EK2360 Hands on Micro-Electro-Mechanical Systems Engineering

Fabrication Lecture

Time Schedule EK 2360, 2015

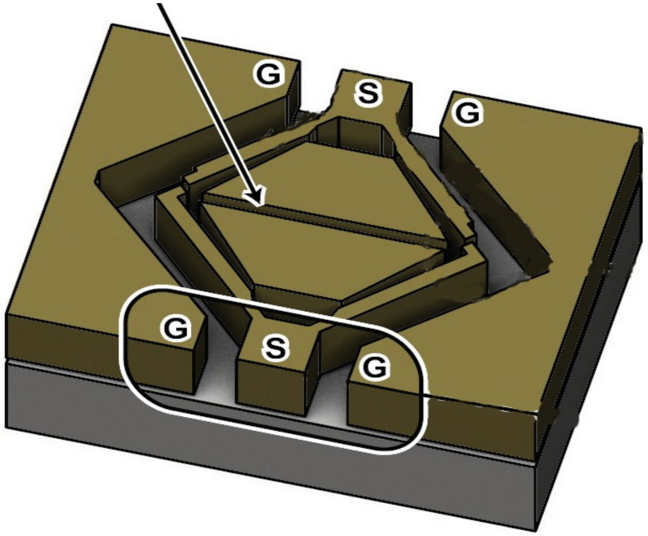
Phase	***Content***
Nov 03-06	1 meetings 1-3 (introduction, MEMS actuators, FEM simulation)
Nov 09-13	2 design week 1: concepts, FEM; meeting 4: CAD layout, design rules, fabrication
Nov 16-20	2 design week 2: FEM simulations, device design
Nov 23-27	2 design week 3: device design, CAD layouting
N30-Dec4	design deadline; intermediate report
Dec 7-11	**3, 4 fabrication week; evaluation work**
Dec 14-18	4 evaluation work
Jan 4-8	(4) (evaluation work), time for report+presentation writing; deadline for report
Jan 12	final presentation (8-12, Q2)

IMPORTANT DATE for the fabrication: mask layout deadline: Monday, Nov 30, 11:59, Lab 1

Lab (two fabrication days in Kista; 8.30 – 16.30; with lunch break)

Lab 1	**3rd and 4th of December**
Lab 2	**11th and 14th of December**
Lab 3	**15th and 16th of December**
Lab 4	**17th and 18th of December**
Lab 5	**21th and 22th of December**

Examples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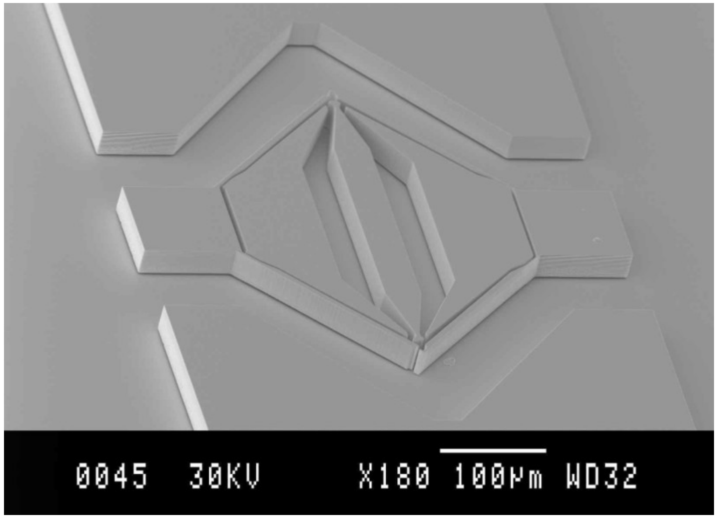
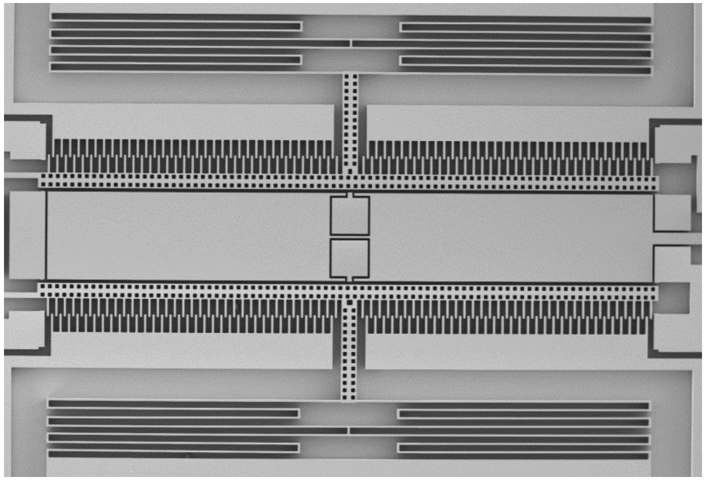
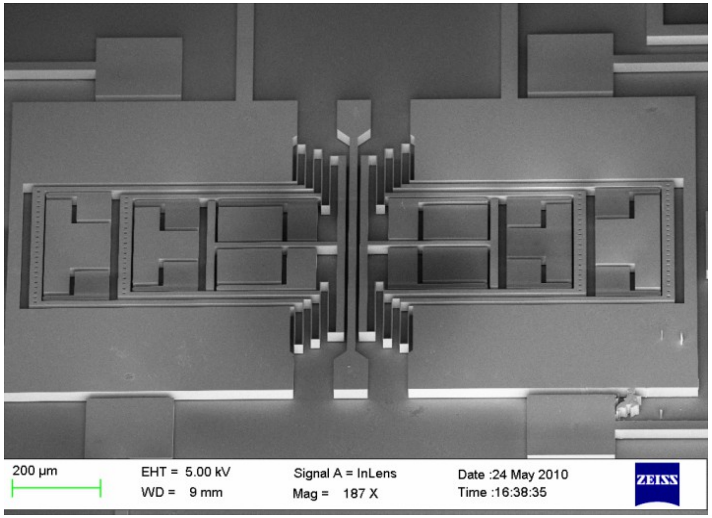
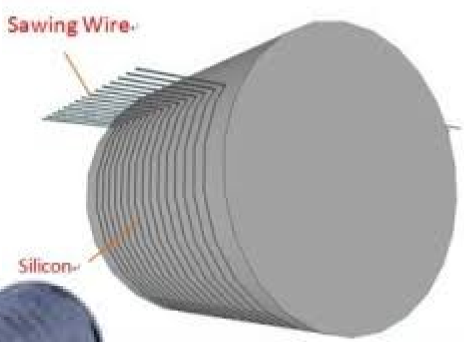

0045 30KV X180 100μm WD32




200 μm
EHT = 5.00 kV
WD = 9 mm
Signal A = InLens
Mag = 187 X
Date :24 May 2010
Time :16:38:35
ZEISS

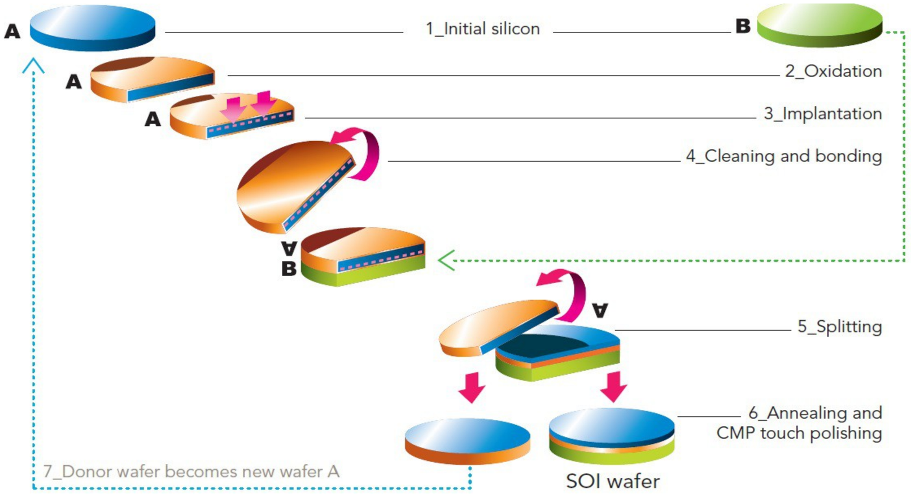
Fabrication of Silicon wafers

- starting material: quartz sand
- chemical reduction to metallurgical grade silicon
- electronic grade silicon (99.999999999%)
- mono-crystalline silicon growing
- ingot slicing
- grinding / chemical – mechanical polishing



Silicon-on-Insolater (SOI)

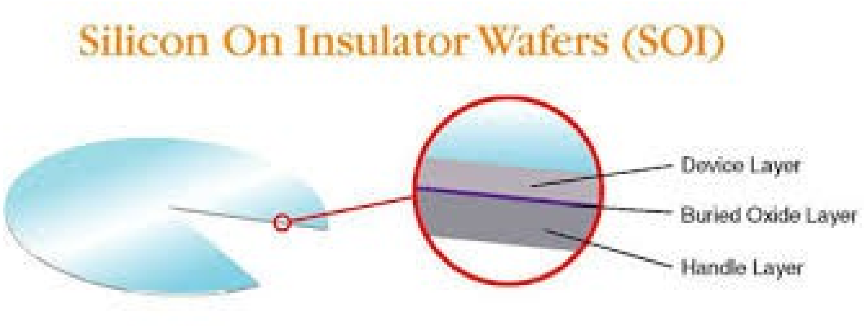
- SOI substrates used in microelectronics and MEMS
  - reduced parasitic capacitance
  - RF MEMS, co-planar wave guides
  - heterogeneous integration approaches
- SIMOX, direct wafer bonding, Smart Cut



[1] Fabrication of Ultra-thin Silicon-on-Insulator (SOI) Using Soitec Smart Cut® Technology
[2] CELLER, G. K.; CRISTOLOVEANU, Sorin. Frontiers of silicon-on-insulator. Journal of Applied Physics, 2003, 93. Jg., Nr. 9, S. 4955-4978.

Device fabrication (1)

- **Starting material**
  - **silicon-on-insolator (SOI) wafer**
- **quartz mask (patterned)**



Device fabrication (2)

Process flow

1. oxidation
2. patterning of the oxide mask
3. etching of the silicon device layer
4. releasing of movable elements
5. metallization

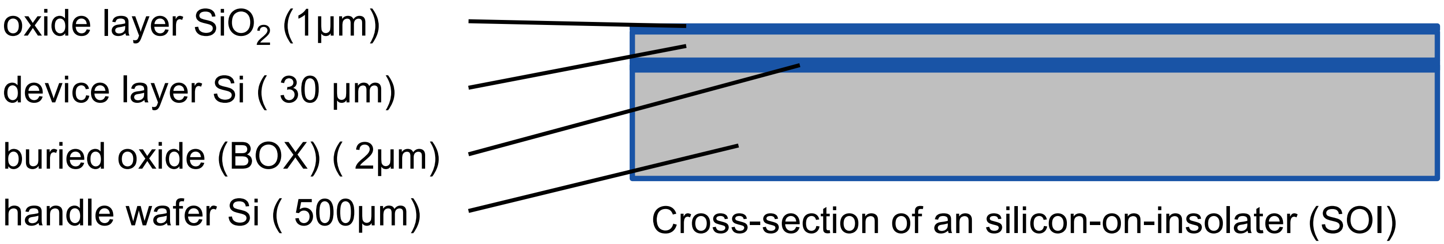
Characterization

- scanning electron microscope (SEM)
- energy dispersive X-ray spectroscopy (EDX)
- optical profilometer

Oxidation

- Thermal grow of SiO_2
- Wet or Dry
- Diffusion limited process
- $Si + 2H_2O \rightarrow SiO_2 + 2H_2$
- Temp: 900 - 1150°C

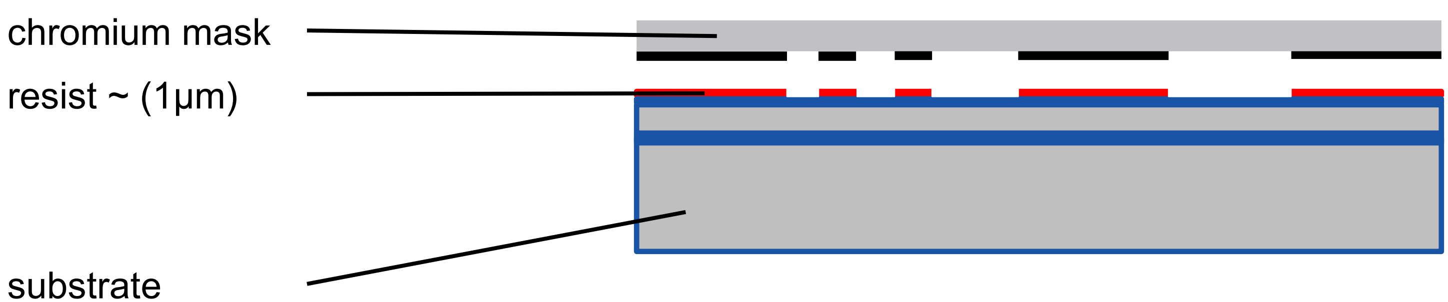
http://www.veonis.com



Cross-section of an silicon-on-insolater (SOI) wafer after thermal oxidation.

Patterning of the oxide mask (lithography)

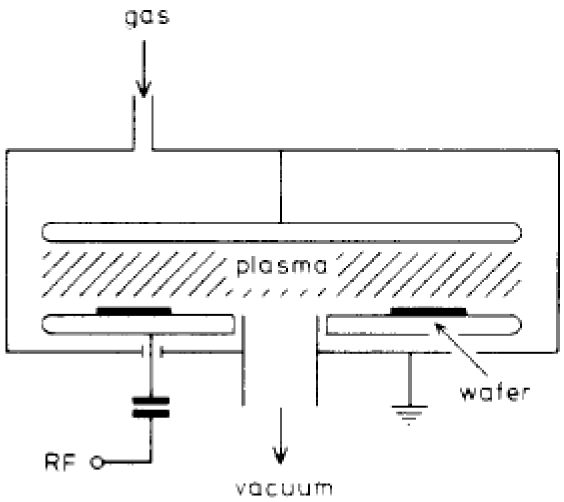
- **application of photo-resist**
- **soft bake**
- **exposure**
- **post exposure bake (PEB)**
- **development**
- **hard bake**



Dry etching of silicon dioxide

Reactive Ion Etching (RIE)

- gas – solid interface
- formation of plasma
- dissociation of molecules to radicals, atoms and ions
- CF_4, H_2, CHF_3, Ar



p= 7 Pa; P = 4 kWm-2

$$CF_4 \rightarrow 2F + CF_2$$
$$H_2 \rightarrow 2H$$
$$H + F \rightarrow HF$$
$$SiO_2 + 2CF_2 \rightarrow SiF_4 + 2CO$$

Substrate

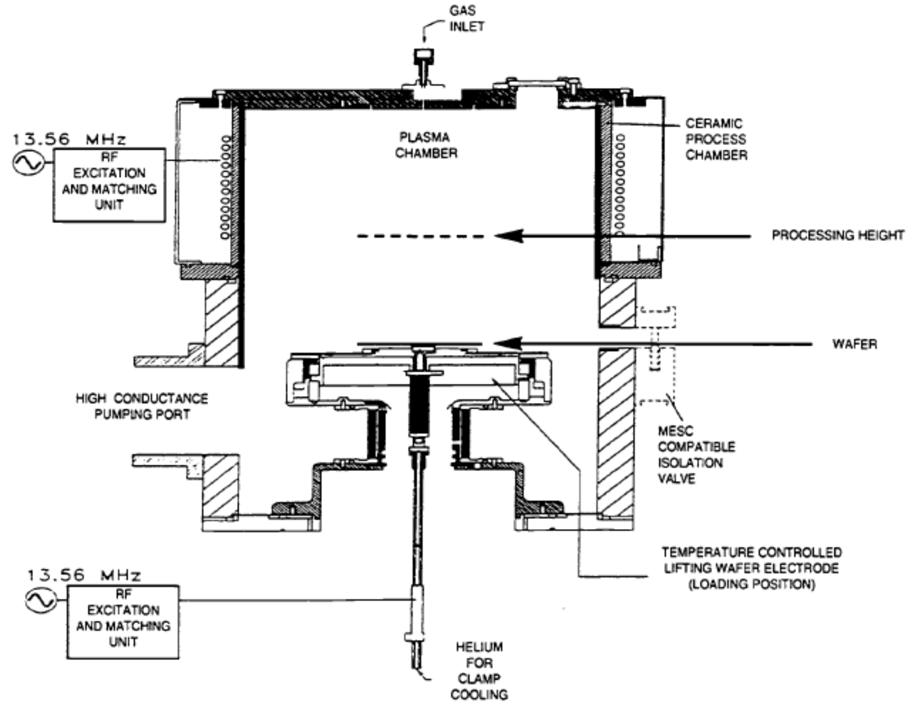
[1] van Roosmalen, Alfred J. "Review: dry etching of silicon oxide." *Vacuum* 34.3 (1984): 429-436.
[2] Jansen, Henri, et al. "A survey on the reactive ion etching of silicon in microtechnology." *Journal of micromechanics and microengineering* 6.1 (1996): 14.

Dry etching of silicon

Deep Reactive Ion Etching (DRIE)

- high density plasma (ICP)
- time multiplexed alternating process
- passivation / etching

- etch:
  $SF_6 \rightarrow SF_{6-x} + xF$
  $Si + 4F \rightarrow SiF_4$
- passivation:
  $C_4F_8 \rightarrow (C_xF_y)_n\ (s)$

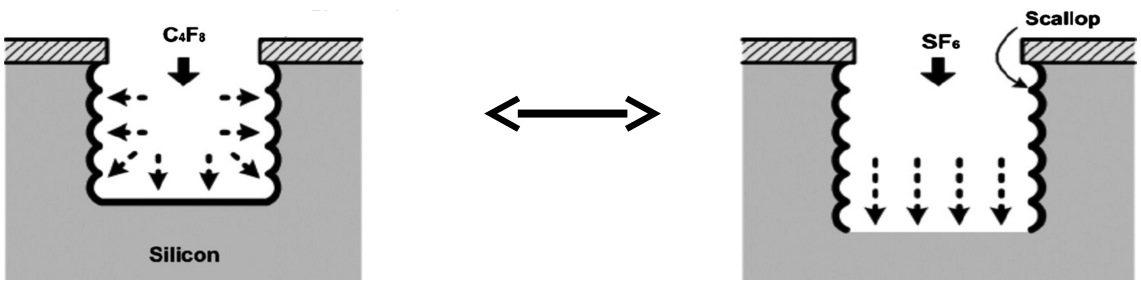


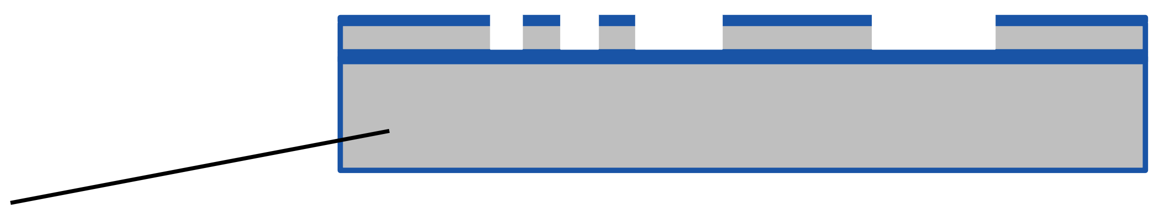
Substrate

[1] Bhardwaj, Jy K., and Huma Ashraf. "Advanced silicon etching using high-density plasmas." *Micromachining and Microfabrication*. International Society for Optics and Photonics, 1995.

Formation of the devices (dry etching)

- **Dissoziation in plasma**
  - $SF_6 + e^- \rightarrow S\dot{F}_5 + \dot{F} + e^- \rightarrow S\dot{F}_4 + \dot{F} + 2e^-$
  - $C_4F_8 + e^- \rightarrow C_3\dot{F}_6 + C\dot{F}_2 + e^-$
- **Reaction on the surface**
  - $Si + 4\dot{F} \rightarrow SiF_4(\uparrow)$
  - $nC\dot{F}_2 \rightarrow nC\dot{F}_{2(ads)} \rightarrow nCF_{2(s)}$



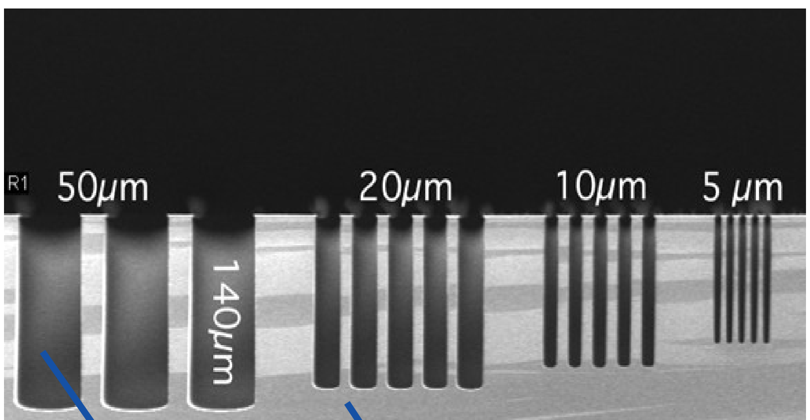


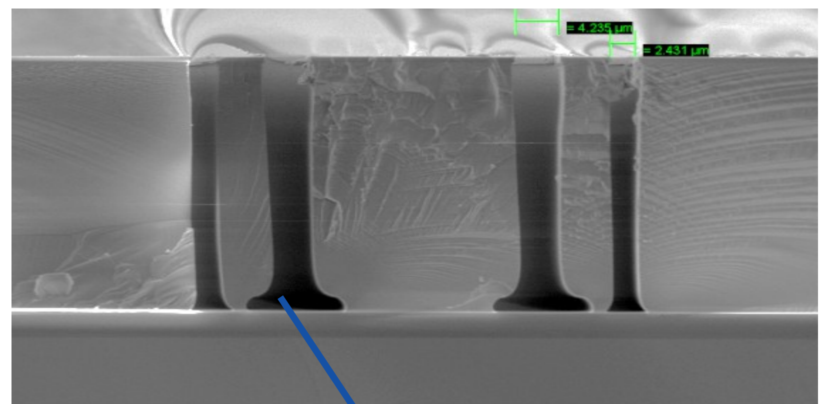
Substrate

[1] Laerme, F., et al. "Bosch deep silicon etching: improving uniformity and etch rate for advanced MEMS applications." *Micro Electro Mechanical Systems, 1999. MEMS'99. Twelfth IEEE International Conference on*. IEEE, 1999.

Etching issues of silicon using DRIE process

- Aspect Ratio Dependence Etching (ARDE)
- Under etching of silicon at the buried oxide (BOX) layer





Variation in depth of trenches

footing (under etching)

Release of movable elements (Wet etching)

Wet etching of silicon dioxide

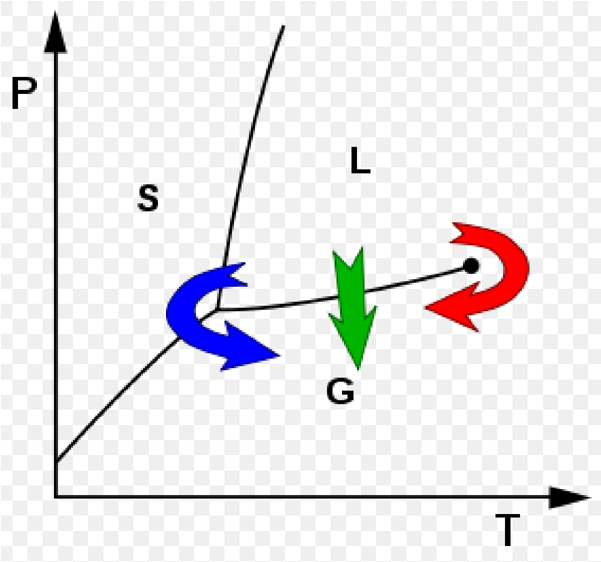
- **Removal of the oxide mask**
- **Locally removal of BOX layer**
- **Isotropic etch**
- **$6HF + SiO_2 \rightarrow H_2O + H_2SiF_6$ (aq.)**

Substrate

Super critical Drying

Critical Point Drying

- Stiction results device failure
- Drying from the solid to the gaseous phase

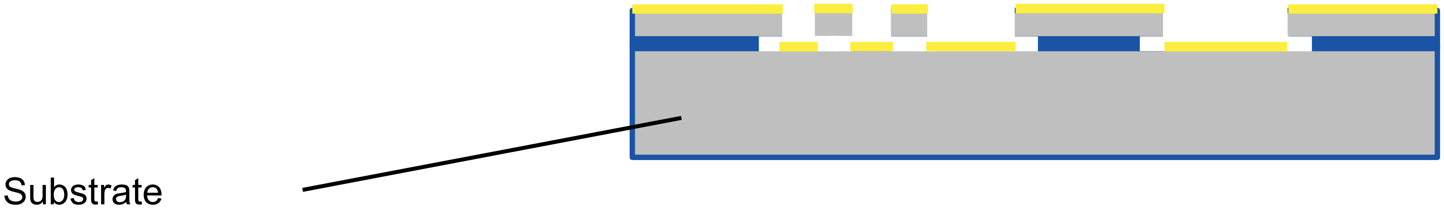


Metallization

(Physical Vapour Deposition)

Sputtering of gold

- Ignition of an Ar+ plasma
- Acceleration towards the target
- Physical removal of Au
- Re-deposition on the substrate

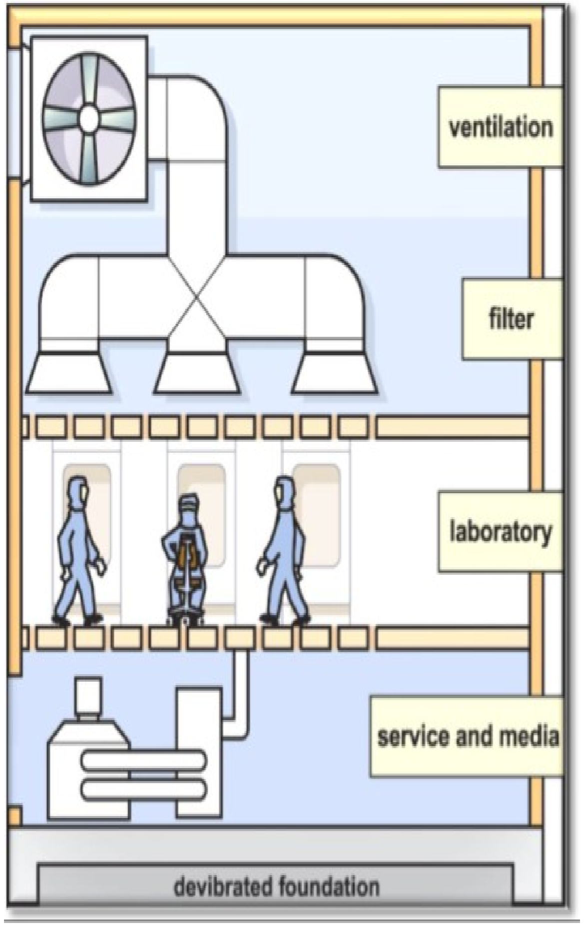


EK2360 Fabrication lab

Safety instruction and lab behavior

Why Cleanroom

- Controlled Laboratory atmosphere
  - Minimizing amount and size of particles
  - Offering laminar air flow
  - Constant temperature
  - Constant humidity
- Critical dimensions in MEMS:
  - Hair diameter:



Cleanroom Behavior

- Effective particle reduction
  - Wearing of cleanroom garments
  - Wearing of gloves
  - Slow walking (no running)
  - No eating
  - Objects have to be cleaned
  - No regular paper

PEOPLE ACTIVITY	Particles/Minute (0.3 um and larger)
Motionless (Standing or Seated)	100,000
Walking about 2 mph	5,000,000
Walking about 3.5 mph	7,000,000
Walking about 5 mph	10,000,000

Safety Instruction

- Cleanroom garments protect the cleanroom environment from particles.
- Goggles and gloves must be worn all times in the cleanroom.
- All actions, such as handling of objects, samples or chemicals must be performed under supervision of the lab assistant.

Safety Instruction

- On stage safety instruction will be given by the lab assistant to inform about
  - **Code of behavior in case of an emergency**
  - **Eye rinsing station**
  - **Emergency showers**
  - **Calciumgluconate (BHF Antidote) gel**
  - **Emergency exit**

Chemicals

Flammable

Corrosive

Toxic

Harmful

Dangerous to the Environment

Oxidizing