Διάλεξη 2

ΘΕΜΑΤΑ ΜΙΚΡΟΗΛΕΚΤΡΟΝΙΚΗΣ

ΟΜΑΔΑ ΜΙΚΡΟΗΛΕΚΤΡΟΝΙΚΗΣ
ΙΝΣΤΙΤΟΥΤΟ ΗΛΕΚΤΡΟΝΙΚΗΣ ΔΟΜΗΣ & ΛΕΙΖΕΡ
ΙΔΡΥΜΑ ΤΕΧΝΟΛΟΓΙΑΣ & ΕΡΕΥΝΑΣ

- ΤΙ ΕΙΝΑΙ ΜΙΚΡΟΗΛΕΚΤΡΟΝΙΚΗ
- ΕΡΓΑΣΤΗΡΙΑΚΟΣ ΧΩΡΟΣ
- ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

TI EINAI ΜΙΚΡΟΗΛΕΚΤΡΟΝΙΚΗ

yotta,	(Y),	meaning 10^{24}
zetta,	(Z),	meaning 10^{21}
exa,	(E),	meaning 10^{18}
peta,	(P),	meaning 10^{15}
tera,	(T),	meaning 10^{12}
giga,	(G),	meaning 10^{9}
mega,	(M),	meaning 10^{6}
kilo,	(k),	meaning 10^{3}
hecto,	(h),	meaning 10^{2}
deka,	(da),	meaning 10^{1}

deci,	(d),	meaning 10^{-1}
centi,	(c),	meaning 10^{-2}
milli,	(m),	meaning 10^{-3}
micro,	(u),	meaning 10^{-6}
nano,	(n),	meaning 10^{-9}
pico,	(p),	meaning 10^{-12}
femto,	(f),	meaning 10^{-15}
atto,	(a),	meaning 10^{-18}
zepto,	(z),	meaning 10^{-21}
yocto,	(y),	meaning 10^{-24}

Units of Length

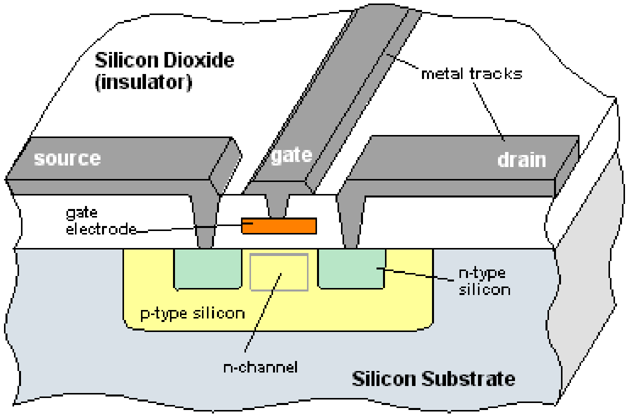
ΕΡΓΑΣΤΗΡΙΑΚΟΣ ΧΩΡΟΣ

ΕΡΓΑΣΤΗΡΙΑΚΟΣ ΧΩΡΟΣ

How Big of a Particle is Tolerable?

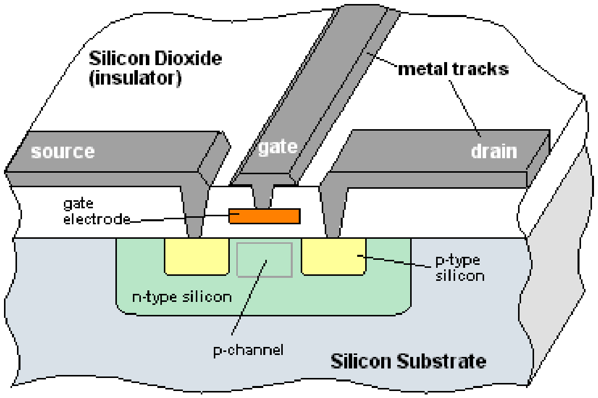
- Example: 0.5 µm CMOS technology
  - Lateral Features:
    - pattern size = 0.5 µm
    - pattern tolerance = 0.15 µm
    - level-level registration = 0.15 µm
  - Vertical Features:
    - gate oxide thickness = 10 nm
    - field oxide thickness = 20 nm
    - film thicknesses = 250-500 nm
    - junction depths = 50-150 nm

NMOS Transistor
(n-channel MOSFET)



🟧 poly-crystalline silicon gate electrode

PMOS Transistor
(p-channel MOSFET)



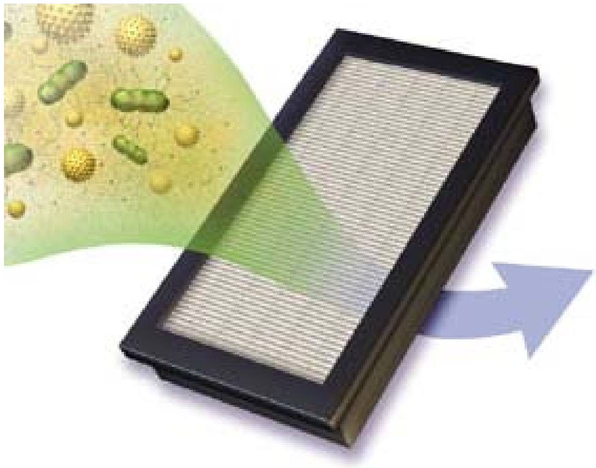
CMOS
When an NMOS and PMOS transistor are wired together in a complementary fashion, they become a CMOS (complementary MOS) gate, which causes no power to be used until the transistors switch. CMOS is the most widely used microelectronic design process and is found in almost every electronic product.

ΕΡΓΑΣΤΗΡΙΑΚΟΣ ΧΩΡΟΣ

HEPA Filter Types

Type	Application	Performance
A	industrial, noncritical	> 99.97 % @ 0.3 μm (MIL-STD-282)
B	nuclear containment	> 99.97 % @ 0.3 μm (certified by DOE)
C	laminar flow	> 99.97 % @ 0.3 μm (MIL-STD-282)
D	ultra-low penetration air (ULPA)	> 99.9995 % @ 0.12 μm
E	toxic, nuclear, and biohazard containment	MIL-F-51477 MIL-F-51068 (classified performance)

Grade 1 = fire resistant
Grade 2 = semicombustible



ΕΡΓΑΣΤΗΡΙΑΚΟΣ ΧΩΡΟΣ

Clean Room Class Ratings

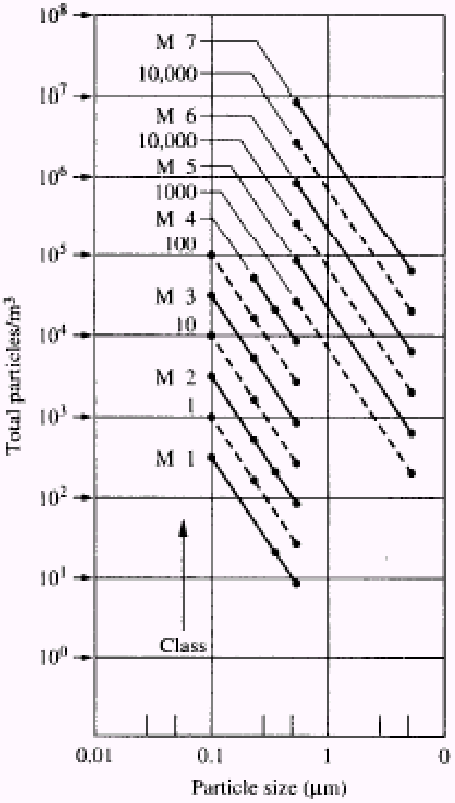


FIGURE 1
Air cleanliness according to U.S. Fed. Std. 209E.

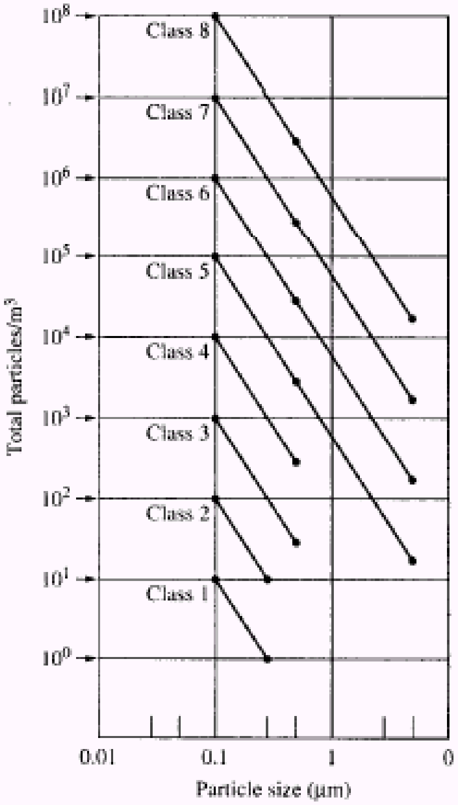
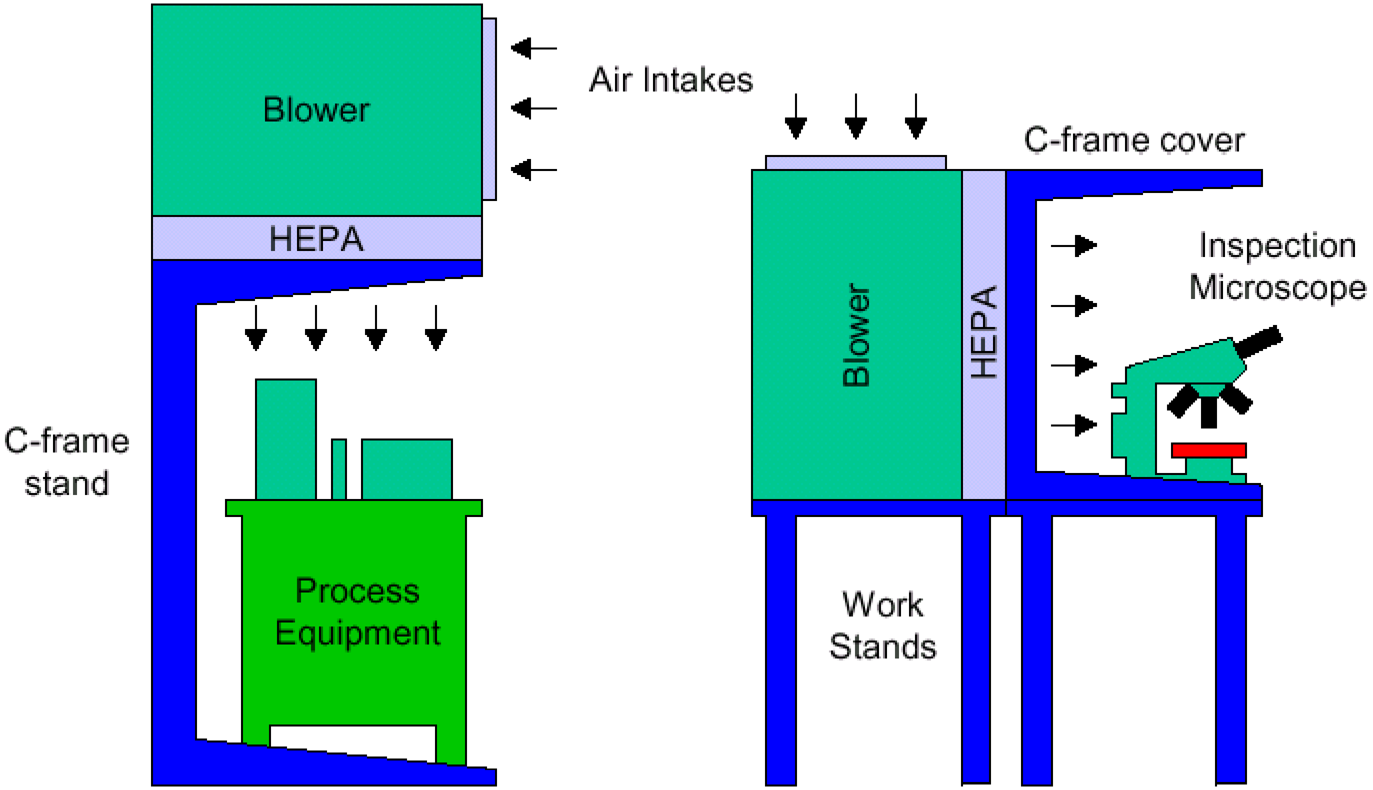


FIGURE 2
Air cleanliness according to Japanese Std. B9920 rev.

Vertical and Horizontal Laminar Benches

- A HEPA filter used to provide local clean air conditions
  - Can usually drop the class rating by 2 decades within a local area
  - Example: Class 100 local environment within a Class 10,000 room



- Designed to minimize turbulence which creates dust and dirt collection pockets

ΕΡΓΑΣΤΗΡΙΑΚΟΣ ΧΩΡΟΣ

Gowning - Class 10,000

Putting
On

Shoe Covers

Laboratory Coat

Hair Net

Safety Glasses

Clean Room Gloves

Taking
Off

ΕΡΓΑΣΤΗΡΙΑΚΟΣ ΧΩΡΟΣ

Gowning - Class 100

Shoe Covers
Hair Net
Gowning Gloves

outside clean area

Bunny Suit
Booties
Hood
Nose/Mouth Mask
Safety Glasses
Clean Room Gloves

Putting On ↓

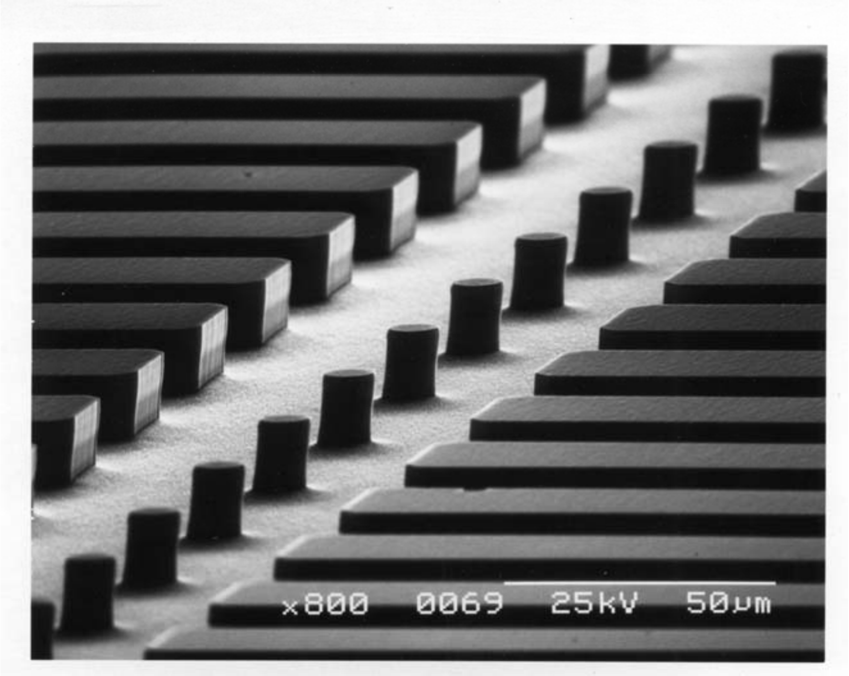
Taking Off ↑

Face Shield
Respirator

for handling wafers

ΕΡΓΑΣΤΗΡΙΑΚΟΣ ΧΩΡΟΣ

ΔΙΑΔΙΚΑΣΙΕΣ ΚΑΤΑΣΚΕΥΗΣ ΔΙΑΤΑΞΕΩΝ ΚΑΙ ΟΛΟΚΛΗΡΩΜΕΝΩΝ ΚΥΚΛΩΜΑΤΩΝ ΑΠΟ ΗΜΙΑΓΩΓΟΥΣ (Si, III-Arsenides, III-Nitrides)

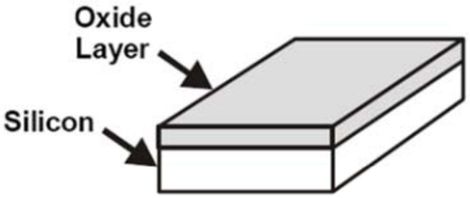


ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

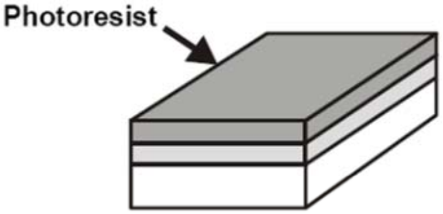
- ΛΙΘΟΓΡΑΦΙΑ
- ΕΝΑΠΟΘΕΣΗ ΜΕΤΑΛΛΩΝ
- ΕΝΑΠΟΘΕΣΗ ΔΙΗΛΕΚΤΡΙΚΩΝ
- ΥΓΡΗ (WET) ΧΗΜΙΚΗ ΧΑΡΑΞΗ
- ΞΗΡΗ (DRY OR PLASMA) ΧΗΜΙΚΗ ΧΑΡΑΞΗ

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

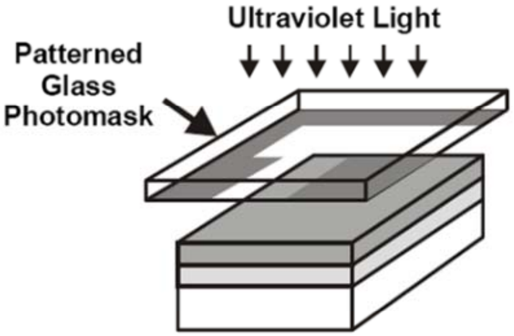
ΛΙΘΟΓΡΑΦΙΑ



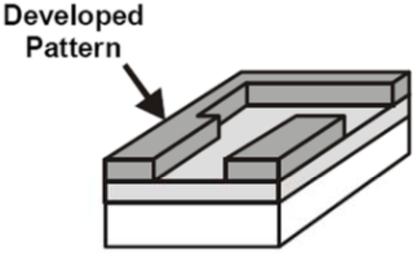
Silicon with
Oxide Layer



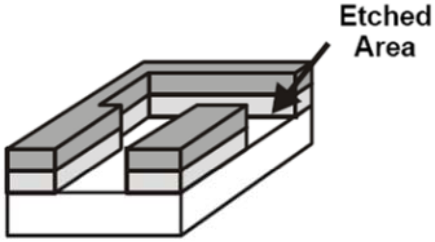
1) Coat with
Photoresist



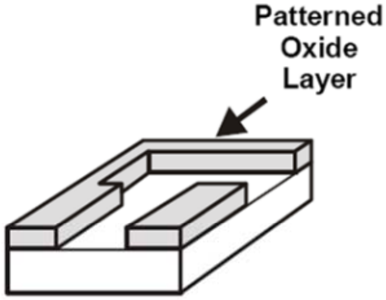
2) Expose
Photoresist



3) Develop
Photoresist



4) Etch
Oxide Layer

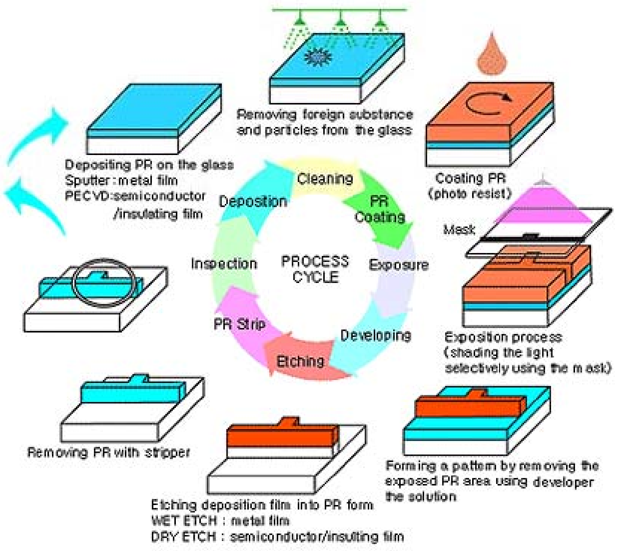


5) Strip
Photoresist

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ
ΛΙΘΟΓΡΑΦΙΑ

Overview of the Photolithography Process

- Surface Preparation
- Coating (Spin Casting)
- Pre-Bake (Soft Bake)
- Alignment
- Exposure
- Development
- Post-Bake (Hard Bake)
- Processing Using the Photoresist as a Masking Film
- Stripping
- Post Processing Cleaning (Ashing)



ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

ΛΙΘΟΓΡΑΦΙΑ

Wafer Cleaning - 1

- Typical contaminants that must be removed prior to photoresist coating:
  - dust from scribing or cleaving (minimized by laser scribing)
  - atmospheric dust (minimized by good clean room practice)
  - abrasive particles (from lapping or CMP)
  - lint from wipers (minimized by using lint-free wipers)
  - photoresist residue from previous photolithography (minimized by performing oxygen plasma ashing)
  - bacteria (minimized by good DI water system)
  - films from other sources:
    - solvent residue
    - H_2O residue
    - photoresist or developer residue
    - oil
    - silicone

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ
ΛΙΘΟΓΡΑΦΙΑ

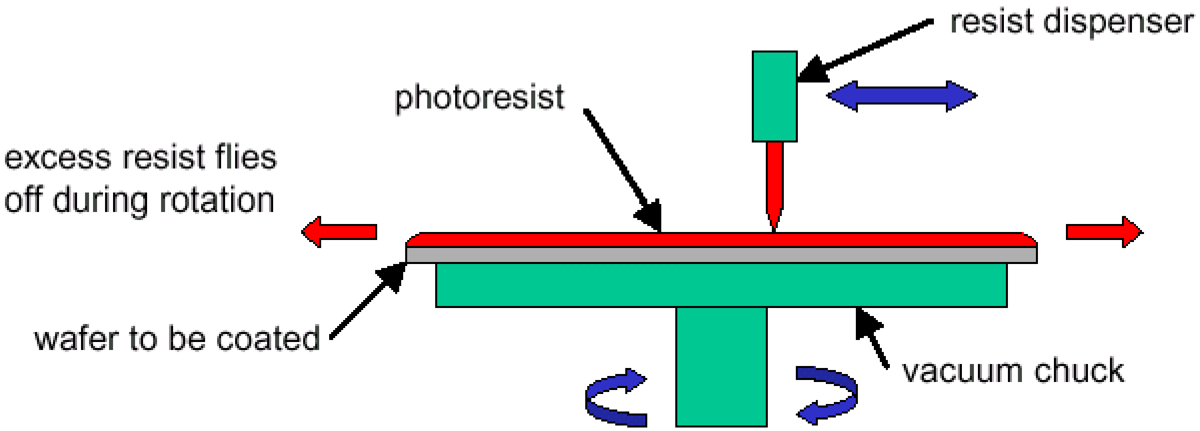
Wafer Cleaning - 2

- Standard degrease:
  - 2-5 min. soak in acetone with ultrasonic agitation
  - 2-5 min. soak in methanol with ultrasonic agitation
  - 2-5 min. soak in DI H_2O with ultrasonic agitation
  - 30 sec. rinse under free flowing DI H_2O
  - spin rinse dry for wafers; N_2 blow off dry for tools and chucks
- For particularly troublesome grease, oil, or wax stains:
  - Start with 2-5 min. soak in 1,1,1-trichloroethane (TCA) or trichloroethylene (TCE) with ultrasonic agitation prior to acetone
- Hazards:
  - TCE is carcinogenic; 1,1,1-TCA is less so
  - acetone is flammable
  - methanol is toxic by skin adsorption

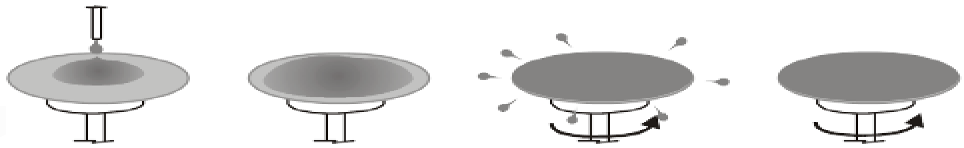
ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

ΛΙΘΟΓΡΑΦΙΑ

Photoresist Spin Coating



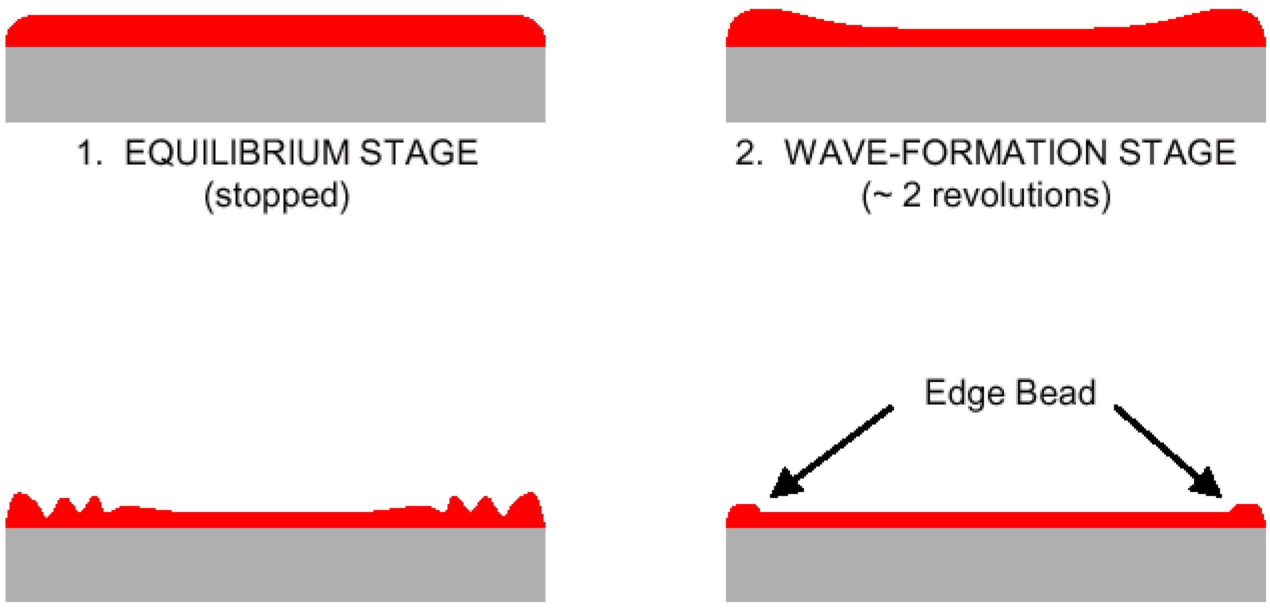
- Wafer is held on a spinner chuck by vacuum and resist is coated to uniform thickness by spin coating.
- Typically 3000-6000 rpm for 15-30 seconds.
- Most resist thicknesses are 1-2 μm for commercial Si processes.



ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

ΛΙΘΟΓΡΑΦΙΑ

Stages of Resist Coating



1. EQUILIBRIUM STAGE
(stopped)

2. WAVE-FORMATION STAGE
(~ 2 revolutions)

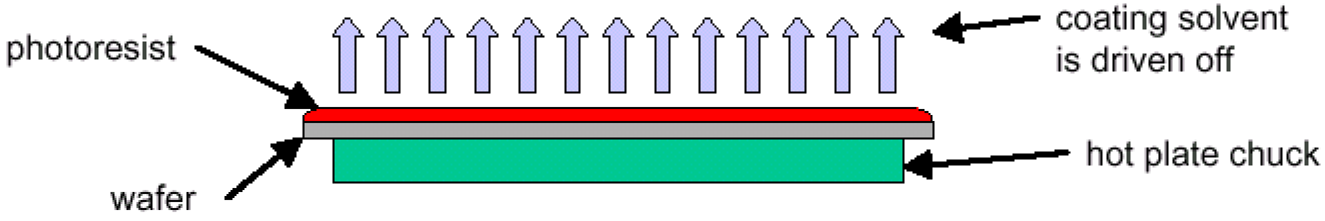
3. CORONA STAGE
(~ 30 revolutions)

4. SPIRAL STAGE
(~ 1000 revolutions)

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ
ΛΙΘΟΓΡΑΦΙΑ

Prebake (Soft Bake) - 1

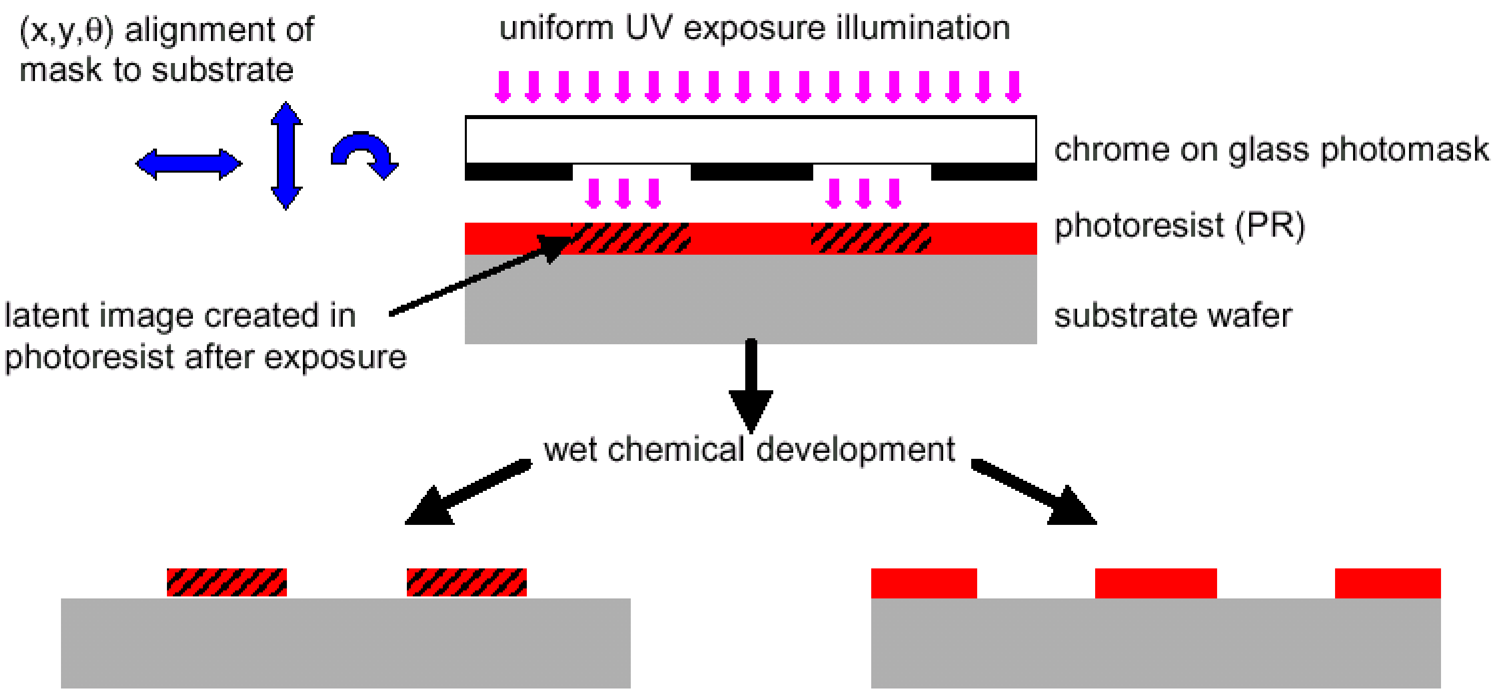
- Used to evaporate the coating solvent and to densify the resist after spin coating.
- Typical thermal cycles:
  - 90-100°C for 20 min. in a convection oven
  - 75-85°C for 45 sec. on a hot plate
- Commercially, microwave heating or IR lamps are also used in production lines.
- Hot plating the resist is usually faster, more controllable, and does not trap solvent like convection oven baking.



ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

ΛΙΘΟΓΡΑΦΙΑ

Overview of Align/Expose/Develop Steps



(x,y,θ) alignment of mask to substrate

uniform UV exposure illumination

chrome on glass photomask

photoresist (PR)

substrate wafer

latent image created in photoresist after exposure

wet chemical development

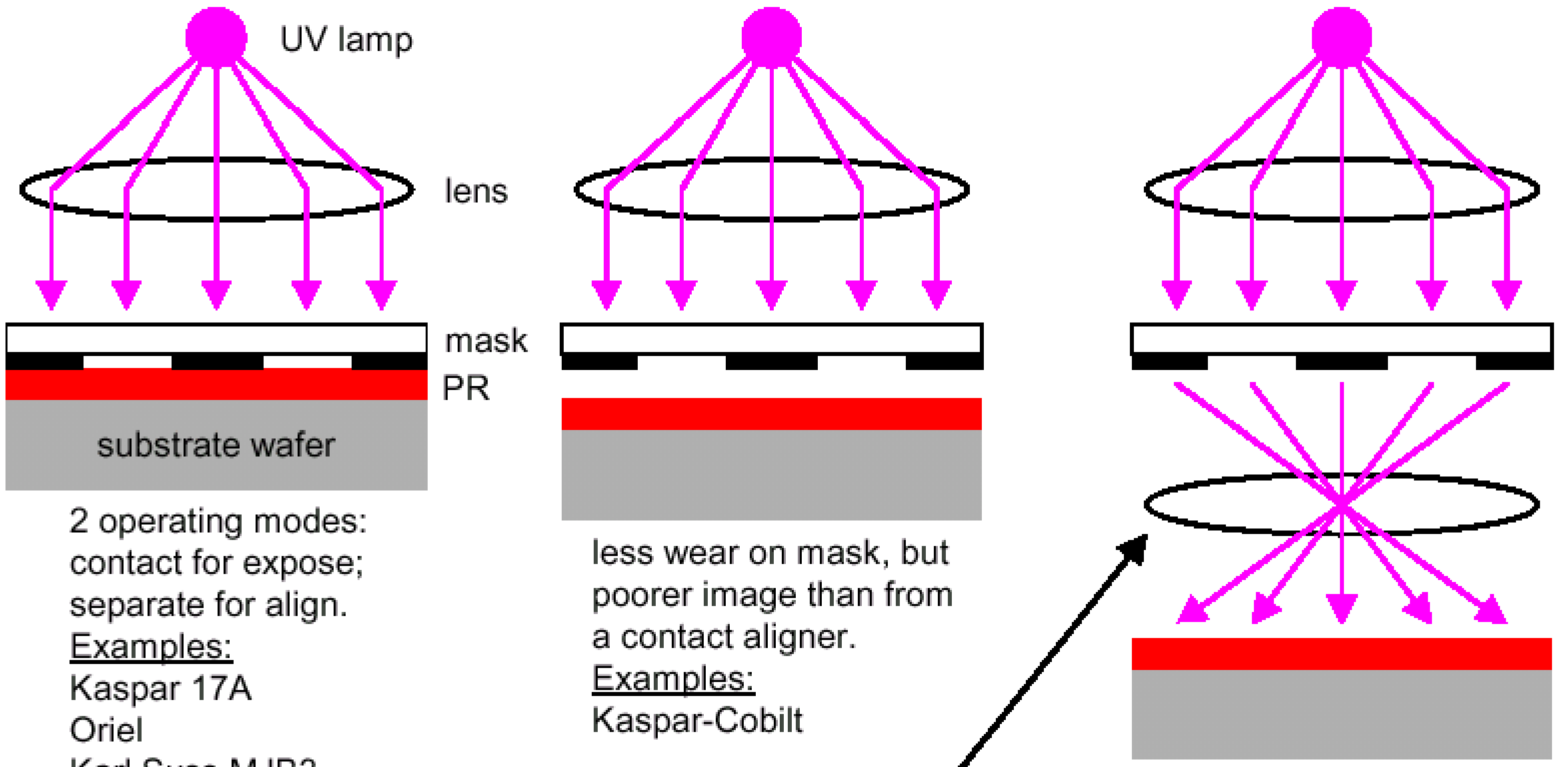
NEGATIVE PHOTORESIST
Photoresist is photopolymerized where exposed and rendered insoluble to the developer solution.

POSITIVE PHOTORESIST
Exposure decomposes a development inhibitor and developer solution only dissolves photoresist in the exposed areas.

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

ΛΙΘΟΓΡΑΦΙΑ

Alignment and Exposure Hardware - 1



CONTACT ALIGNER

2 operating modes:
contact for expose;
separate for align.
<u>Examples:</u>
Kaspar 17A
Oriel
Karl Suss MJB3

PROXIMITY ALIGNER

less wear on mask, but poorer image than from a contact aligner.
<u>Examples:</u>
Kaspar-Cobilt

PROJECTION ALIGNER

<u>Examples:</u>
Perkin-Elmer Micralign

Projection systems use imaging optics in between the mask and the wafer

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ
ΛΙΘΟΓΡΑΦΙΑ

Alignment and Exposure Hardware - 3

- Higher end research systems go one step further and use Direct Write on Wafer (DWW) exposure systems.
- This can be accomplished using:
  - Excimer lasers for geometries down to 1-2 μm
  - Electron beams for geometries down to 0.1-0.2 μm
  - Focused ion beams for geometries down to 0.05-0.1 μm
- No mask is needed for these technologies.
- These are serial processes, and wafer cycle time is proportional to the beam writing time-- the smaller the spot, the longer it takes!

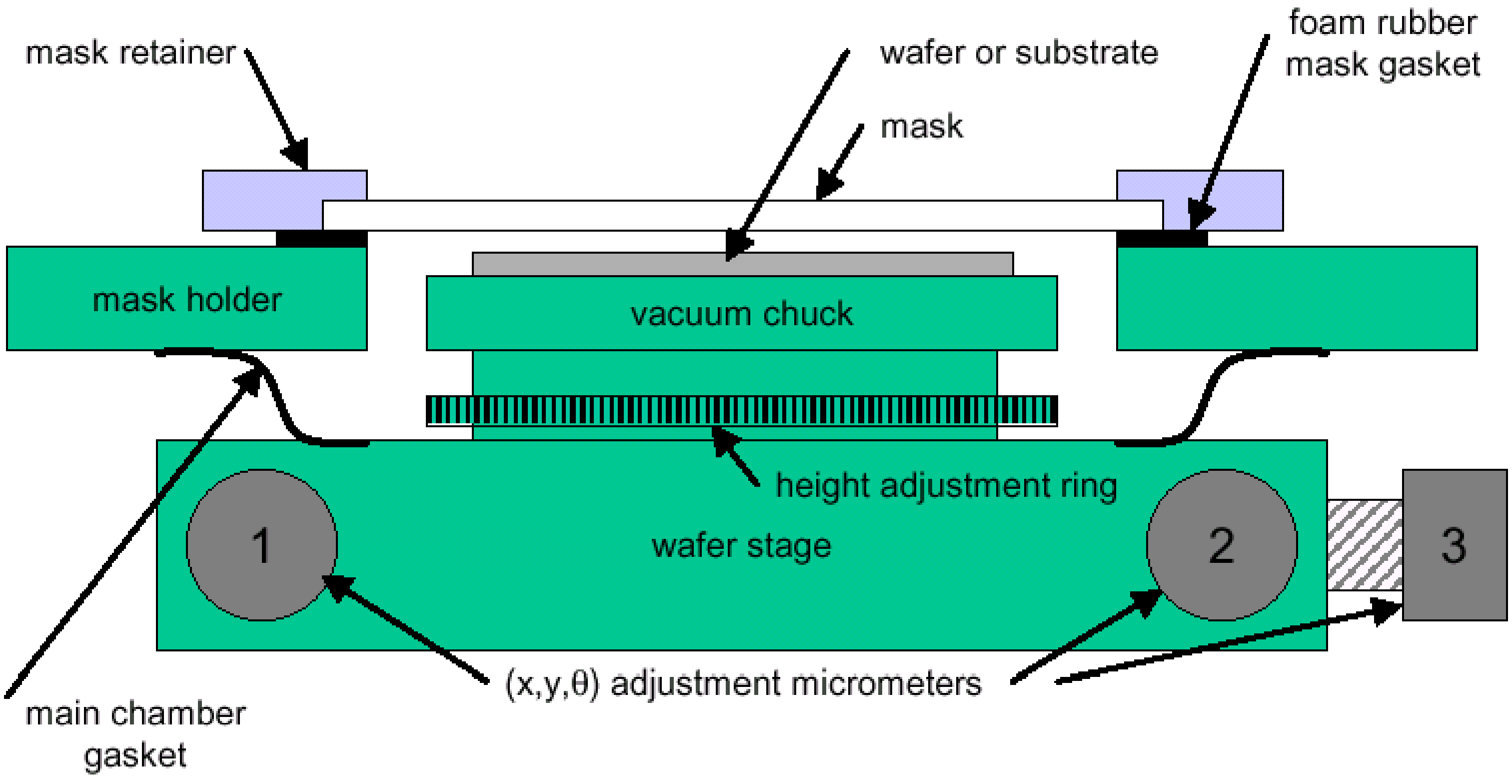
ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ
ΛΙΘΟΓΡΑΦΙΑ

Photomasks

- Master patterns which are transferred to wafers
- Types:
  - photographic emulsion on soda lime glass (cheapest)
  - Fe_2O_3 on soda lime glass
  - Cr on soda lime glass
  - Cr on quartz glass (most expensive, needed for deep UV litho)
- Dimensions:
  - 4” x 4” x 0.060” for 3-inch wafers
  - 5” x 5” x 0.060” for 4-inch wafers
- Polarity:
  - “light-field” = mostly clear, drawn feature = opaque
  - “dark-field” = mostly opaque, drawn feature = clear

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

ΛΙΘΟΓΡΑΦΙΑ



ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

ΛΙΘΟΓΡΑΦΙΑ

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ
ΛΙΘΟΓΡΑΦΙΑ

Photoresist Removal (Stripping)

- Want to remove the photoresist and any of its residues.
- Simple solvents are generally sufficient for non-postbaked photoresists:
  - Positive photoresists:
    - acetone
    - trichloroethylene (TCE)
    - phenol-based strippers (Indus-Ri-Chem J-100)
  - Negative photoresists:
    - methyl ethyl ketone (MEK), $CH_3COC_2H_5$
    - methyl isobutyl ketone (MIBK), $CH_3COC_4H_9$
- Plasma etching with O_2 (ashing) is also effective for removing organic polymer debris.
  - Also: Shipley 1165 stripper (contains n-methyl-2-pyrrolidone), which is effective on hard, postbaked resist.

[redacted]

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ
ΛΙΘΟΓΡΑΦΙΑ

Basics of Photolithography for Processing

- Microfabrication processes:
  - Additive → deposition
  - Subtractive → etching
  - Modifying → doping, annealing, or curing
- Two primary techniques for patterning additive and subtractive processes:
  - Etch-back:
    - photoresist is applied overtop of the layer to be patterned
    - unwanted material is etched away
  - Lift-off:
    - patterned layer is deposited over top of the photoresist
    - unwanted material is lifted off when resist is removed

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

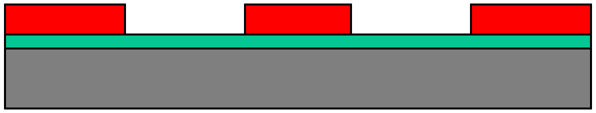
ΛΙΘΟΓΡΑΦΙΑ

Etch-back

1

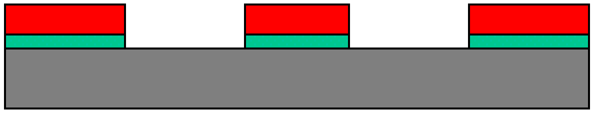
deposit thin film of desired material

2



coat and pattern photoresist

3



etch film using photoresist as mask

4

remove photoresist

<u>NOTE:</u> photoresist has same polarity as final film; photoresist never touches the substrate wafer.

[redacted]

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

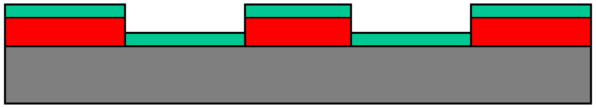
ΛΙΘΟΓΡΑΦΙΑ

Lift-off

1

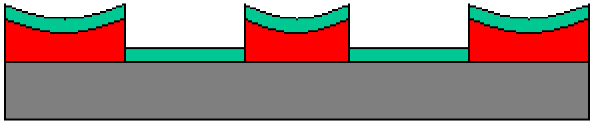
coat and pattern photoresist

2



deposit thin film of desired material

3



swell photoresist with a solvent

4

remove photoresist and thin film above it

NOTE: photoresist has opposite polarity as final film; excess deposited film never touches the substrate wafer.

[redacted]

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

ΕΝΑΠΟΘΕΣΗ

- Conductors - metal films, polysilicon
- Insulators – dielectrics $Si0_2$
- Semiconductors – GaAs …

- Evaporation
  - Thermal (Filament)
  - Electron-beam
  - Flash
- Sputtering

- Epitaxy
  - Vapor Phase (VPE)
  - Liquid Phase (LPE)
  - Molecular Beam (MBE)

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

ΕΝΑΠΟΘΕΣΗ

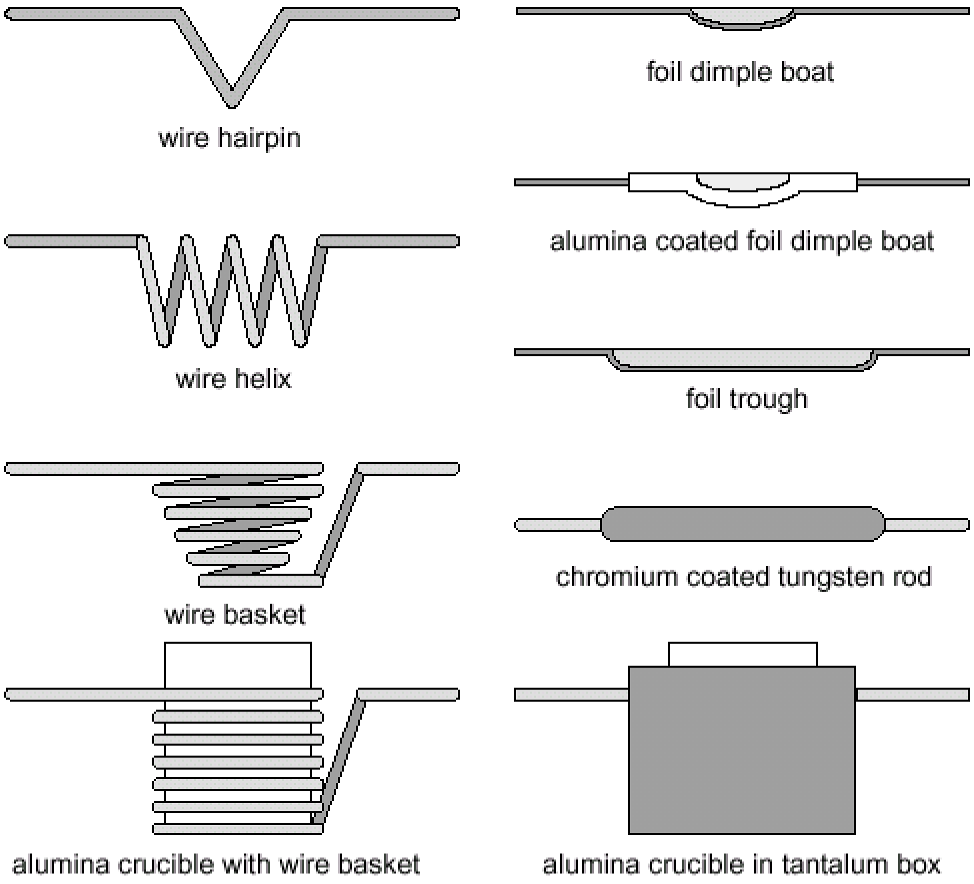
Evaporation System

- Vacuum:
  - Need 10^{-6} torr for medium quality films.
  - Can be accomplished in UHV down to 10^{-9} torr.

- Common evaporant materials:
  - Au, Ag, Al, Sn, Cr, Sb, Ge, In, Mg, Ga
  - CdS, PbS, CdSe, NaCl, KCl, AgCl, MgF_2, CaF_2, $PbCl_2$
- Typical deposition rates are 1-20 Angstroms/second.
- Use W, Ta, or Mo filaments to heat evaporation source.

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ
ΕΝΑΠΟΘΕΣΗ

Resistance Heated Evaporation Sources



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ΕΝΑΠΟΘΕΣΗ

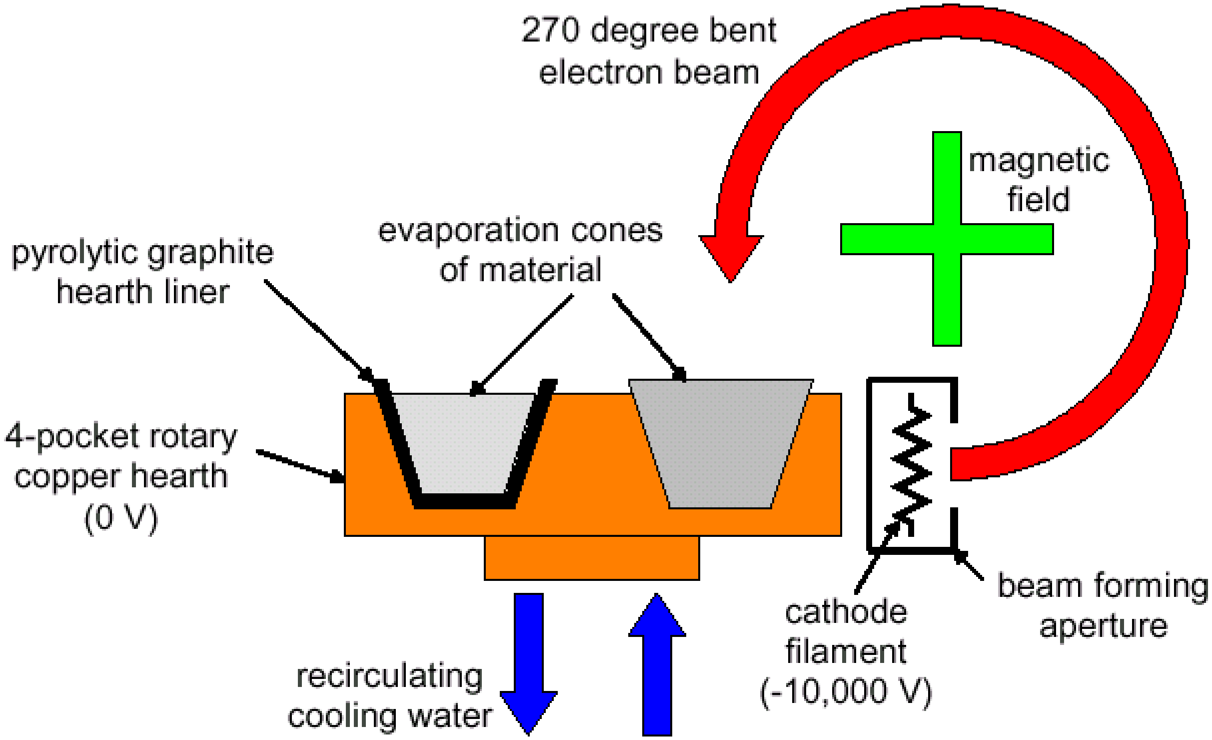
Electron Beam Heated Evaporation - 1

- More complex, but extremely versatile.
- Can achieve temperatures in excess of 3000°C.
- Use evaporation cones or crucibles in a copper hearth.
- Typical emission voltage is 8-10 kV.
- Exposes substrates to secondary electron radiation.
  - X-rays can also be generated by high voltage electron beam.
- Typical deposition rates are 10-100 Angstroms/second.
- Common evaporant materials:
  - Everything a resistance heated evaporator will accommodate, plus:
  - Ni, Pt, Ir, Rh, Ti, V, Zr, W, Ta, Mo
  - Al_2O_3, SiO, SiO_2, SnO_2, TiO_2, ZrO_2

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

ΕΝΑΠΟΘΕΣΗ

Electron Beam Heated Evaporation Source



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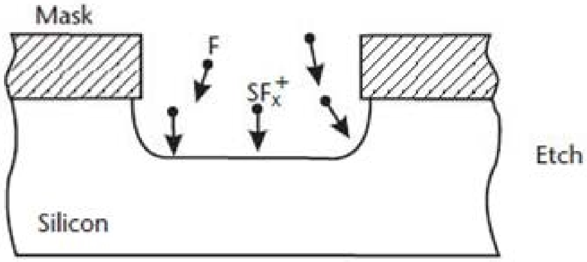
ΕΝΑΠΟΘΕΣΗ

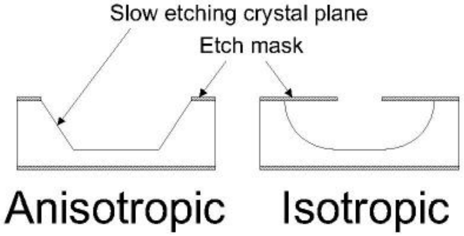
ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

ΥΓΡΗ (WET) ΧΗΜΙΚΗ ΧΑΡΑΞΗ

Etching Chemistry



- The etching process involves:
  - Transport of reactants to the surface
  - Surface reaction
  - Transport of products from the surface
- Key ingredients in any wet etchant:
  - Oxidizer
    - examples: H_2O_2, HNO_3
  - Acid or base to dissolve oxidized surface
    - examples: H_2SO_4, NH_4OH
  - Dillutent media to transport reactants and products through
    - examples: H_2O, CH_3COOH

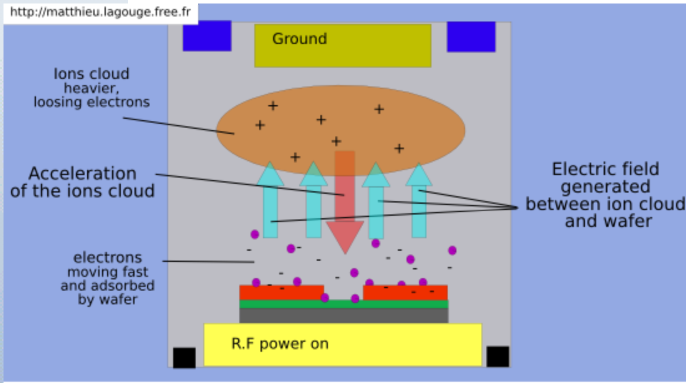


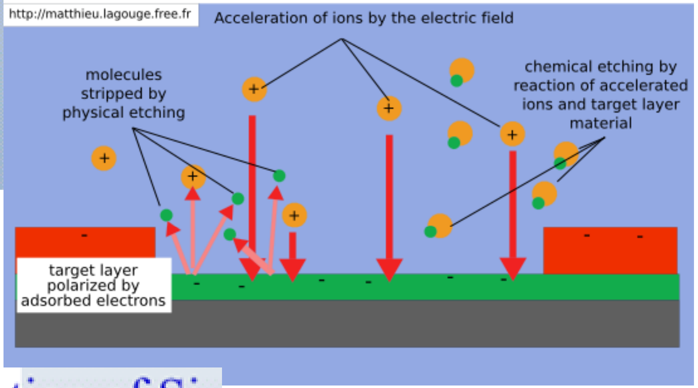
ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

ΞΗΡΗ (DRY OR PLASMA) ΧΗΜΙΚΗ ΧΑΡΑΞΗ

Plasma Based Dry Etching

- RF power is used to drive chemical reactions
- Plasma takes place of elevated temperatures or very reactive chemicals
- Types:
  - – Physical etching
  - – Chemical etching
  - – Reactive ion etching (RIE)
  - – Deep reactive ion etching (DRIE)


http://matthieu.lagouge.free.fr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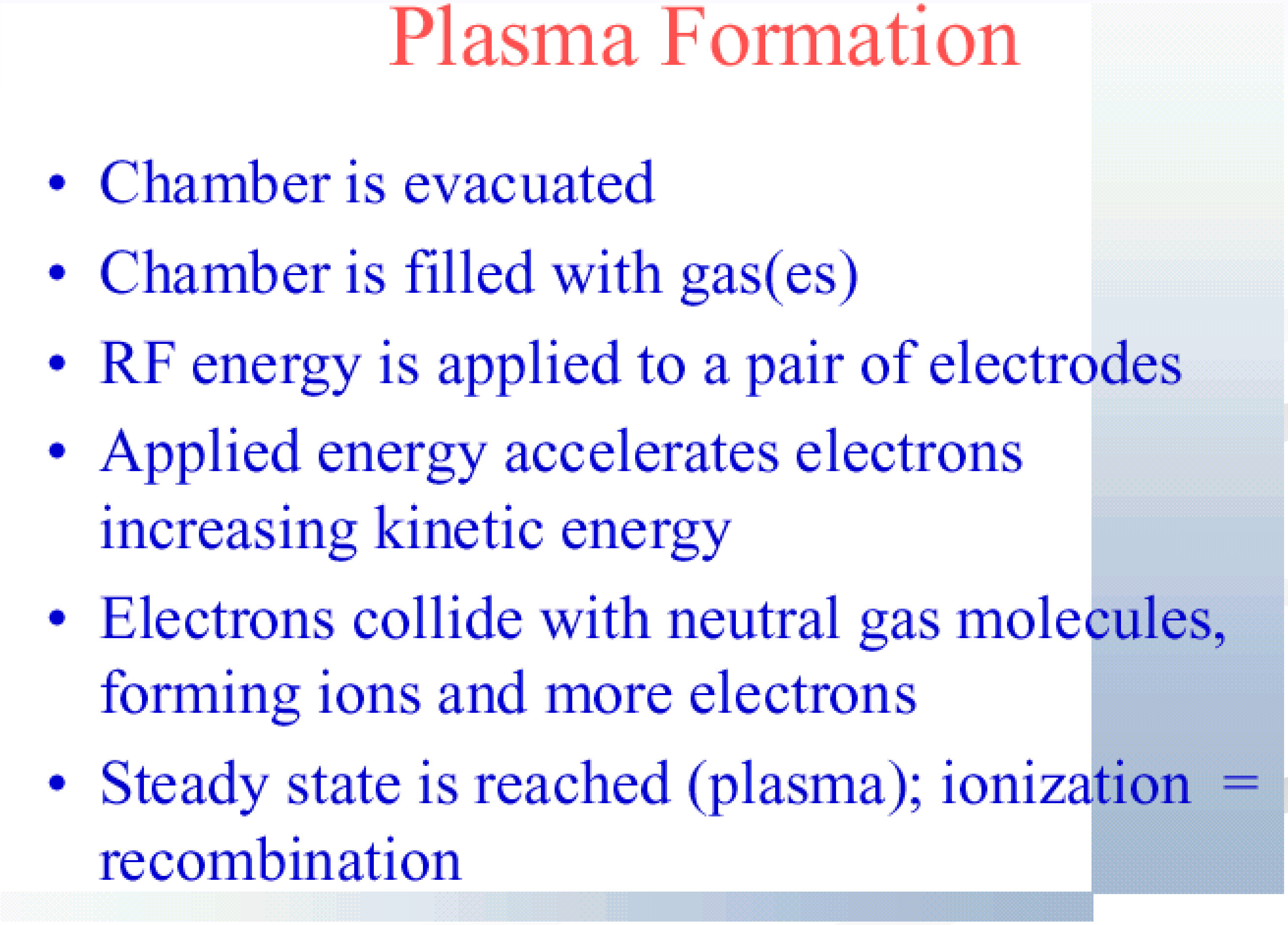
- Directional etching without using the crystal orientation of Si

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

ΞΗΡΗ (DRY OR PLASMA) ΧΗΜΙΚΗ ΧΑΡΑΞΗ



Plasma Formation

- Chamber is evacuated
- Chamber is filled with gas(es)
- RF energy is applied to a pair of electrodes
- Applied energy accelerates electrons increasing kinetic energy
- Electrons collide with neutral gas molecules, forming ions and more electrons
- Steady state is reached (plasma); ionization = recombination

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

ΞΗΡΗ (DRY OR PLASMA) ΧΗΜΙΚΗ ΧΑΡΑΞΗ

Chemical (Plasma) Etching:

- Plasma is used to produce chemically reactive species (atoms, radicals, and ions) from inert molecular gas
- Six major steps:
  - Generation of reactive species (eg, free radicals)
  - Diffusion to surface
  - Adsorption on surface
  - Chemical reaction
  - Desorption of by-products
  - Diffusion into bulk gas
- Production of gaseous by-products is extremely important

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

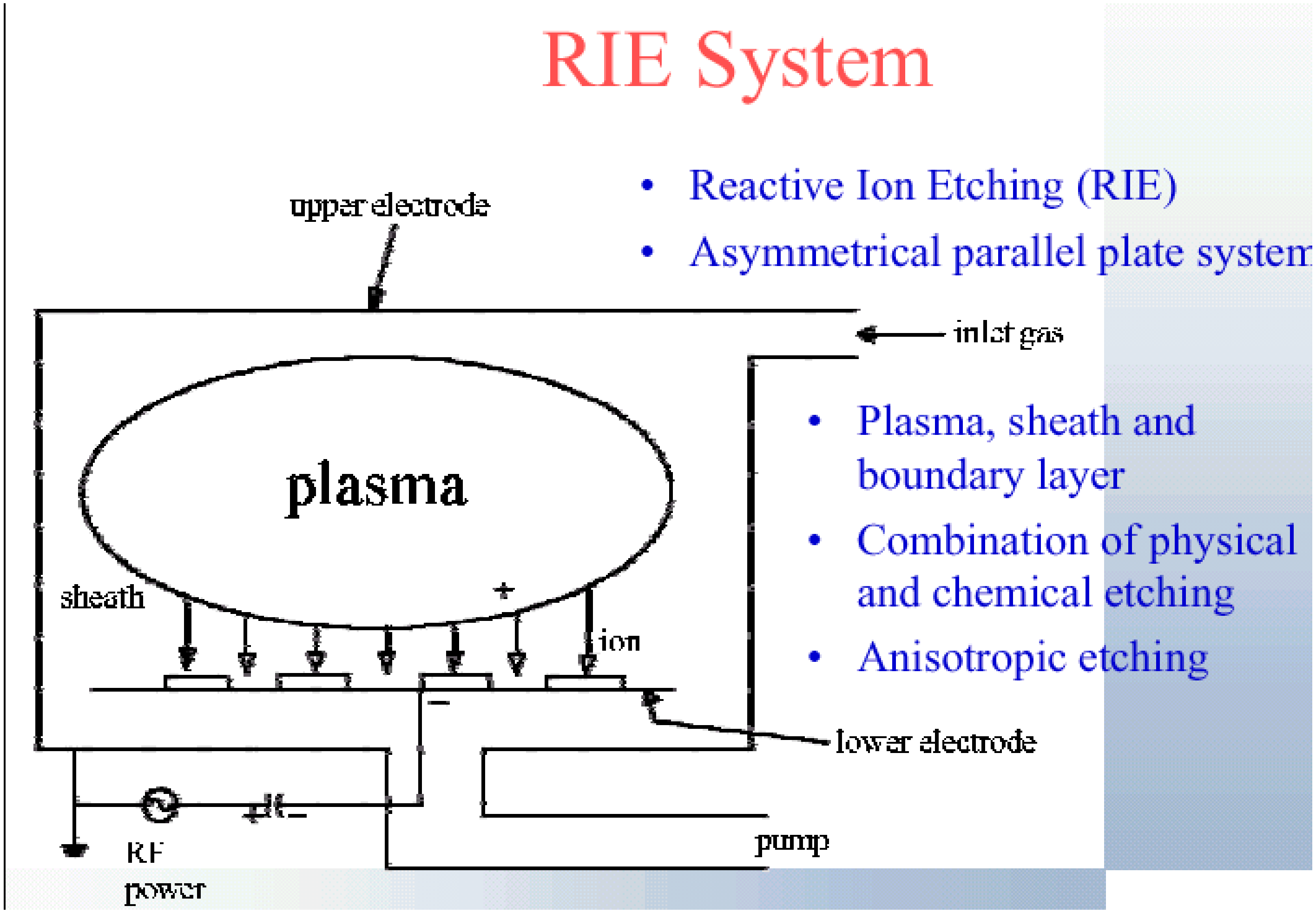
ΞΗΡΗ (DRY OR PLASMA) ΧΗΜΙΚΗ ΧΑΡΑΞΗ

Reactive Ion Etching (RIE)

- RIE = process in which chemical etching is accompanied by ionic bombardment (ie ion-assisted etching)
- Bombardment opens areas for reactions
- Ionic bombardment:
  - No undercutting since side-walls are not exposed
  - Greatly increased etch rate
  - Structural degradation
  - Lower selectivity

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

ΞΗΡΗ (DRY OR PLASMA) ΧΗΜΙΚΗ ΧΑΡΑΞΗ



RIE System

- Reactive Ion Etching (RIE)
- Asymmetrical parallel plate system
- Plasma, sheath and boundary layer
- Combination of physical and chemical etching
- Anisotropic etching

ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΔΙΑΔΙΚΑΣΙΕΣ

ΞΗΡΗ (DRY OR PLASMA) ΧΗΜΙΚΗ ΧΑΡΑΞΗ