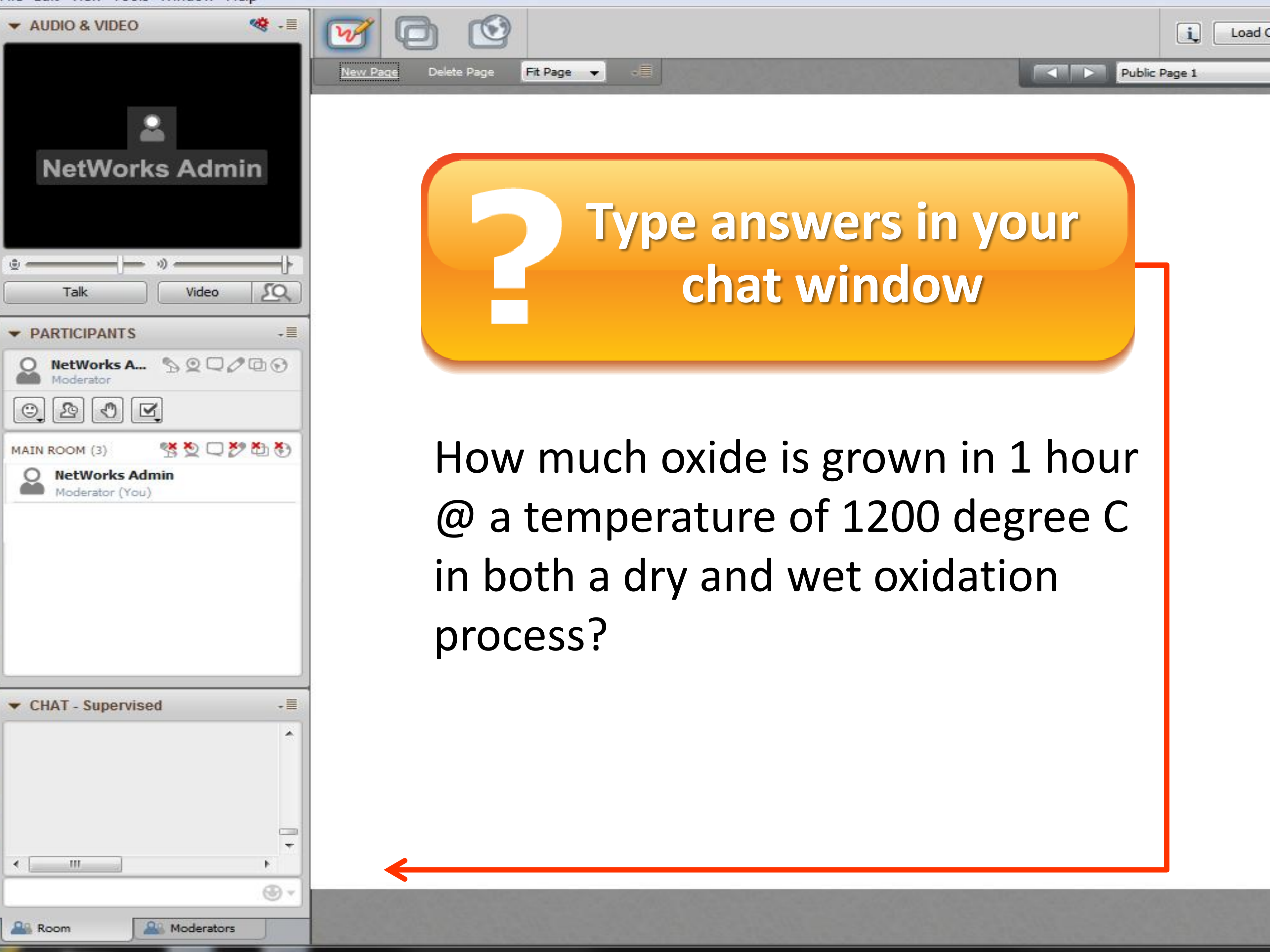
- H_2O is much more soluble in SiO_2 than O_2. This leads to higher oxidation rates.

Bubbler used to generate steam for wet oxidation process





[Graphs courtesy of University of Michigan]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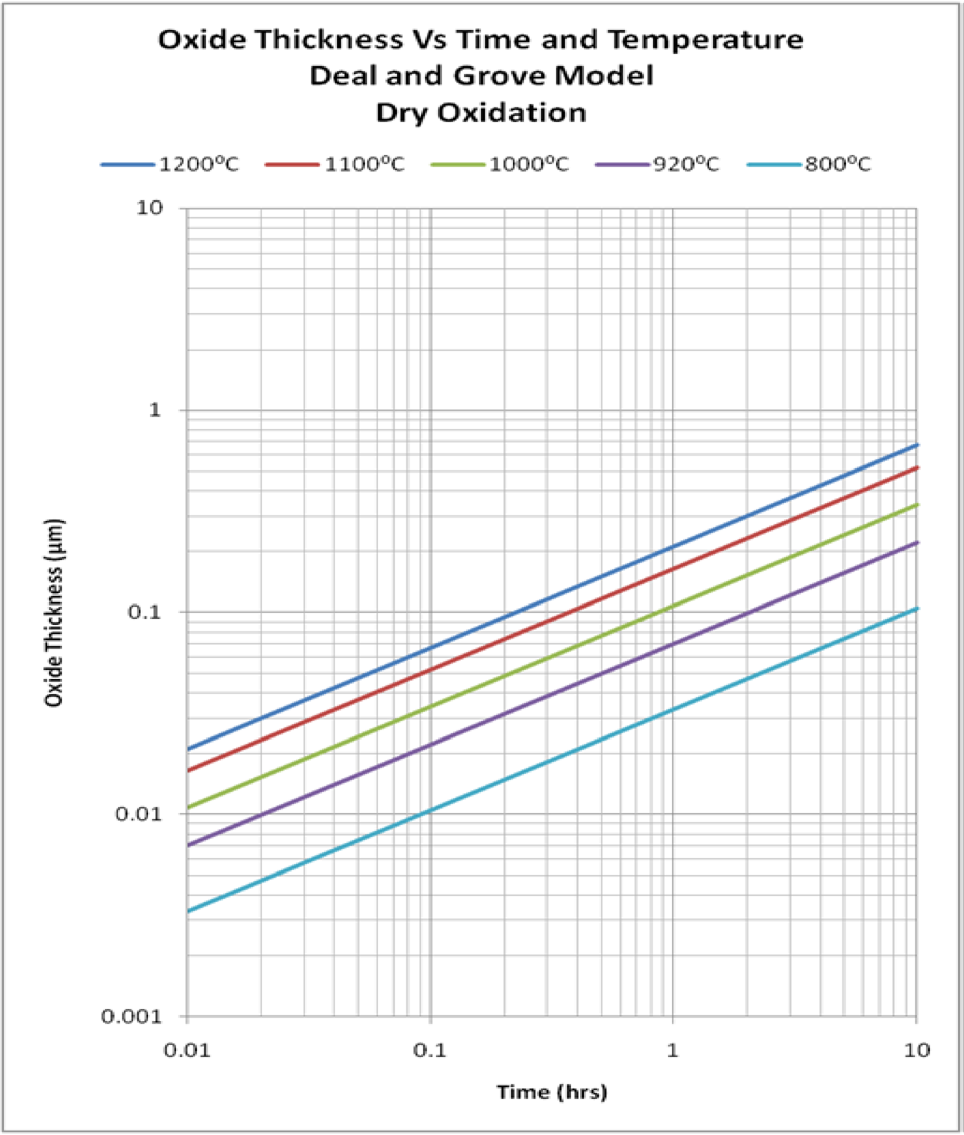
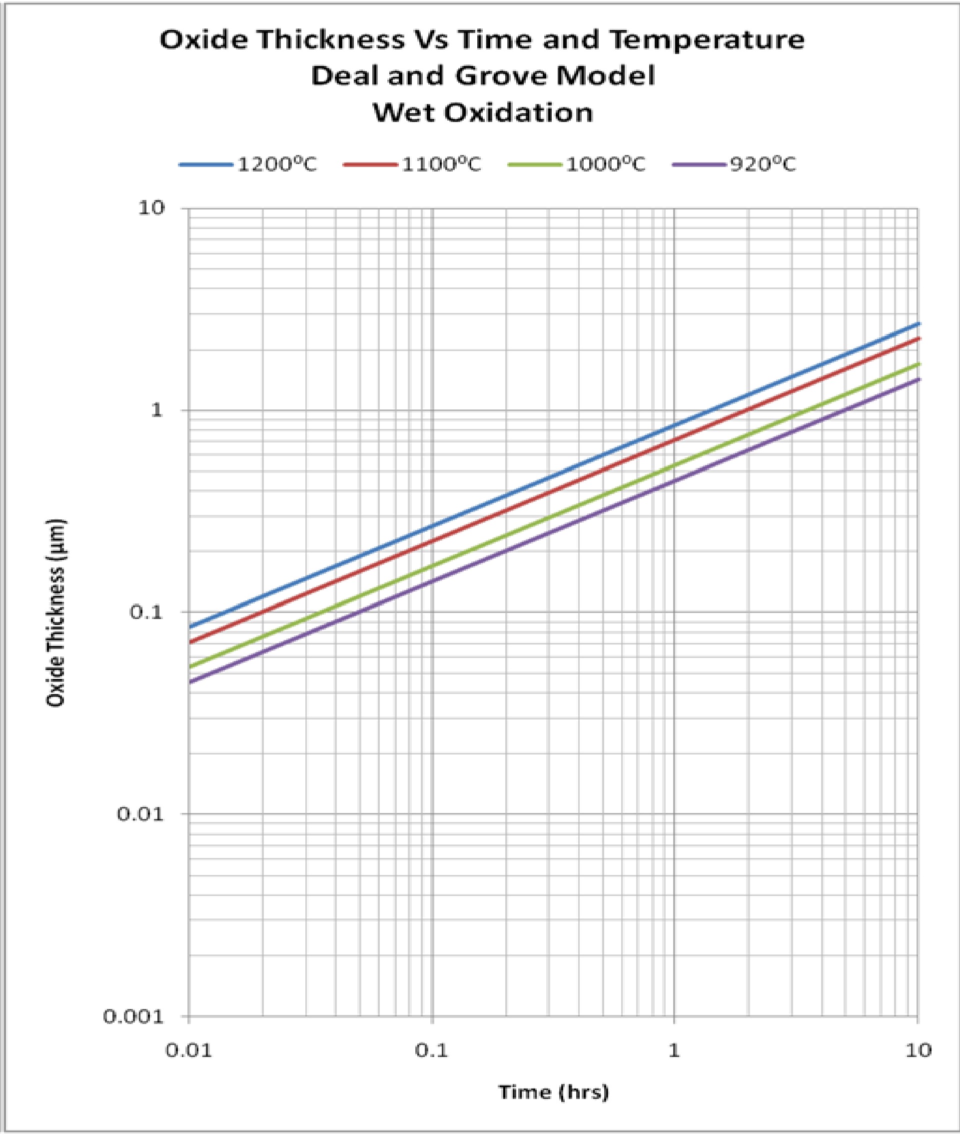
Type answers in your chat window
How much oxide is grown in 1 hour @ a temperature of 1200 degree C in both a dry and wet oxidation process?

How much oxide is grown in 1 hour @ a temperature of 1200 degree C in both a dry and wet oxidation process?

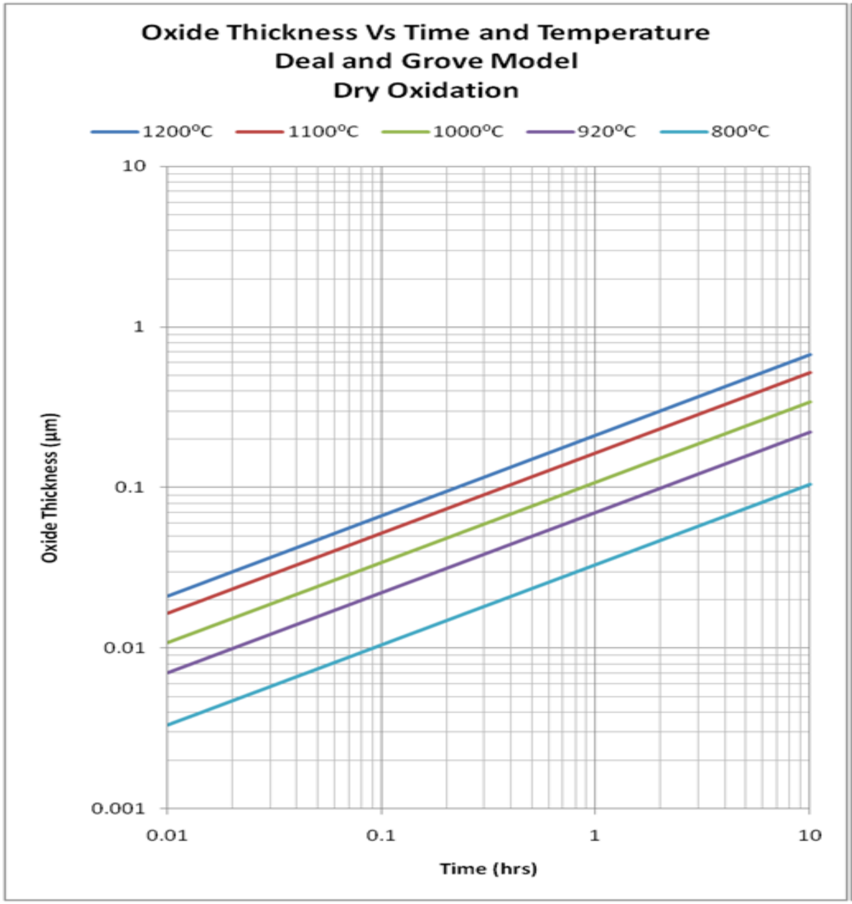


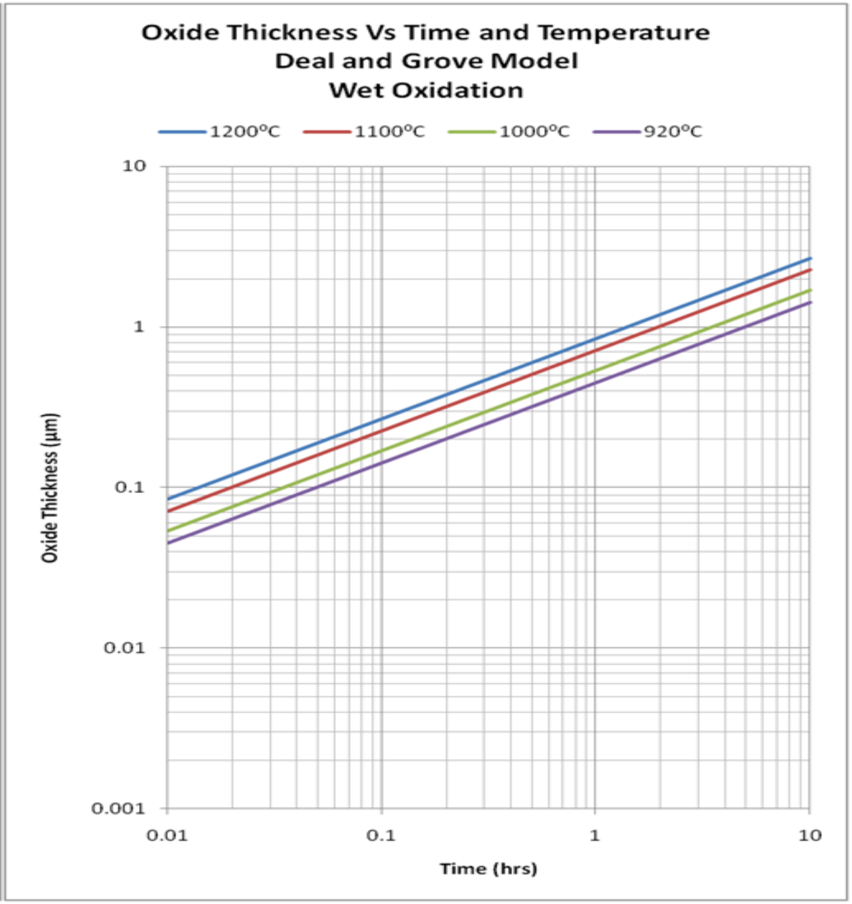


[Graphs courtesy of University of Michigan]

Wet vs. Dry Oxidation

If a device calls for an oxide thickness of 1 micrometer, which process would you use – wet or dry and why?

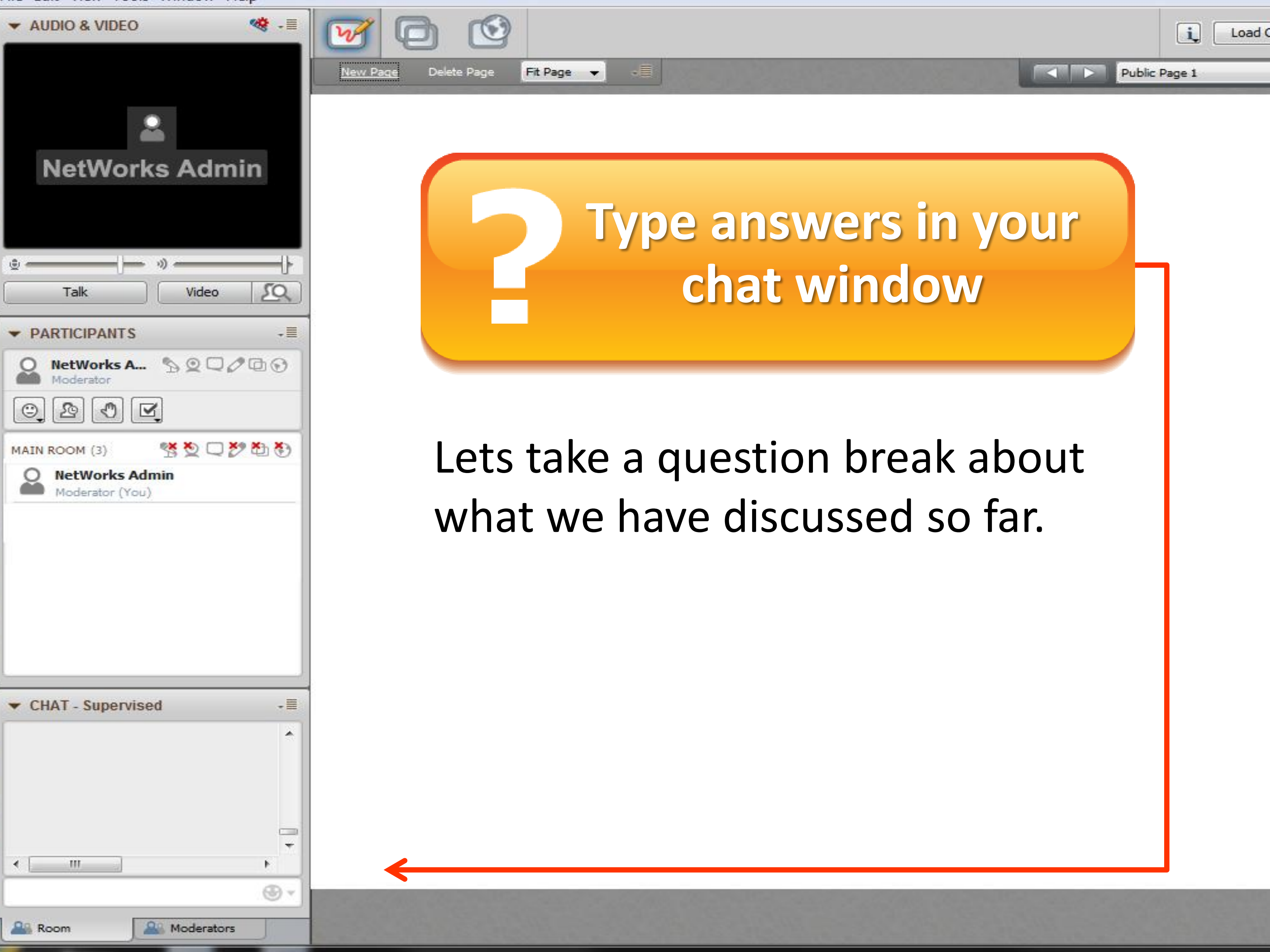




[Graphs courtesy of University of Michigan]

Wet vs. Dry Oxidation

- Both processes use heat to assist in the reaction rate.
- Wet oxidation is used in the manufacturing of microsystems to grow the thicker layers (in the micrometers) at a faster rate than is possible with dry oxidation (faster deposition).
- Dry oxidation is used for thin layers (in the nanometers). Dry oxidation allows better control over the growth of thin oxides.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Moderator (You)
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Moderators
New Page
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Fit Page
Public Page 1
Type answers in your chat window
Lets take a question break about what we have discussed so far.

Chemical Vapor Deposition (CVD)

- Most widely used deposition method.
- Deposits silicon nitride, polysilicon, zinc oxide, silicon dioxide
- Films deposited during CVD are a result of the chemical reaction
  - between the reactive gas(es) and
  - between the reactive gases and the atoms of the substrate surface.
- A silicon dioxide reaction between silane gas and oxygen

$$SiH_4 + O_2 \rightarrow SiO_2 + 2\ H_2$$

CVD Reactions

Two types of reactions can occur during the CVD process:

- Homogeneous (gas phase)
- Heterogeneous (surface phase)

The rate at which a reaction occurs in either phase affects the deposition rate and quality of the deposited layer.

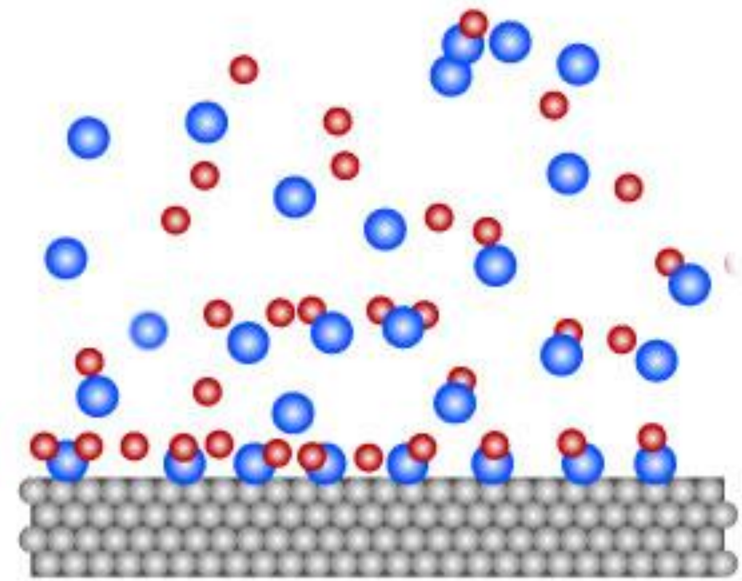
Both phases are greatly affected by temperature. The higher the temperature the greater the reaction rate.

Homogeneous Reactions

Homogeneous reactions occur before the gas molecules reach the wafer surface.

Because homogeneous reactions consume the gas reactants before reaching the substrate, the reaction rate at the surface is reduced.

The result is a low-density and normally, a poorer quality film.



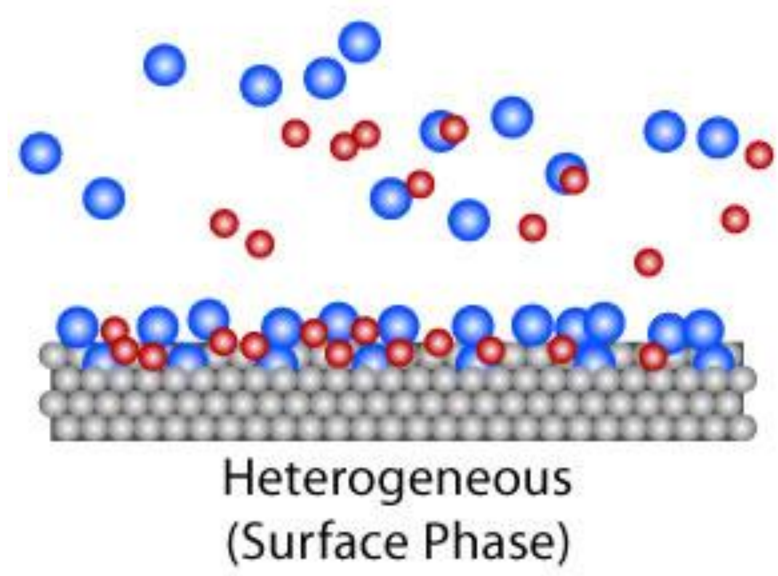
Homogeneous Reaction

Heterogeneous Reactions

Heterogeneous reactions occur on or near the substrate surface.

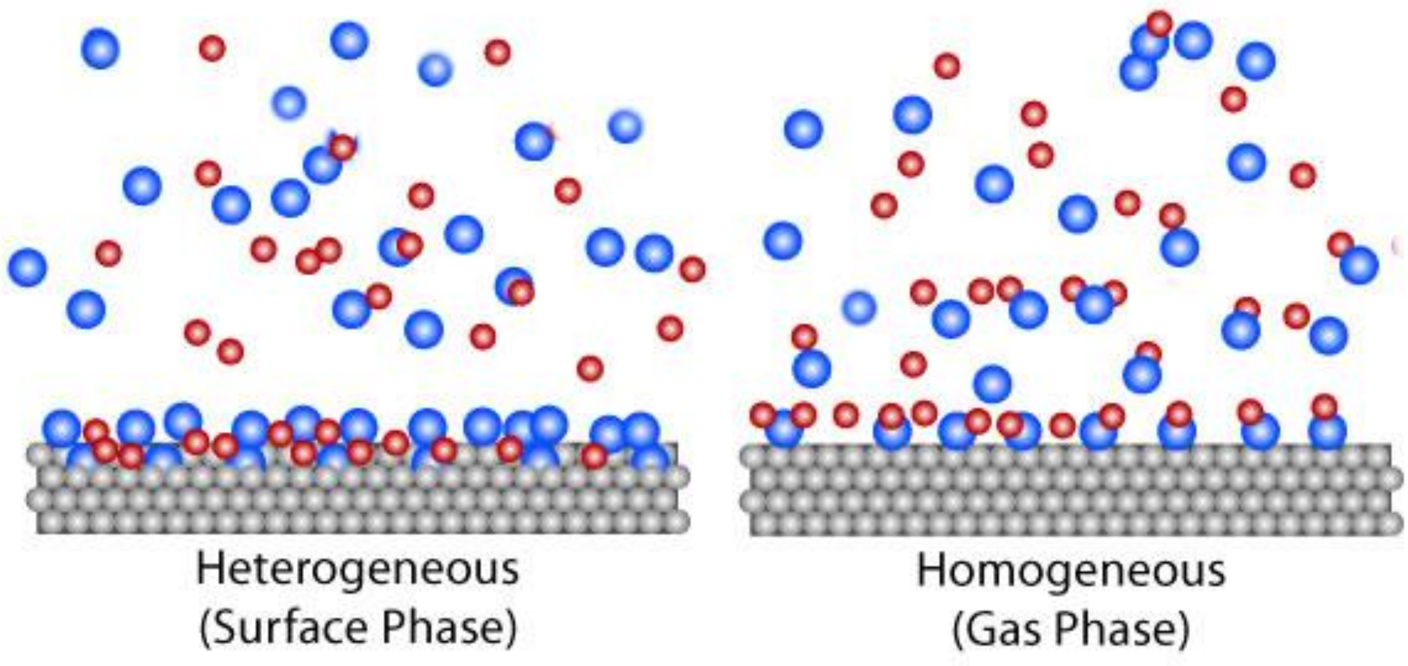
These reactions occur as the reactant gasses reach the heated substrate.

Heterogeneous reactions produce good quality films because of the proximity of the reaction to the wafer's surface.



Heterogeneous Reaction

Heterogeneous or Homogeneous?

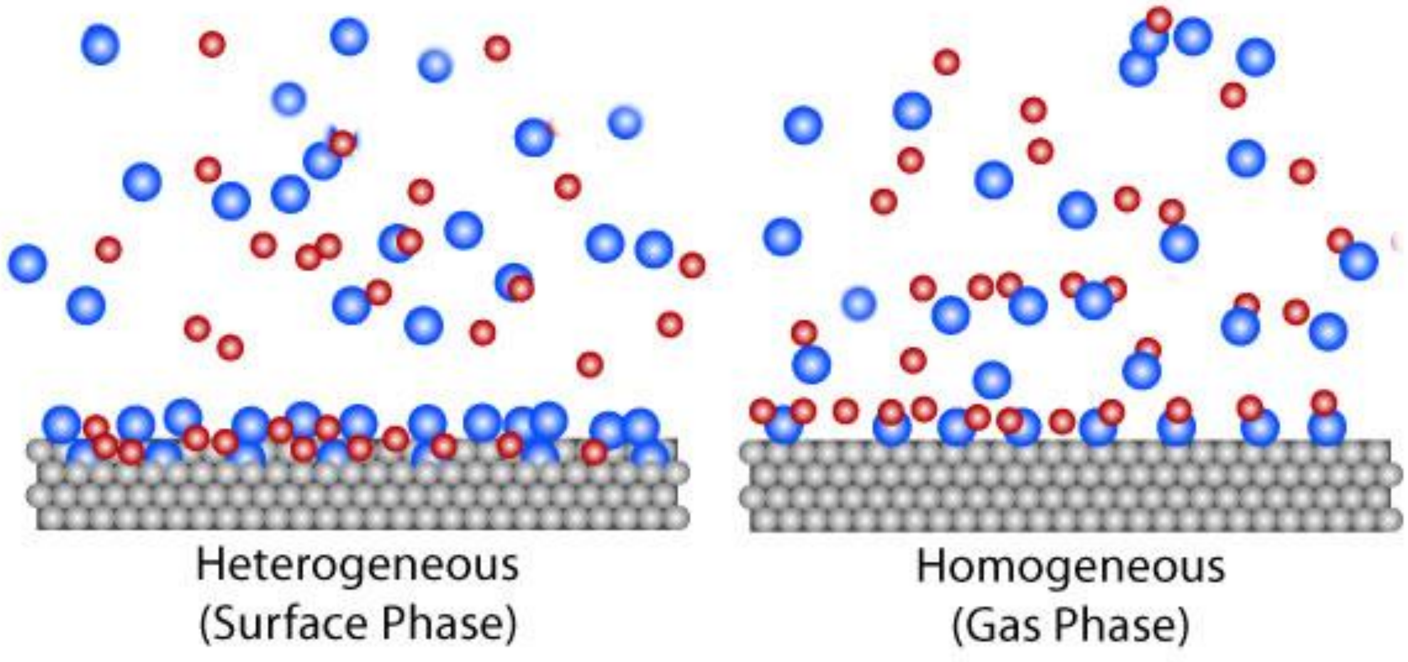


Heterogeneous or Homogeneous?

Which do you think is the preferred method for microsystems?

Why?

Heterogeneous or Homogeneous?



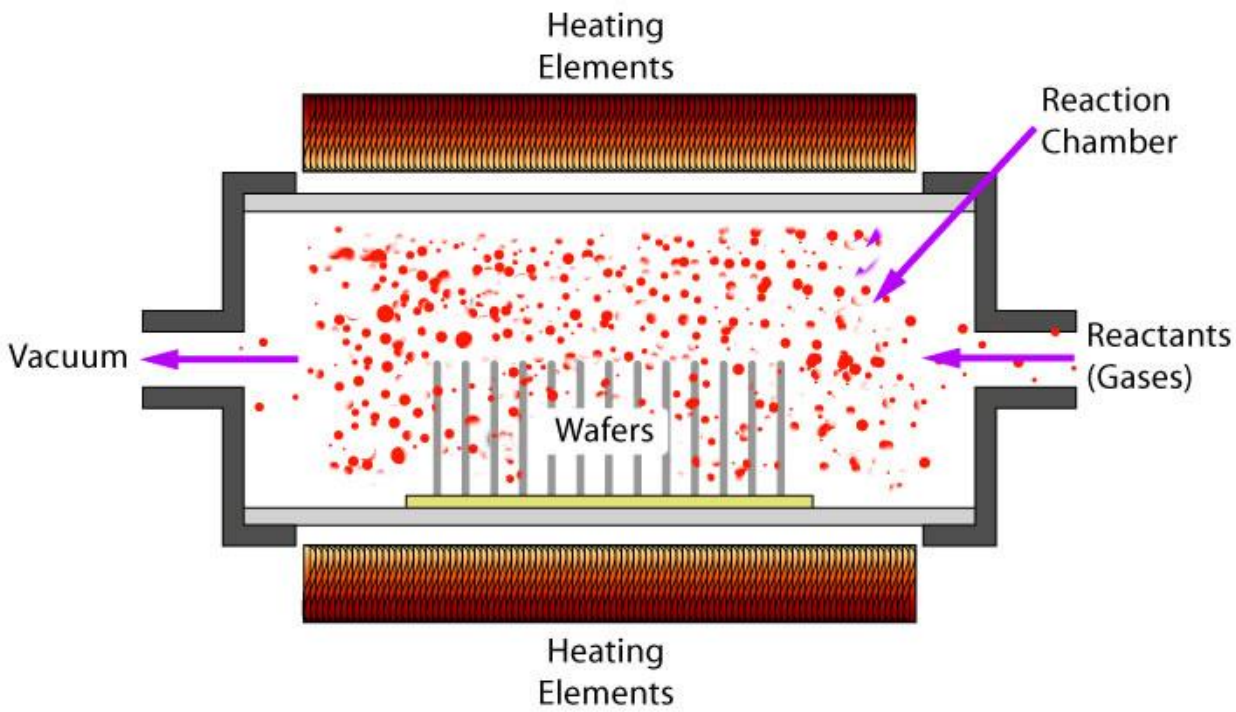
Heterogeneous or Homogeneous?

Which do you think if the preferred method for microsystems?

heterogeneous

Why? Higher quality films

CVD Subsystems

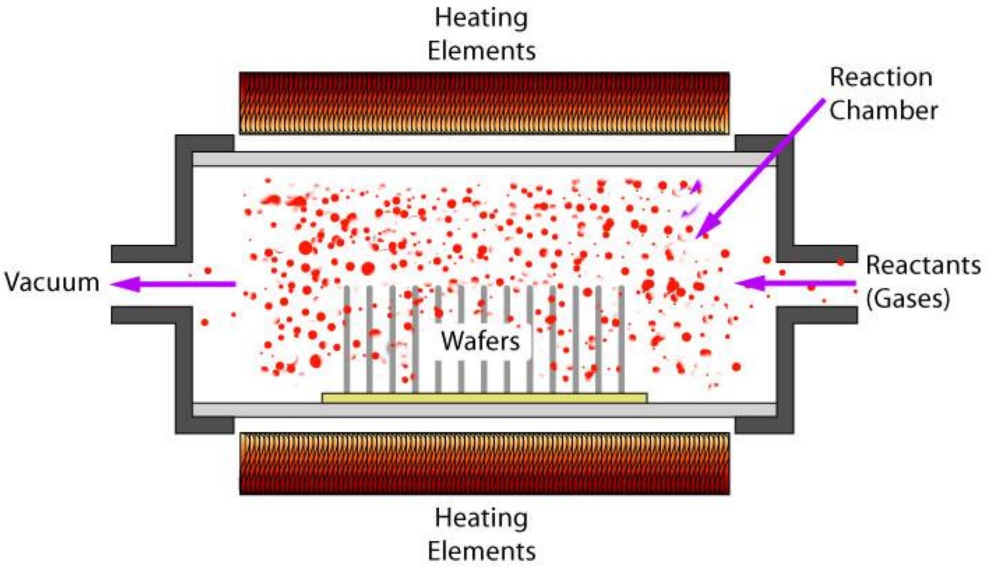


CVD system with gas delivery, gas removal (vacuum), and heat source

All CVD systems consist of the following three subsystems:

- gas delivery to the chamber
- gas removal from the chamber (vacuum system or exhaust)
- a heat source

CVD Process Steps



- Substrate is placed inside reactor
- Chamber pressure is set to process pressure
- Heat is applied (to substrate or entire chamber)
- Select (reactants) gases are introduced
- Gas molecules chemically react with each other or with the substrate forming a solid thin film on the wafer surface.
- Gaseous by-products produced by the chemical reaction are removed from the chamber.

CVD Systems

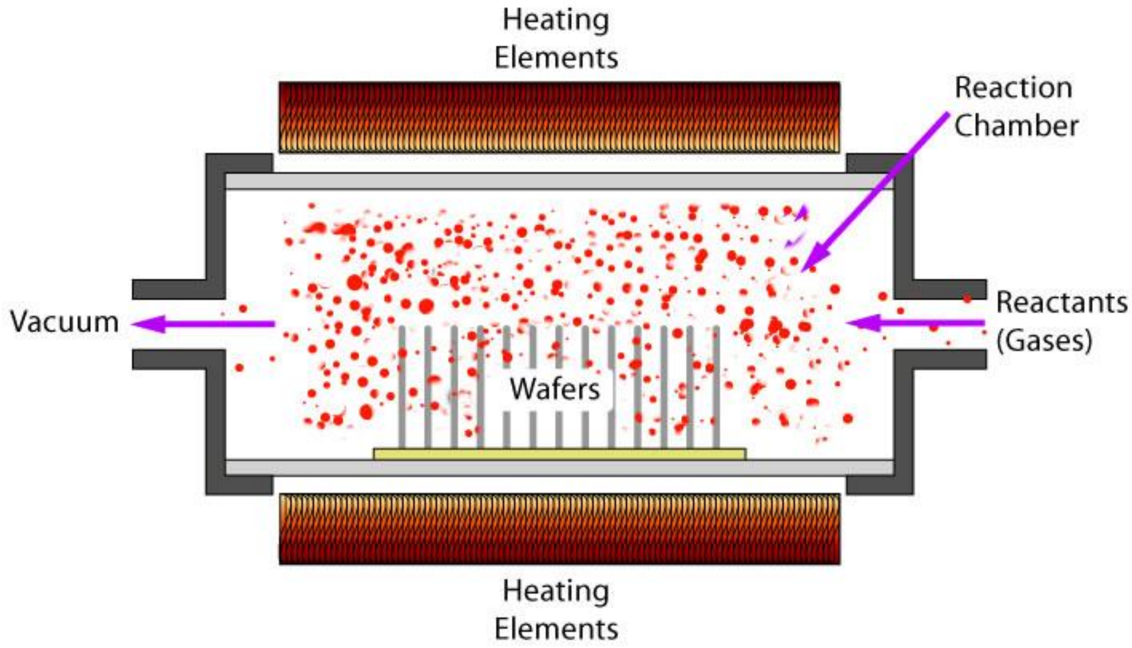
Four types of CVD systems:

- Atmospheric Pressure CVD (APCVD)
- Low Pressure CVD (LPCVD)
- Plasma-Enhanced CVD (PECVD)
- High Density PECVD

LPCVD and PECVD are commonly used for microsystems fabrication.

PECVD *[Imagine courtesy of MTTC – UNM]*

Low Pressure CVD (LPCVD)

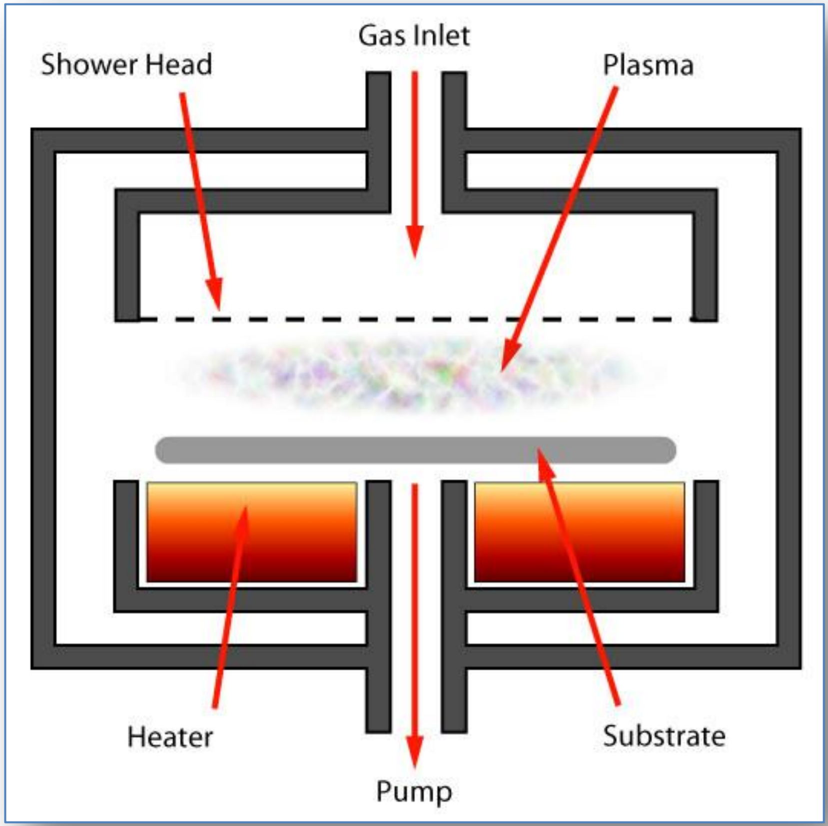


LPCVD uses a vacuum to reduce the pressure inside the reaction chamber to a pressure less than 1 atm.

LPCVD is used for 2-sided films (same film on both sides of wafer) and for phosphosilicate glass (PSG), polysilicon, phosphorus-doped polysilicon, and silicon nitride.

Plasma Enhanced CVD (PECVD)

- PECVD also uses low pressure chambers.
- A plasma provides higher deposition rates at lower temperatures than a LPCVD system.
- PECVD is used for films or wafers that contain layers of film that cannot withstand the high temperatures of the LPCVD systems.



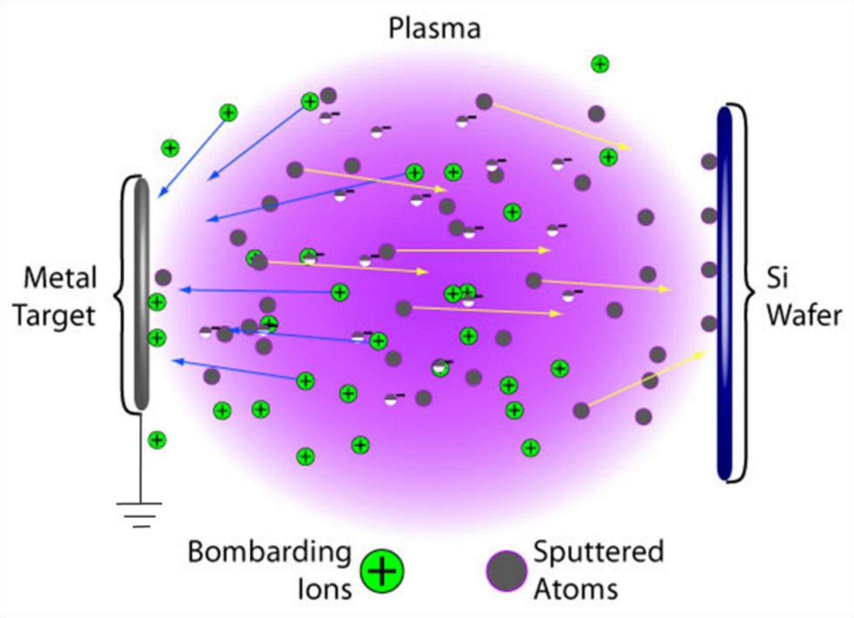
PECVD System

Physical Vapor Deposition (PVD)

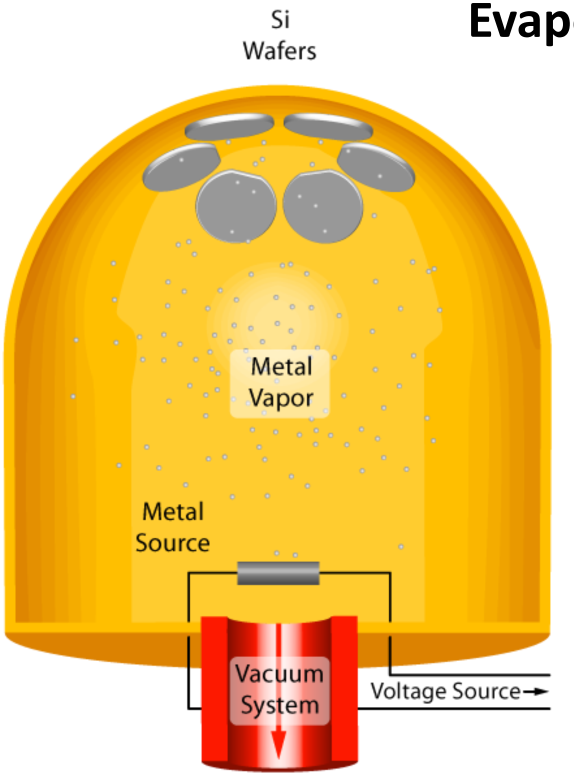
PVD includes deposition processes in which the desired film material is released from a source as a vapor and physically deposited onto the substrate.

No chemical reaction occurs.

Sputtering



Evaporation



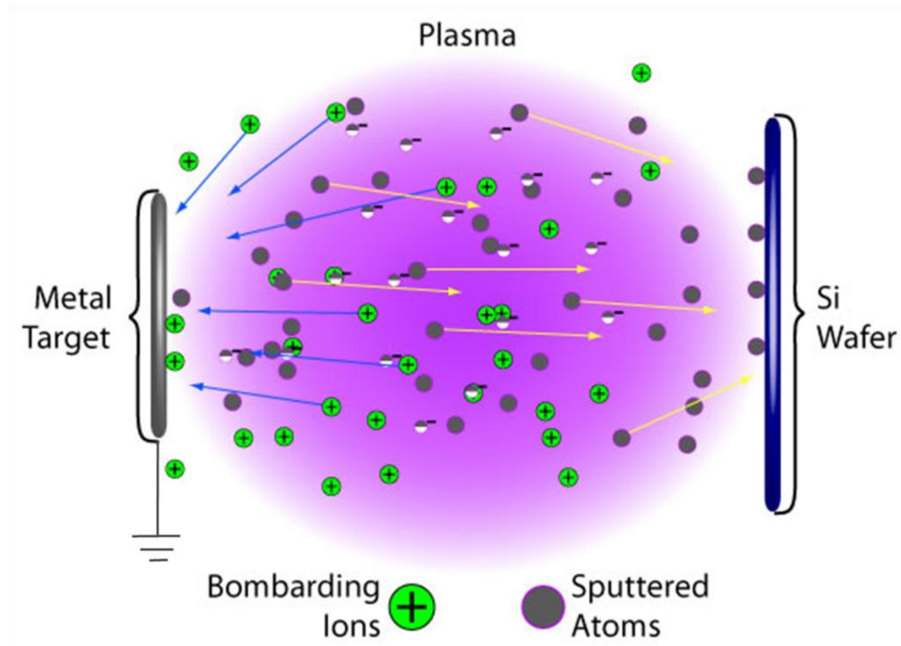
PVD Basic Process

There are three basic steps to a PVD process:

- The material to be deposited (the source) is converted into a vapor of source molecules and atoms.
- The vapor travels across a low pressure region from the source to the substrate.
- The vapor condenses on the substrate to form the desired thin film.

Sputtering Process

- Substrate and film material (target) placed in the chamber
- Chamber evacuated
- An inert gas (such as argon) introduced
- Plasma generated
- Gases ionize and ions accelerate toward the target
- Ions bombard target
- Target atoms and molecules break off target material and enter plasma



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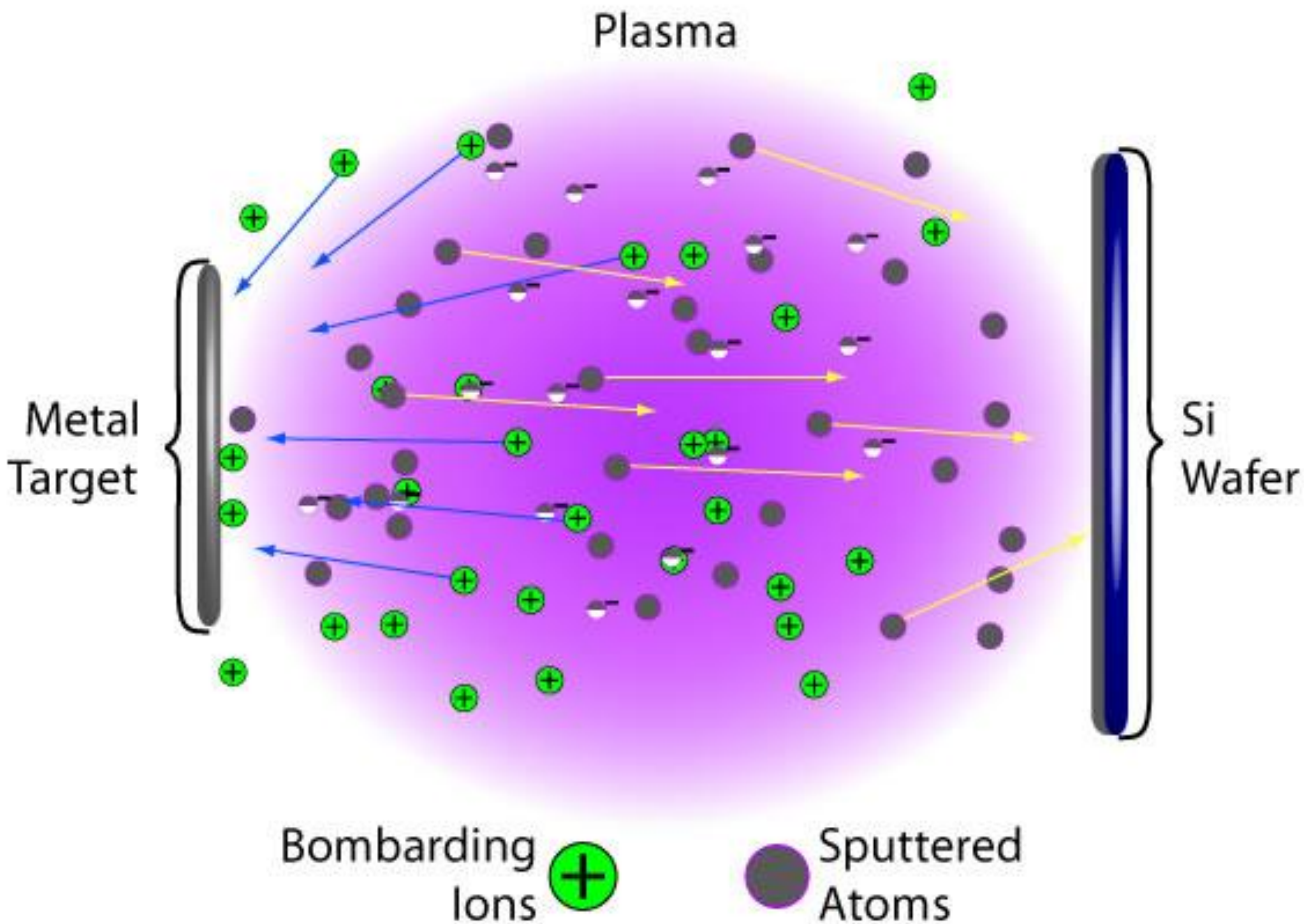
Sputtering Process



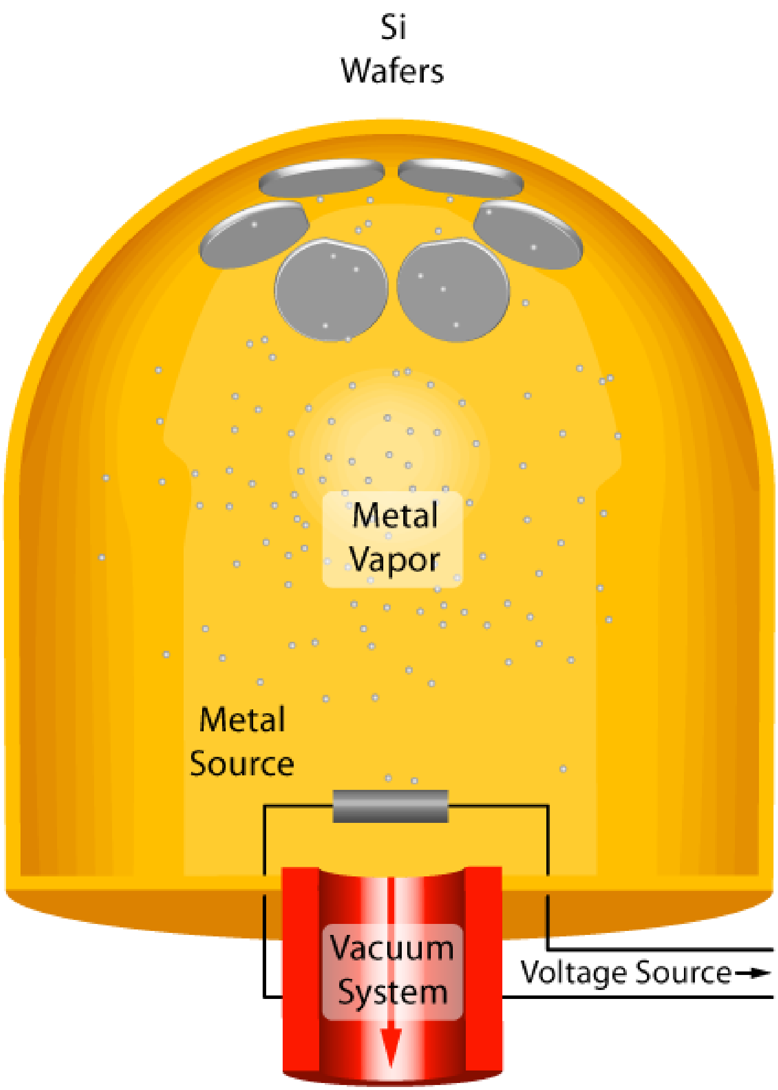
Evaporation

- Source material is heated to its boiling point, at which point it vaporizes
- A high-vacuum environment minimizes collisions as vapor expands
- At the substrate the vapor condenses forming the desired thin film

Single planetary for Evaporator. Evaporator can hold several planetary units.

Evaporation Process

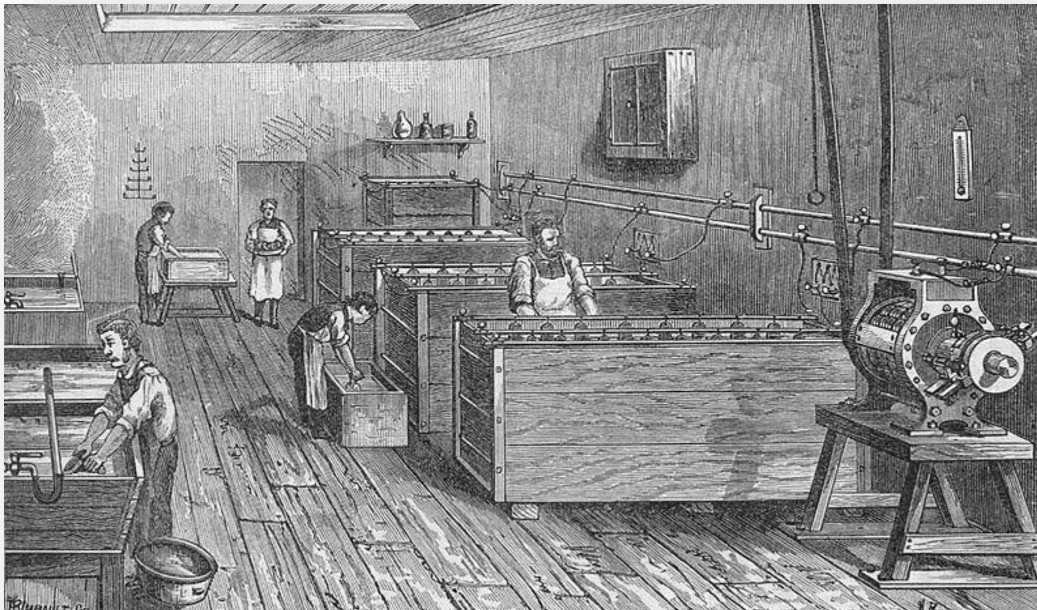
- Substrates and source material are placed inside a vacuum chamber.
- Chamber is evacuated to process pressure.
- Source material is heated to its vaporization temperature.
- Source molecules and atoms travel to the substrates. Vacuum allows travel with minimal collisions.
- Molecules and atoms condense on all surfaces including the substrates.



Evaporation Heat Sources

- e-beam evaporation or resistive evaporation
- In e-beam evaporation an electron beam is aimed at the source material causing local heating and evaporation.
- In resistive evaporation, a tungsten boat containing the source material is heated electrically with high current causing the material to boil and evaporate.

Electrodeposition (Electroplating)

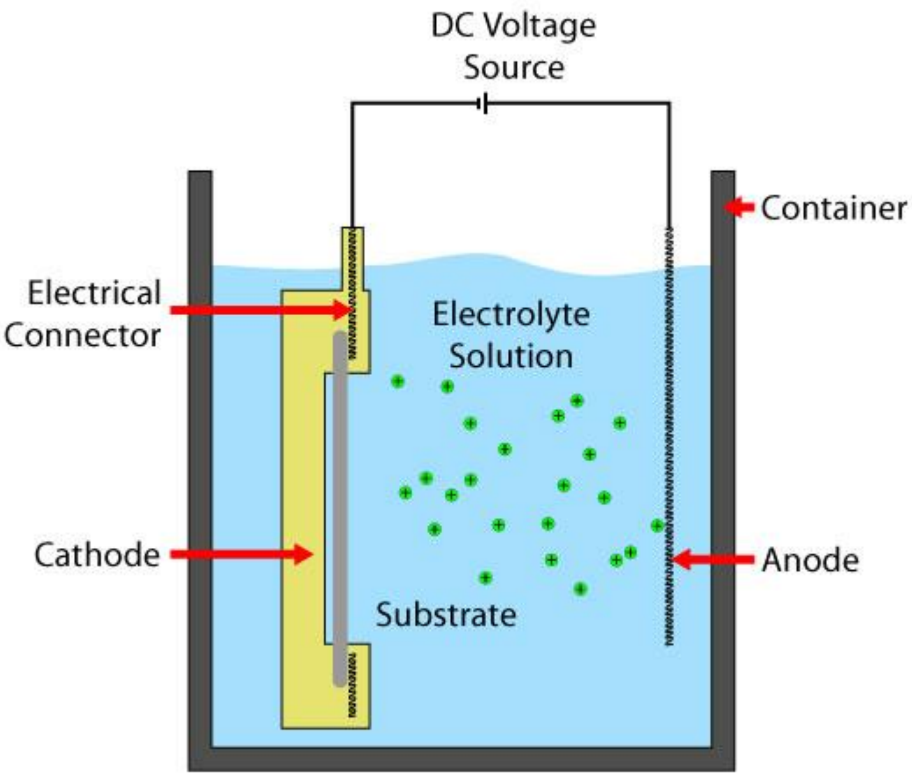


- Uses electrical current to coat an electrically conductive object with a relatively thin layer of metal (~1μm to >100μm).
- Used for thousands of everyday objects such as faucets, inexpensive jewelry, and various automobile parts.
- For microsystems, used to deposit films of metals such as copper, gold and nickel.

Electroplating Components

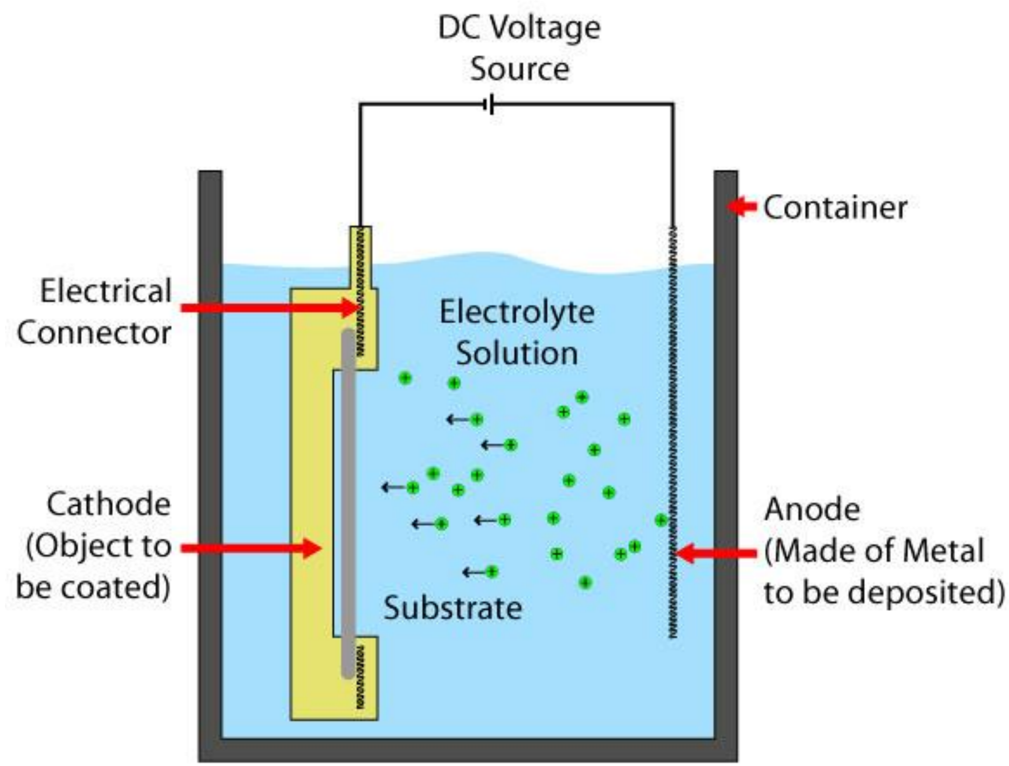
Electroplating is a simple process using very few materials:

- Container
- Electrolyte Solution
- DC power source
- Anode (Desired metal coating)
- Cathode (Object to be coated)
- Cathode holder with electrical connector



Electroplating Process

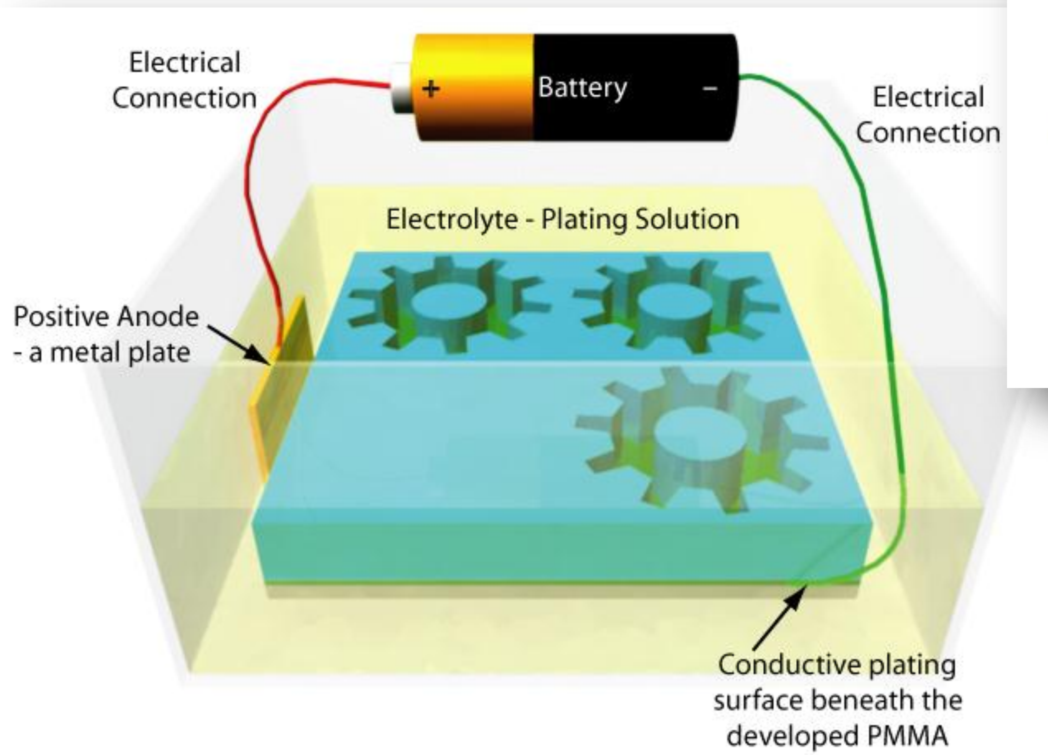
- Substrate is immersed into electrolyte.
- DC power source –
  - Negative to the cathode.
  - Positive side to anode.
- Metallic ions in electrolyte are positively charged and attracted to the cathode.
- At the cathode, ions are neutralized into metallic form.
- Ions are replenished by ions from the anode.

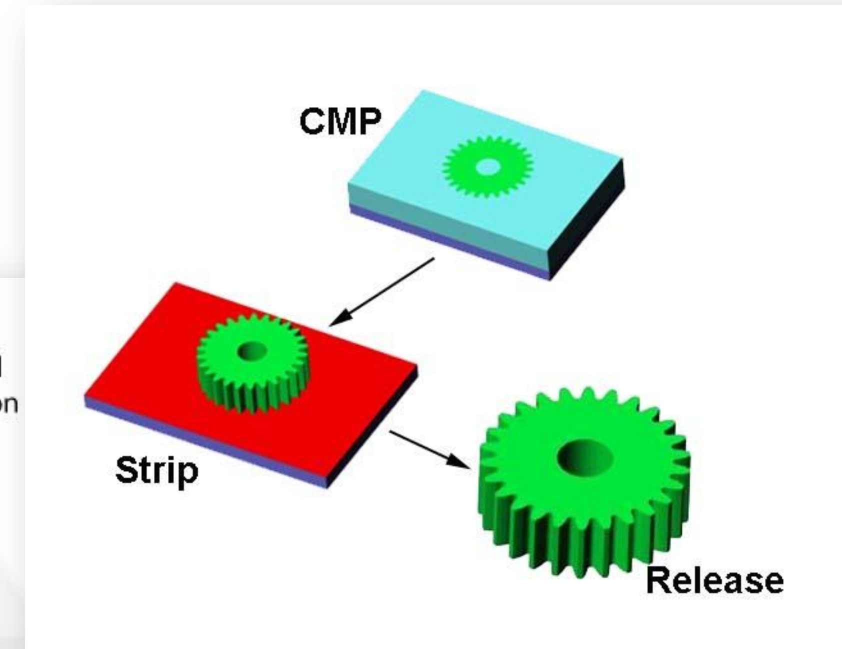


Electroplating Process

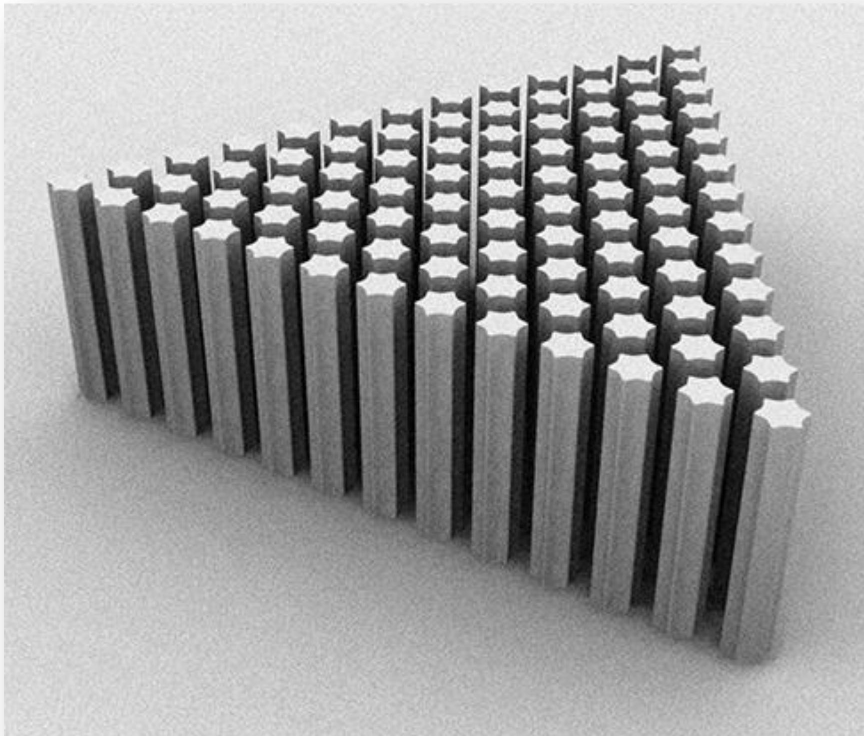
Electrodeposition (Electroforming)

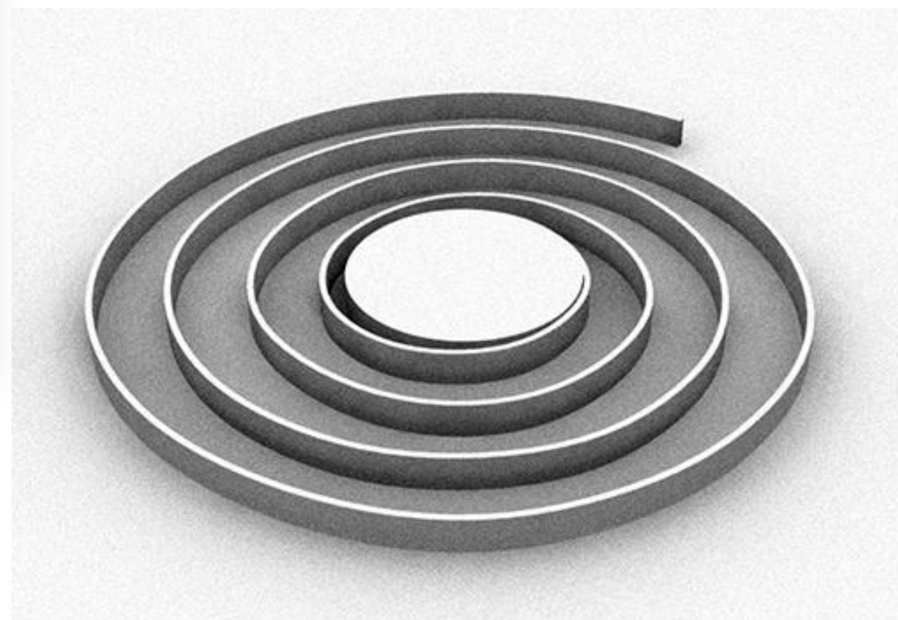
- LIGA (lithography, electroforming and molding)

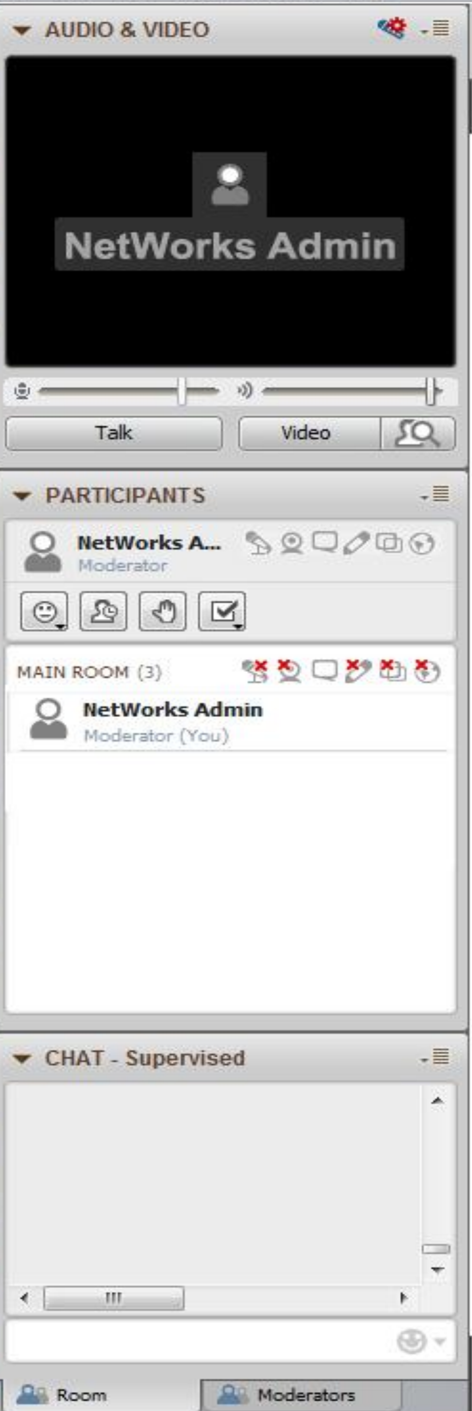




LIGA Examples







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? Type answers in your chat window

You see deposited films everyday of your life even though you may not realize it.

What are some examples of deposited films outside of microsystems or semiconductor processing?

Match Process to Characteristic

Deposition Process	Characteristic
Evaporation	Requires an electrically conductive Cathode
Dry Thermal Oxidation	Is used to deposit silicon nitride and poly
Electrodeposition	Uses resistive heating of the source material
Spin-on Deposition	Grows oxide using oxygen gas
CVD	Used to deposit photoresist

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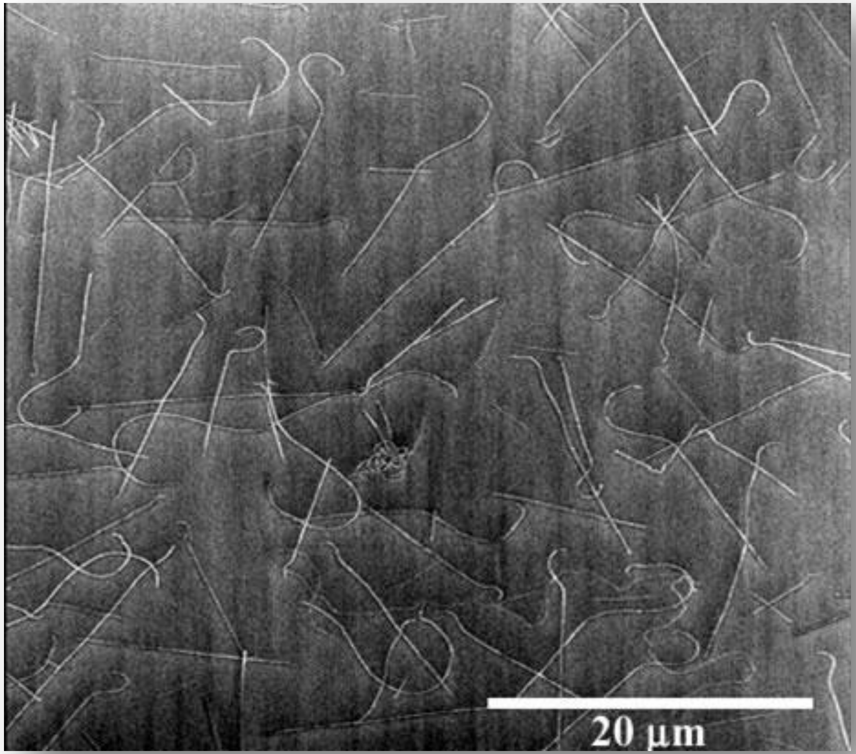
Deposition and Nanotechnology

Nanotechnology creates new applications for deposition.

Chemical vapor deposition is used for the self-assembly of carbon nanotubes (CNTs), structures that might be used as

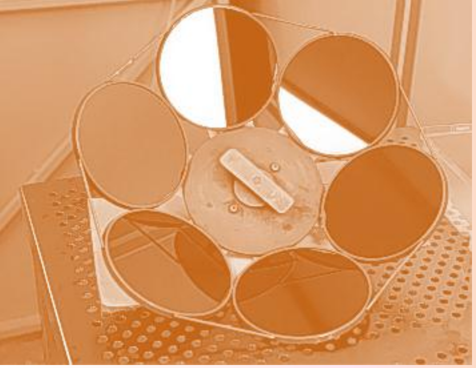
- nanowires in integrated circuits,
- tips for scanning-probe microscopy, and
- in conducting films.



Carbon nanotubes (or hooktubes) grown by the CVD process on a silicon dioxide covered silicon chip. The thin white lines are the nanotubes.
[Courtesy of Michael S. Fuhrer, University of Maryland]

SUMMARY

- Deposition is any process that deposits a thin film of material onto a substrate.
- Thin film thickness can range from greater than 100 micrometers to only a few nanometers.
- Microsystems technology uses various types of deposition processes.
- The type of process used depends on the thin film being deposited, its application, and the desired thickness.



Thank You For Joining Us

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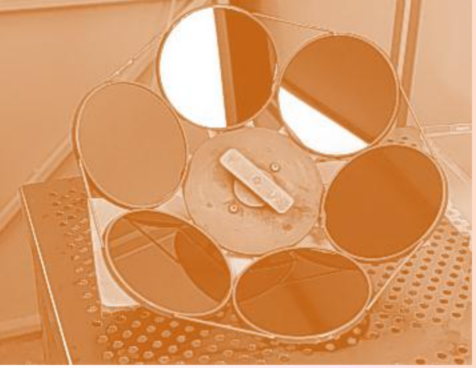
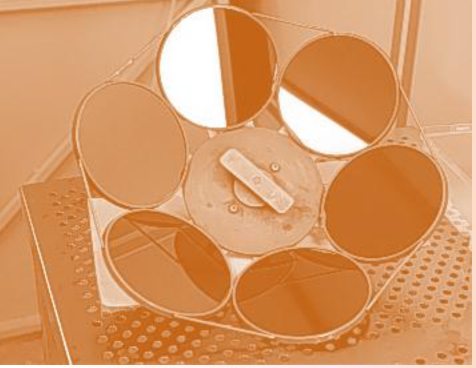


How Can We Serve You Better?

Please take 1 minute to provide your feedback and suggestions

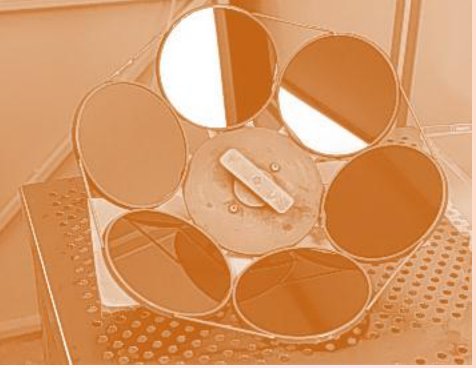
https://www.research.net/s/Z98GZXR



Webinar Resources

To access this webinar recording, slides, and handout, please visit

www.scme-nm.org



SCME Upcoming Webinars

November 1, 2012: Microsystems Processes Part II – Photolithography and Etch

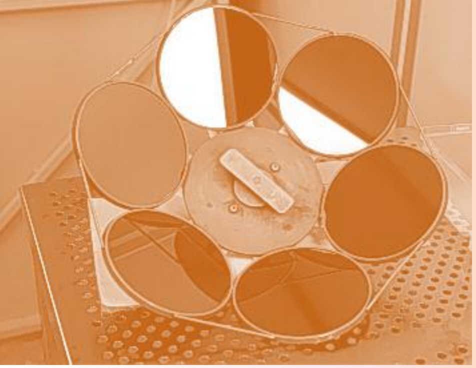
November 29, 2012: Problem Solving for Technicians

January 24, 2013: Statistical Process Control for Technicians

February 28, 2013: Design of Experiments for Technicians

TBA: Problem-solving Tools Applied to Microfabrication

All Webinars on Thursday @ 1 PM ET



It was Fun!

Thank you for attending this SCME Webinar

Microsystems Processes Part I

Deposition