Chemical Vapour Deposition

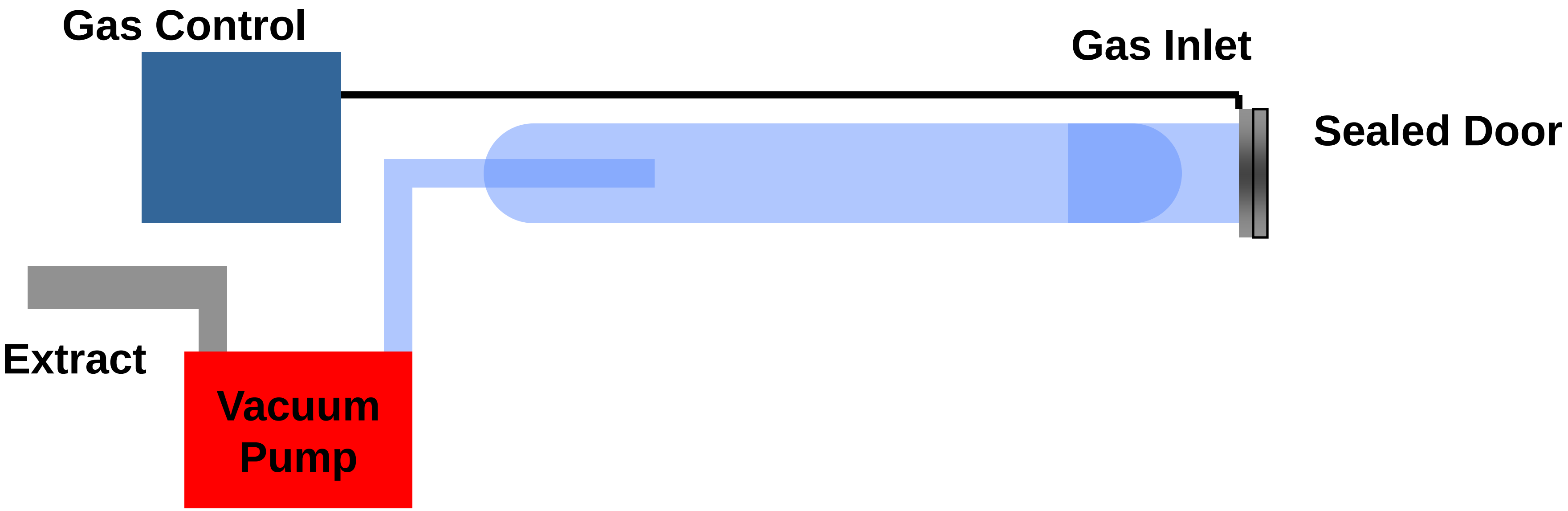
Four Main CVD Techniques

- **LPCVD - Low pressure CVD**
  - Polysilicon, silicon nitride and tungsten deposition
- **PECVD - Plasma Enhanced CVD**
  - Silicon dioxide, PSG, BPSG, Silicon Nitride
- **APCVD - Atmospheric pressure CVD**
  - Silicon dioxide, BPSG, PSG
- **EPITAXY**
  - Deposition of single crystal silicon

LPCVD

- **The main processes run in LPCVD reactors are :**
  - **Polysilicon**
  - **Silicon Nitride**
  - **Silicon Dioxide**
- **Of these Polysilicon and Silicon Nitride are the most common.**

FURNACE SET-UP



Polysilicon

- Polysilicon is an "insulator" (high resistance) as deposited
- It becomes a conductor when doped with a dopant such as phosphorous
- The most common use of polysilicon in the semiconductor industry is as a gate electrode in a CMOS process
- It is also used as a first level conductor in a MOS process

Chemistry

- The chemical process to deposit polysilicon is one of the simplest of the LPCVD processes

$$SiH_4 \xrightarrow[600^{o}C]{} Si + 2H_2$$

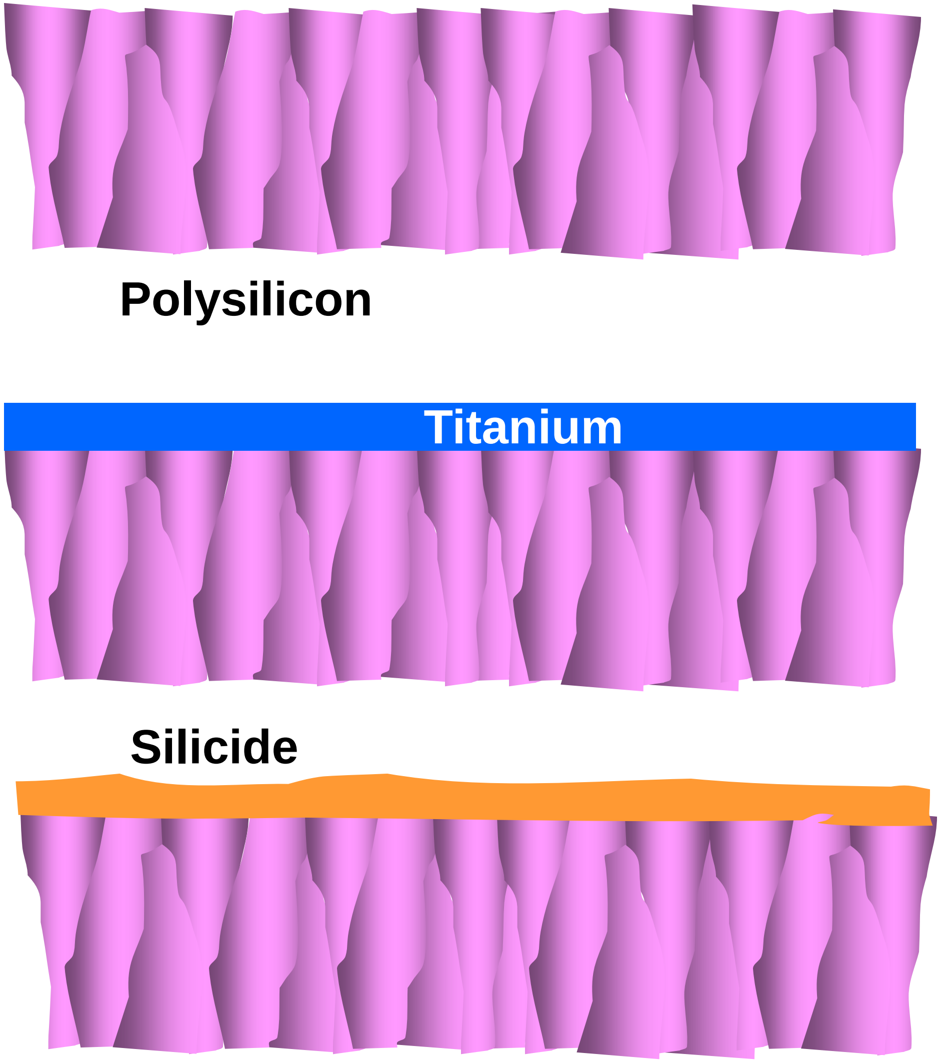
- The decomposition of the gas, silane, at a temp of about 600ºC gives these by-products
  - Silicon deposited as polycrystalline silicon and Hydrogen taken away in the pumping system

- The process can either use dilute silane or pure silane

Polysilicon Deposition

- Polysilicon is deposited as polycrystalline film at temperatures of 600ºC to 650ºC.
- Below 600ºC the deposition is called amorphous or pseudo amorphous
- Films deposited as amorphous can be recrystallised by an anneal subsequent to the deposition
- The deposition rate is dependant on the temperature in an exponential relationship

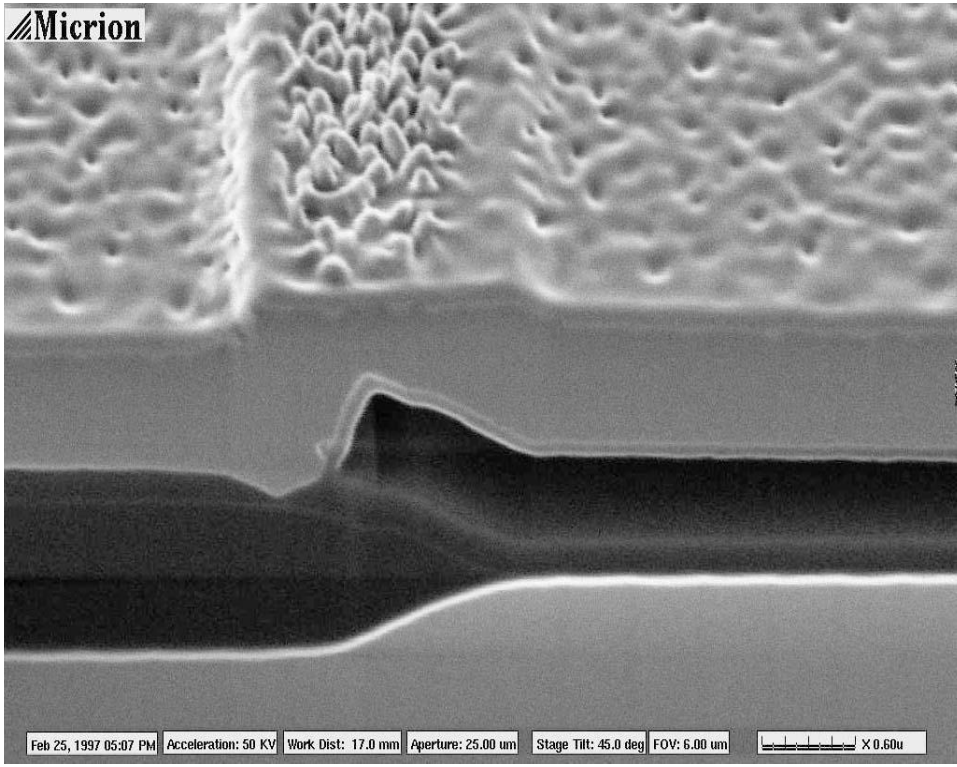
Polysilicon Structure



- Grain size can be varied by changing dep and anneal temperatures
- In modern CMOS processes often combined with refractory metals to form silicides
  - Titanium - $TiSi_2$

Polysilicon Surface Micromachining

- A material used in surface micromachining
- In NMRC as a pressure sensor and as a bolometer table



Pressure Sensor

Silicon Nitride

- Can be deposited as a LPCVD film or a PECVD film

- LPCVD films are of a stoichiometric composition with a high film density (between 2.9 - 3.1 g/cm^3)

- LPCVD Silicon Nitride is very useful as a barrier layer for numerous applications and provides a very good barrier to sodium penetration.

- LPCVD Silicon Nitride acts as a barrier to oxide growth in the LOCOS process

Chemistry

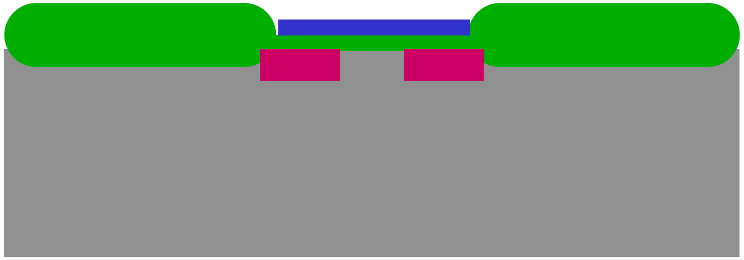
- Silicon nitride in LPCVD reactions is formed from the thermal decomposition of dichlorosilane and ammonia

$$3SiCl_2H_2 + 4NH_3 \xrightarrow[700^{\circ}C]{} Si_3N_4 + 6HCl + 6H_2$$

- Silicon Nitride is deposited as a solid on all surfaces in the hot wall reaction chamber
- Hydrogen chloride and hydrogen are pumped away as by-products

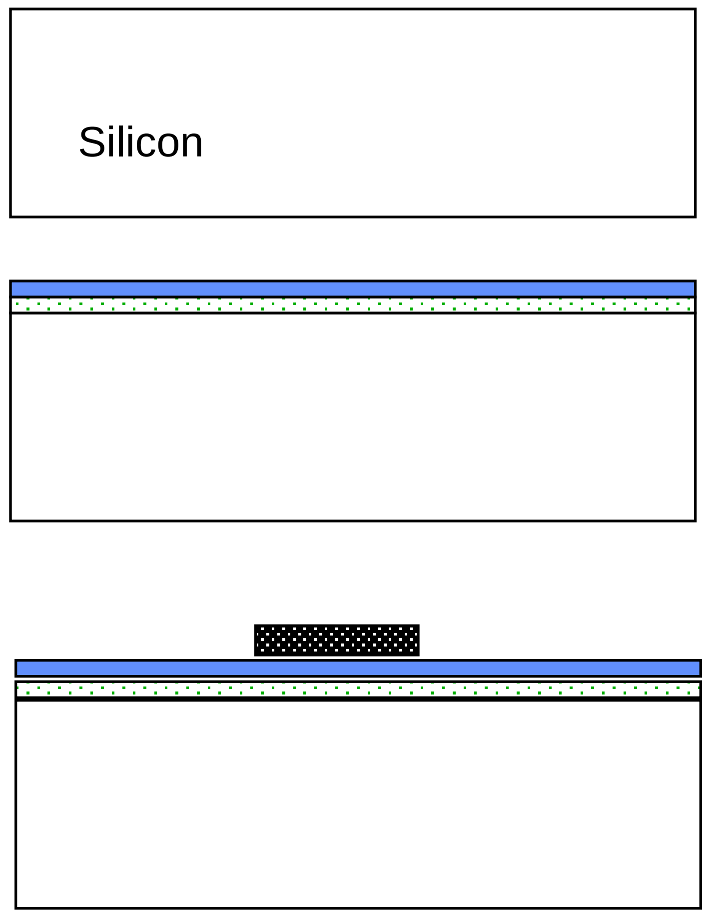
LPCVD Nitride in Process

- Nitride in the CMOS active areas to prevent Field Oxidation (FOX)
- Used as a masking material for KOH etching
- A gate dielectric material for ISFET applications



Tyndall National Institute
Institiúid Náisiúnta

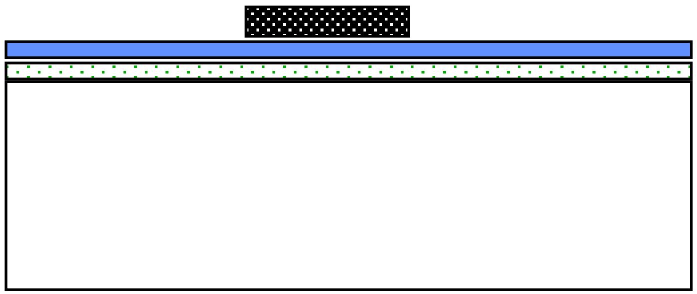
LOCOS or Semi Recessed Oxide



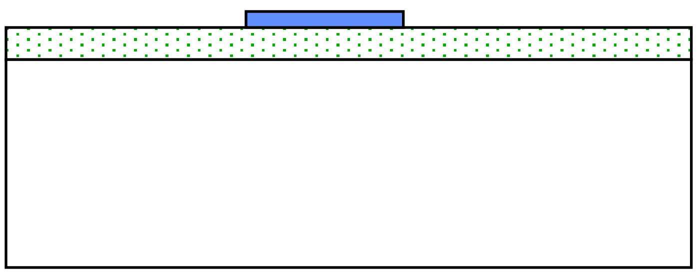
Deposit Silicon Nitride
Grow Thin Oxide

Pattern with
Photoresist

Chemical Vapour Deposition

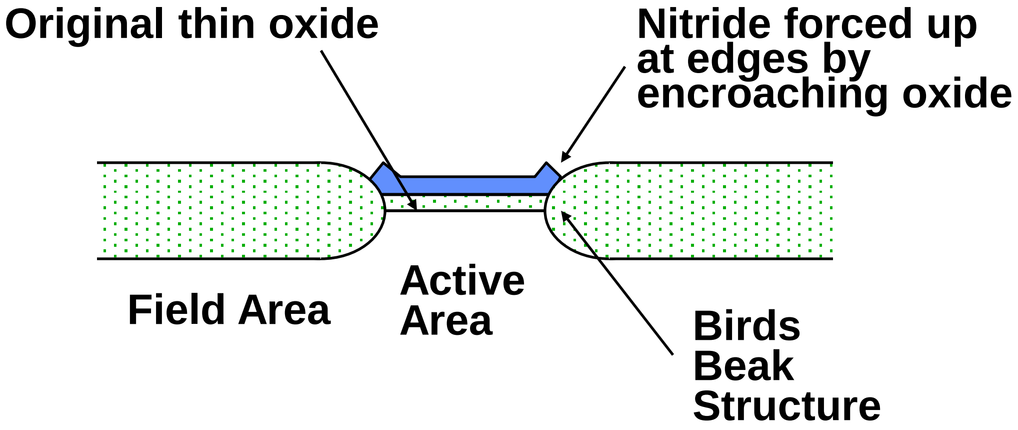


Etch unprotected nitride

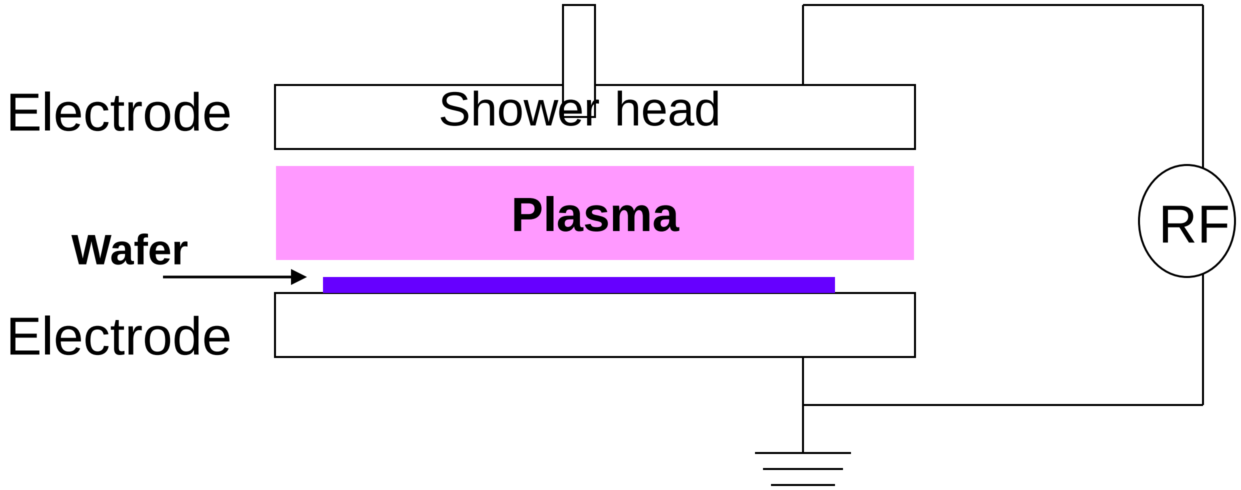


Remove the Resist
Leaving nitride pad
on thin oxide

Grow the field oxide

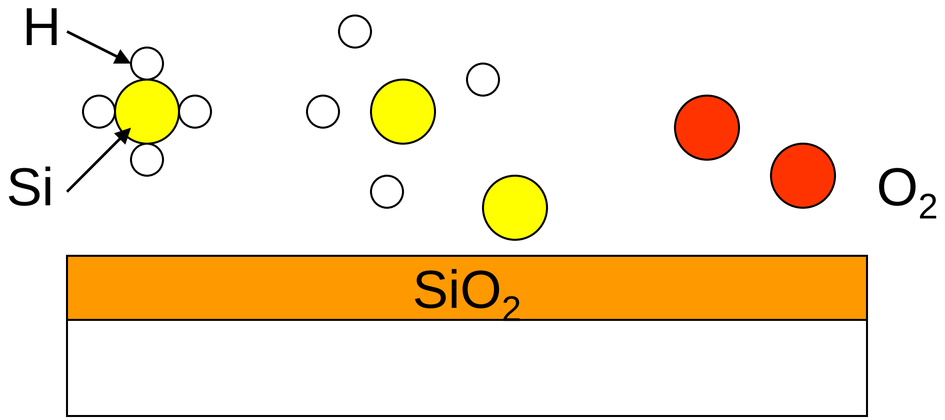


Plasma Enhanced CVD



- **R.F. energy is used to excite gases and initiate the reaction**
- **The main advantage of this is that deposition can be performed at low temperatures 300 - 400ºC**
- **Because of the low deposition temp PECVD is particularly useful after metal deposition [temp must be kept below 450ºC]**

Plasma Deposition



- Plasma deposition consists of exciting a gas so that it will react with itself or another gas
- Plasma deposition systems are basically the same as etch etch systems but different types of gas are used
- It is essential that the gases used in plasma deposition do not react spontaneously

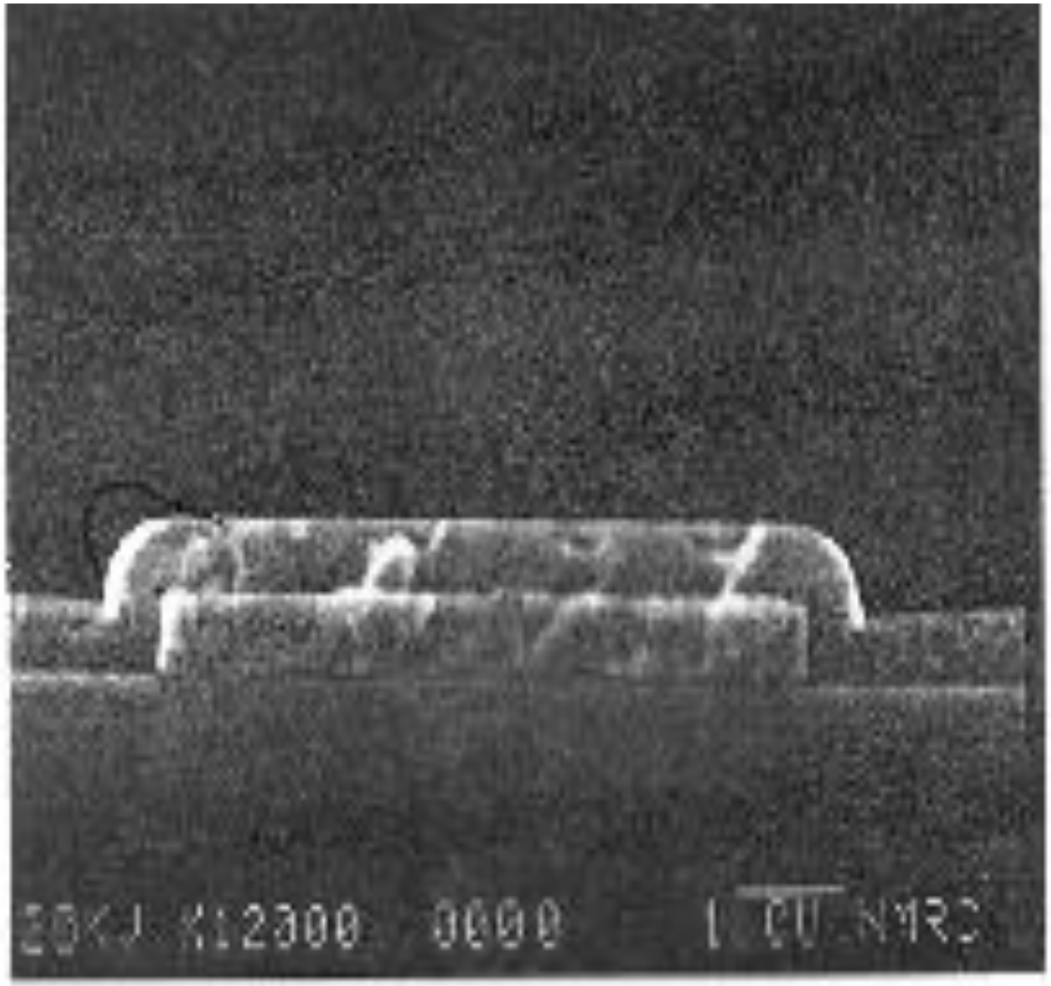
Plasma Silicon Dioxide

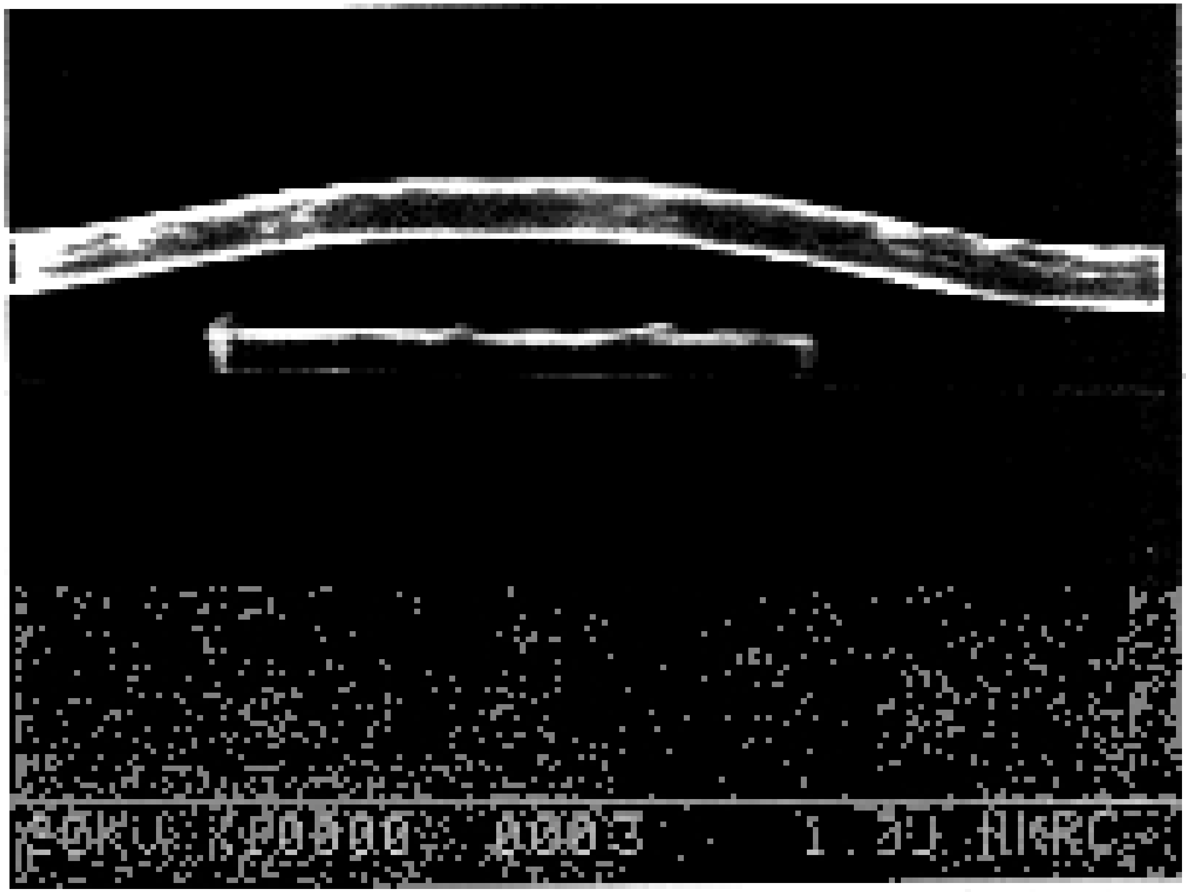
$$SiH_4 + 2N_2O \text{ -----> } SiO_2 + 2H_2 + 2N_2$$

- Silane and nitrous oxide react to give silicon dioxide at a deposition temperature of 300 - 400ºC
- These oxides can be doped by using phosphine and diborane
- Plasma oxides are generally poorer quality than thermally grown or LPCVD oxides
- Plasma oxides tend to contain large amounts of hydrogen (>12 wt%) due to incomplete dissociation of silane
- Step coverage tends to be mediocre

Variations

- BPSG, plasma deposited silicon dioxide with a percentage of boron and phosphorus incorporated
  - BoroPhosphoSilicate Glass
- The BPSG becomes “plastic” at high temperatures in the presence of steam and can be reflowed


X12000 0000
NMRC



Plasma Silicon Nitride

$$SiH_4 + NH_3 + N_2 \text{ -----> } Si_xN_y(H)$$

- Silicon nitride films are deposited by the reaction of silane, ammonia and nitrogen
- Deposition temperature is 300 - 350ºC
- These films have found widespread use as final passivation films since they are good barriers to moisture and ionic contamination
- Plasma nitride films also have large amounts of hydrogen (>20 wt%)

Plasma Silicon Oxynitride

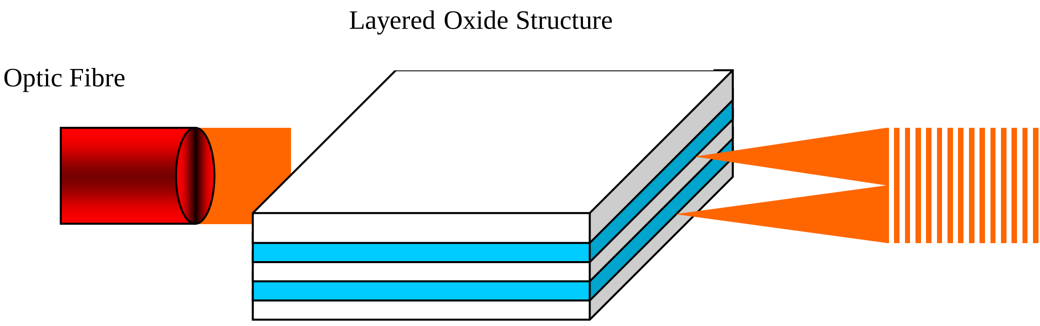
$$SiH_4 + NH_3 + N_2O \text{ -------> } Si_xO_yN_z(H)$$

- Used in certain applications where the properties required are somewhere between that of nitride and oxide

- For example where the process requires the optical properties of oxide and the barrier properties of nitride

Plasma Oxide/Oxynitride in Process

- Poly-metal dielectric
- Interlevel metal dielectric
- Waveguide material
- Masking material for implant or etch
- Doped with phosphorus as a passivation material



PECVD TEOS

$$Si(OC_2H_5)_4 \text{ ------> } SiO_2 + \text{by-products}$$

- PECVD TEOS is popular because of the excellent step coverage
- Quality of the oxides tends to be superior to silane based oxides

Atmospheric CVD

- Formerly extensively used method for inter-level dielectric and passivation
- Disappeared because of particulate deposition
- Return as the “Watkins Johnson” APCVD system
- Now ASML

CVD Tungsten

- First level contacts often filled with CVD tungsten
- Generally called a tungsten plug process
- Eliminates Al contact fill problems
- $WF_6 + 3H_2$ $W + 6HF$

High aspect ratio contact hole

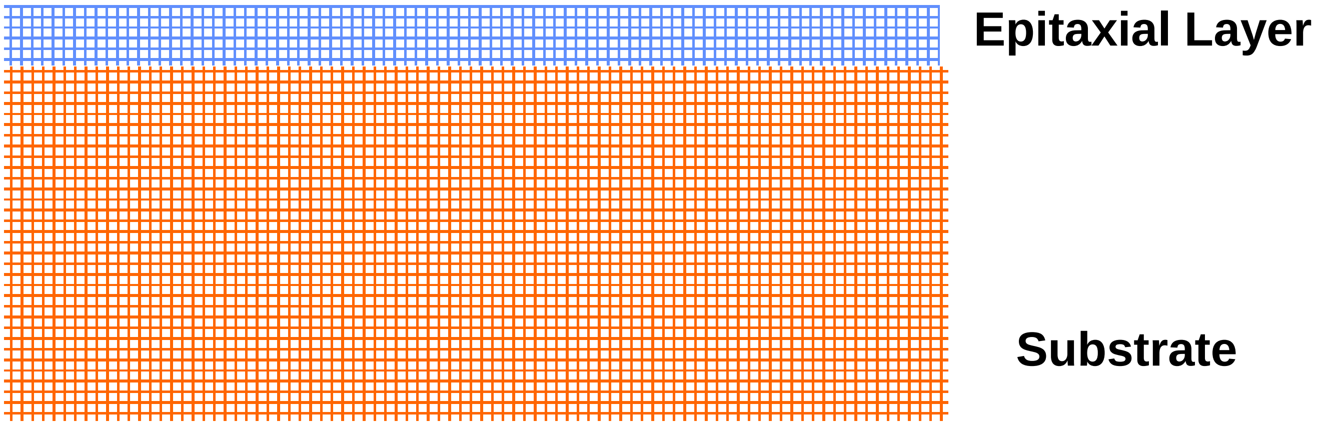
CVD tungsten deposition

Tungsten etch back

Epitaxial Layers

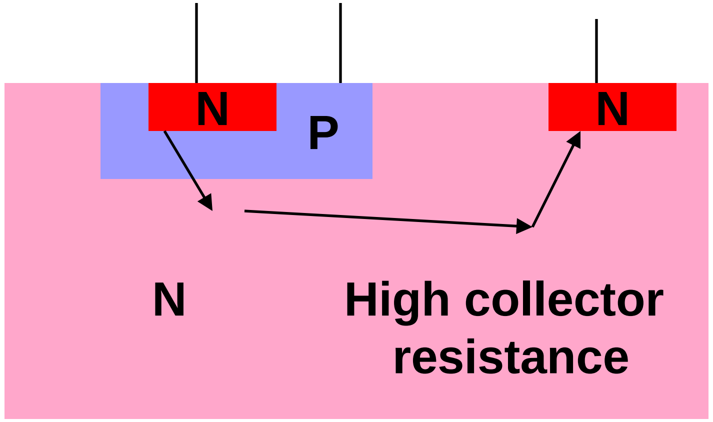
- Growing extra silicon layers on top of the existing crystal
- The new layer takes up the crystal structure of the underlying layers/substrate
- The type and/or doping concentration can be changed

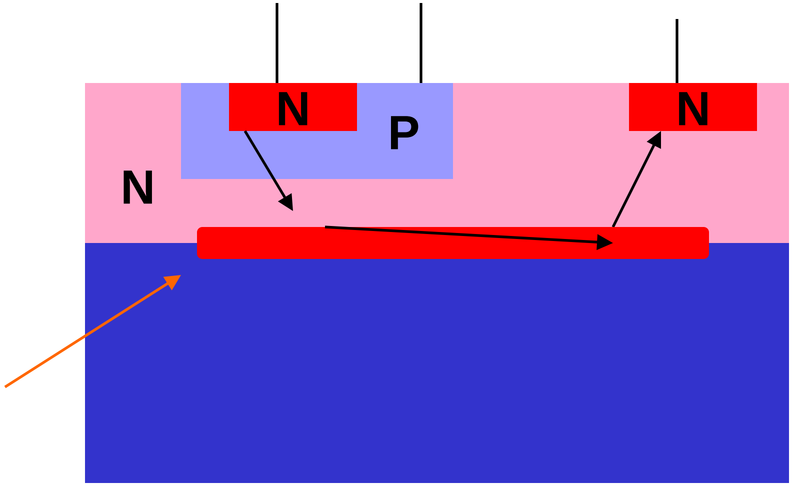
Layer Growth



Bipolar Epitaxial Use

- Bipolar processes traditionally use epi wafers
- This is to enable the formation of a buried layer
- Buried reduces the collector resistance





Buried Layer

CMOS Epitaxial Layers

- Epi layers traditionally not used in MOS processes
- With very small geometry processes it has become the norm
- The structure or “P on P+” or “N on N+” helps prevent “latch-up”