EE669: VLSI Technology

Cleanroom Practice

Anil Kottantharayil

Department of EE, IIT Bombay

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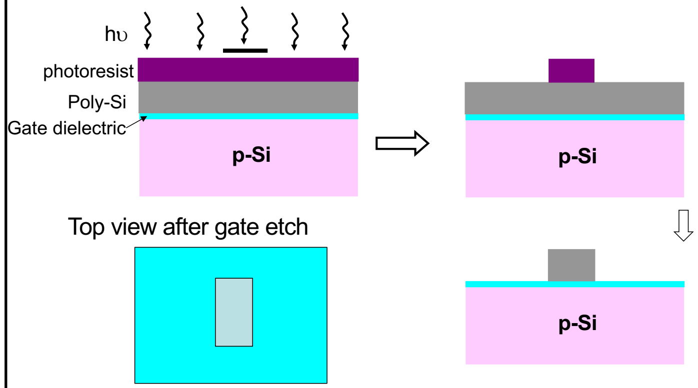
Manufacturing yield: exercise

An IC manufacturing plant produces 1000 wafers per week. Assume that each wafer contains 100 chips, each of which can be sold for $50 if it works. The yield on these chips is currently running at 50%. If the yield can be increased, the incremental income is almost pure profit, because all 100 chips on each wafer are manufactured whether they work or not. How much would the yield have to be increased to produce an annual profit increase of $10,000,000?

2

Particulate contaminants

Example: Gate patterning in a MOS technology



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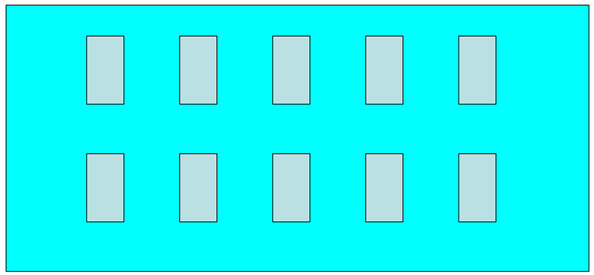
Particulate contaminants (2)



Several devices: Top view after gate etch.

This is what we want.

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Particulate contaminants (3)

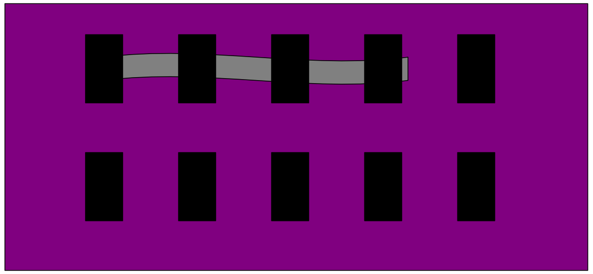

Photo resist with mask on top before exposure.

Hypothetical condition: A particle, for example a piece of the hair of an engineer in the processing area falls on the wafer prior to the photo exposure process.

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Particulate contaminants (4)

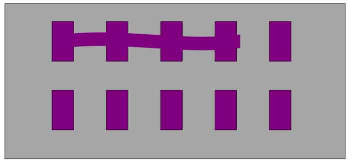
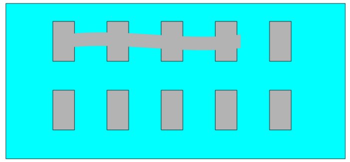
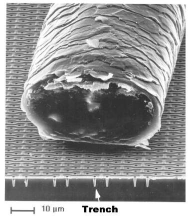


Photo resist after exposure and development.



Poly Si gates after etch of poly Si and removal of the resist.



Human hair on a 4 Mbit memory chip.
https://www.tf.uni-kiel.de

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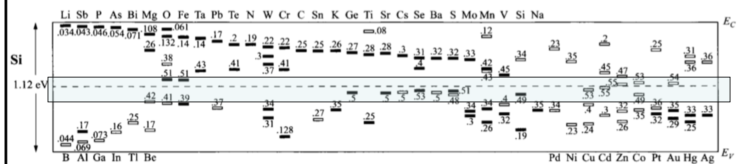
Metallic Impurities (1)



S. M. Sze, Physics of Semiconductor Devices

These are efficient generation – recombination centers

$$\tau = \frac{1}{\sigma v_{th} N_t}$$

- Cause high reverse bias leakage in diodes
- Reduce gain of BJT
- Reduction of bulk lifetime - carrier collection in solar cells would be reduced – reduced power conversion efficiency

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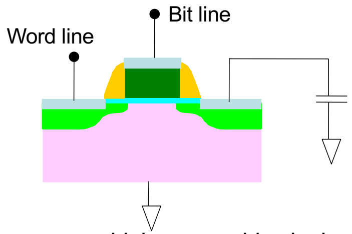
Metallic Impurities – life time killers (2)



Impurities can cause high reverse bias leakage in diodes

$$J = \frac{qn_i W}{2\tau} = \frac{1}{2} qn_i W \sigma v_{th} N_t$$

- When the capacitor is charged to ~ V_{DD}, and holding logic 1, the source to substrate junction is reverse biased.
- Leakage determines how often the DRAM cell has to be refreshed.

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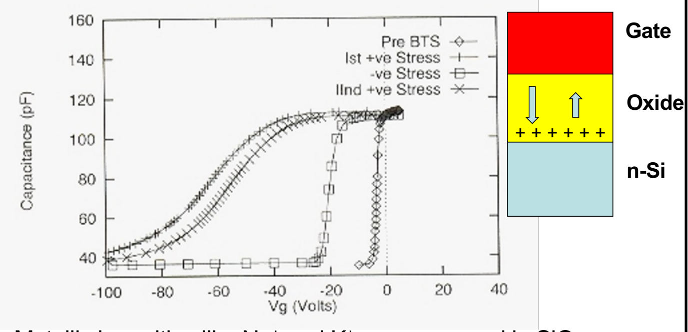
Metallic impurities: exercise

A particular metallic impurity is known to reduce the minority carrier lifetime in silicon. The capture cross-section of the trap level introduced by the impurity is 10^{-15} cm^2, thermal velocity at room temperature is 10^7 cm/s. For a target minority carrier lifetime of 1 msec, what is the maximum concentration of the impurity that can be tolerated in the material? Express this both per cm^3 as well as in percentage.

Metallic Impurities – ionic mobile charge (3)



• Metallic impurities like Na^+ and K^+ moves around in SiO_2 under electrical field causing instability in characteristics.
• Typical surface contamination should be less than 10^{11} cm^{-2}

K. G. Anil, M. Tech thesis, IIT Bombay, 1997

Mobile ions: exercise

The threshold voltage instability that can be tolerated in a MOSFET circuit is 10 mV. If the MOSFET uses 2.2 nm SiO_2 as gate oxide, what is maximum surface concentration of mobile ions in the oxide (per cm^2) that can be tolerated?

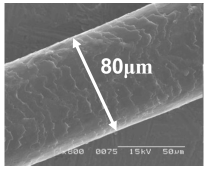
Tackling contamination

Three strategies:

• Specially designed low particle count clean rooms for manufacturing and R & D.
• Particle control during processing.
• Strict delineation of processes as clean and contaminating and intermediate process steps to avoid contamination.
  • Separation of tools and areas in clean rooms
  • Wafer cleaning procedures between steps to remove contaminants
  • Diffusion barriers to prevent contamination of critical regions
• Impurity gettering to handle contaminants, especially metals, incorporated in the wafer during processing.

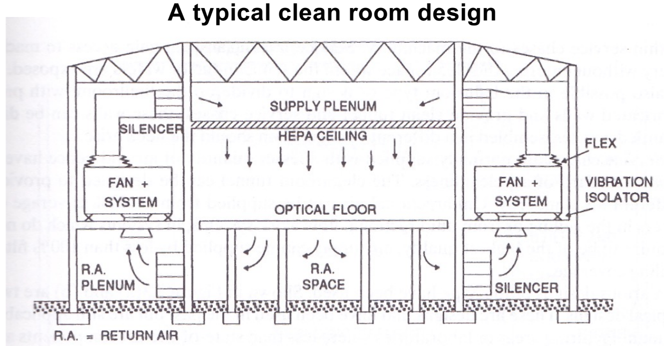
Particle Contamination

- Particle contamination
  - Size of typical air borne particles can be of the order of magnitude of the structural dimensions of the devices
  - Sources
    - Air
    - Human beings: 50,00,000 to 100,00,000 particles/minute
    - Clean room walls
    - Gases and chemicals
    - Processes and equipment



www.semguy.com

A typical clean room design



HEPA filter: High Efficiency Particulate Air filter. Minimum efficiency of particle removal = 99.97%

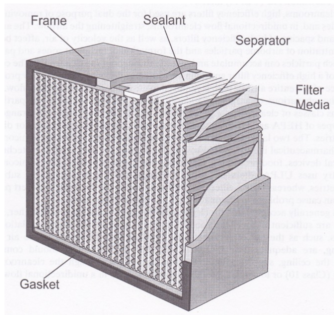
ULPA filter: Ultra Low Penetration Air filter. Efficiency of 99.999% for ~0.1 to 0.2µm

W. Whyte (ed.), Cleanroom Design, II[nd] edition, Wiley, 1991

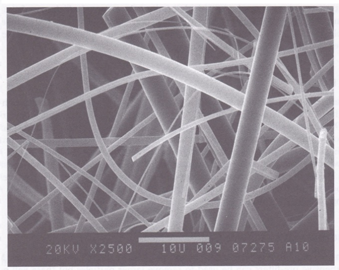
Clean room example

CeNSE cleanroom, IISc

Particulate Filters



HEPA filter



Filter medium: glass fiber

W. Whyte (ed.), Cleanroom Design, II[nd] edition, Wiley, 1991

Clean room classification: ISO 14644-1

Definitions

- **Cleanroom or clean zone – room or zone in which the concentration of airborne particles is controlled, and which is used in a manner to minimize the introduction, generation, and retention of particles inside the room, and in which other relevant parameters, e.g. temperature, humidity and pressure are controlled as necessary**

- **Classification – the process of specifying the level of airborne particulate, expressed in terms of an ISO Class N, which represents maximum allowable concentrations (in particles per cubic meter of air) for considered sizes of particles**

Clean room classification: ISO 14644-1

Classification number (N) –

$$C_n = 10^N \left(\frac{0.1}{D} \right)^{2.08}$$

where
C_n- is the maximum permitted concentration (in particles per cubic meter of air) of airborne particles that are equal to or larger than the considered particle size, D. C_n is rounded to the nearest whole number.

N – is the ISO classification number, which shall not exceed the value of 9. Intermediate ISO classification numbers may be specified with 0.1, the smallest permitted increment of N

D – is the considered particle size in micrometers

0.1 – is a constant with dimensions of micrometers

Clean room classification: ISO 14644-1

ISO Class (N)	Maximum Concentration (Cn) of Particles in Air {Particles in each cubic meter equal to or greater than the specified size (D in µm)} per m³					
	Particles size					
	> 0.1 µm	> 0.2 µm	> 0.3 µm	> 0.5 µm	> 1 µm	> 5 µm
ISO Class 1	10	2				
ISO Class 2	100	24	10	4		
ISO Class 3	1,000	237	102	35	8	
ISO Class 4	10,000	2,370	1,020	352	83	
ISO Class 5	100,000	23,700	10,200	3,520	832	29
ISO Class 6	1,000,000	237,000	102,000	35,200	8,320	293
ISO Class 7				352,000	83,200	2930
ISO Class 8				3,520,000	832,000	29,300
ISO Class 9				35,200,000	8,320,000	293,000

Clean room classification: ISO 14644-1

LAB NAME	Location ID.	No. of Particles ≥ 0.5 µm/m3	No. of Particles ≥ 5 µm/m3
NCPRE LAB (2.1)	L1	21293	220
	L2	10240	60
	L3	2590	130
	L4	8448	60
	L5	8839	20
	L6	6928	120
	L7	9808	230
	L8	9046	30
	L9	12056	20
	L10	13117	140
	L11	11379	80
	L12	11488	40

Exercise: What is the ISO class of the NCPRE clean room?