EEE6395

Compound Semiconductor Device Manufacture

Cleanroom Infrastructure

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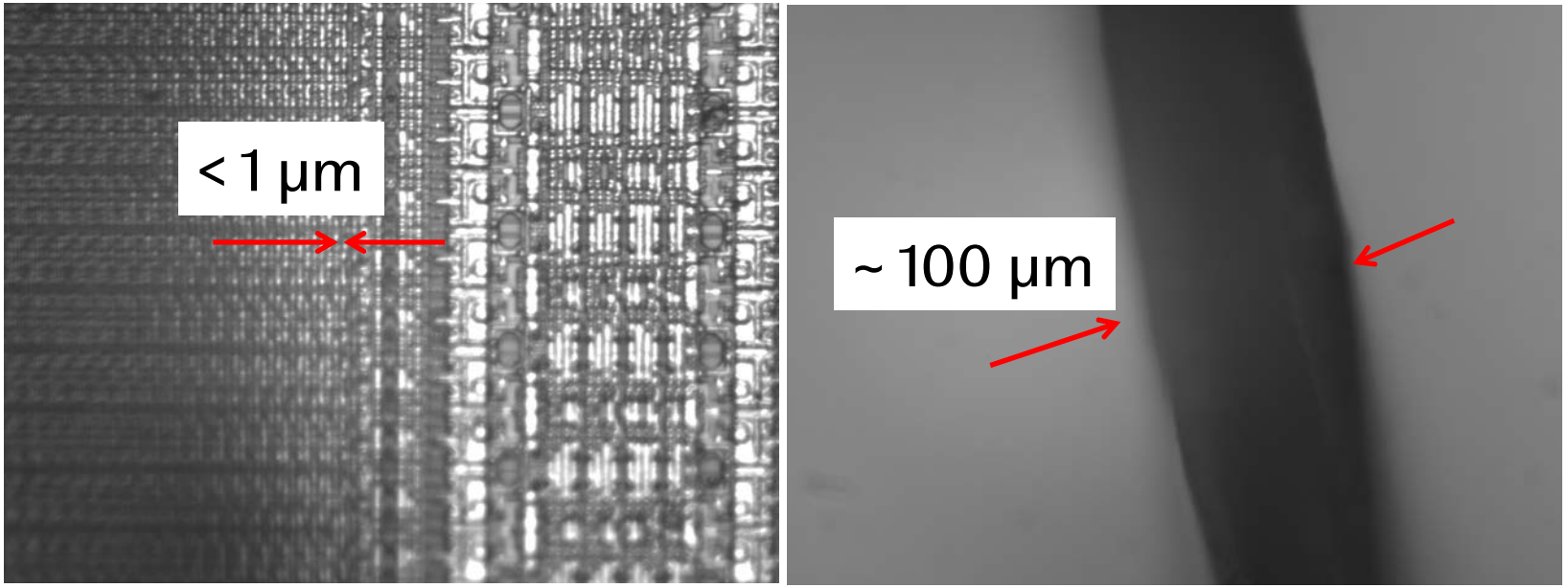
References
‘Cleanroom Technology’ W. Whyte Wiley & Sons (2010)
‘Cleanroom Design’ W. Whyte Wiley & Sons (1999)

Why do we need a cleanroom for semi-conductor fab?



IC

Human hair

At same scale!

Any dust on wafer surface during manufacture will destroy device

Manufacturers spend $billions being clean and tidy

Purposes of cleanroom

- Reduce concentration of airborne particulates - to ensure a high *yield*
- Temperature *T* control – to ensure consistent results, since: $Rate = A\exp(\frac{-E_a}{k_B T})$
- Humidity *RH* control – to ensure consistent results (photoresist cross-linking needs water vapour)
- Vibration isolation – lithography needs sub-micron alignment accuracy
- EM isolation – to prevent interference

Semiconductor cleanrooms at Sheffield University #1

EEE Departmental Cleanroom
C Floor
Mappin Building

- Undergraduate teaching
- Undergraduate projects
- Lithography research

Semiconductor cleanrooms at Sheffield University #2

- GaAs and GaN wafer growth
- Device fabrication
- Device characterisation and testing
- PhD research
- Masters projects

National Centre for III-V semiconductors

‘North Campus’ ‘Kroto Innovation Centre’ ‘NC’

Broad Lane

Semiconductor cleanrooms at Sheffield University #3

New Engineering Building ('Jessops')
Opens 2015
Including a large teaching cleanroom

Types of clean room

- Microelectronics
- Medical devices (pacemaker, cannula)
- Pharmaceuticals (drugs –oral, injection, skin)
- Biotechnology (genetic modification)

Extra factors: Sterile environment
Containment of waste (solid, liquid, airborne)
(not considered in this course)

Cleanroom classification

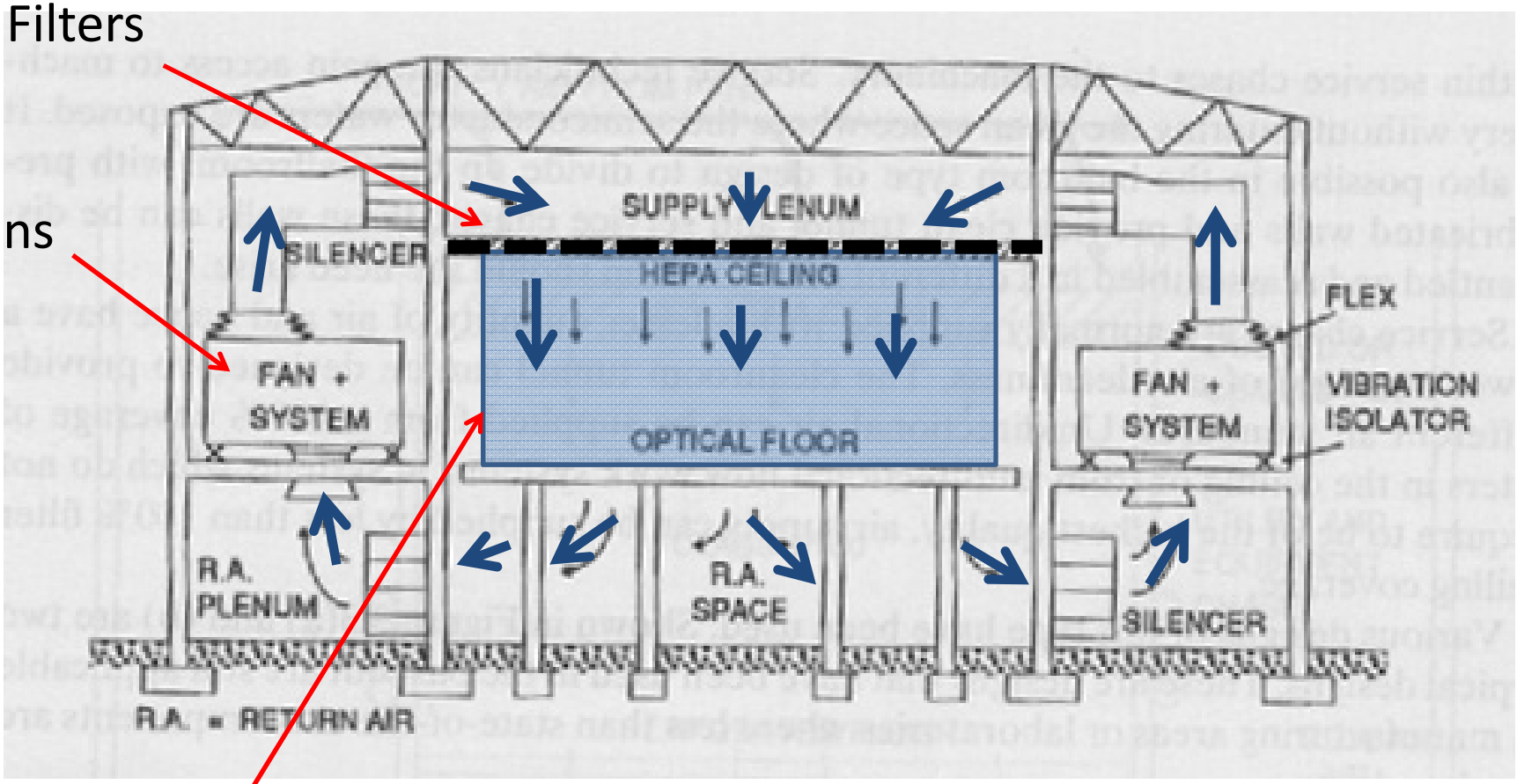
= 1/foot^3

Class (ISO)	Maximum particles/m³						FED STD 209E equivalent
	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥1 µm	≥5 µm	
1	10	2.37	1.02	0.35	0.083	0.0029	
2	100	23.7	10.2	3.5	0.83	0.029	
3	1,000	237	102	35	8.3	0.29	Class 1
4	10,000	2,370	1,020	352	83	2.9	Class 10
5	100,000	23,700	10,200	3,520	832	29	Class 100
6	1.0×10^6	237,000	102,000	35,200	8,320	293	Class 1,000
7	1.0×10^7	2.37×10^6	1,020,000	352,000	83,200	2,930	Class 10,000
8	1.0×10^8	2.37×10^7	1.02×10^7	3,520,000	832,000	29,300	Class 100,000
9	1.0×10^9	2.37×10^8	1.02×10^8	35,200,000	8,320,000	293,000	Room air

Cleaner, more expensive

In 1 m^3 of room air there are *millions* of <1µm particles!

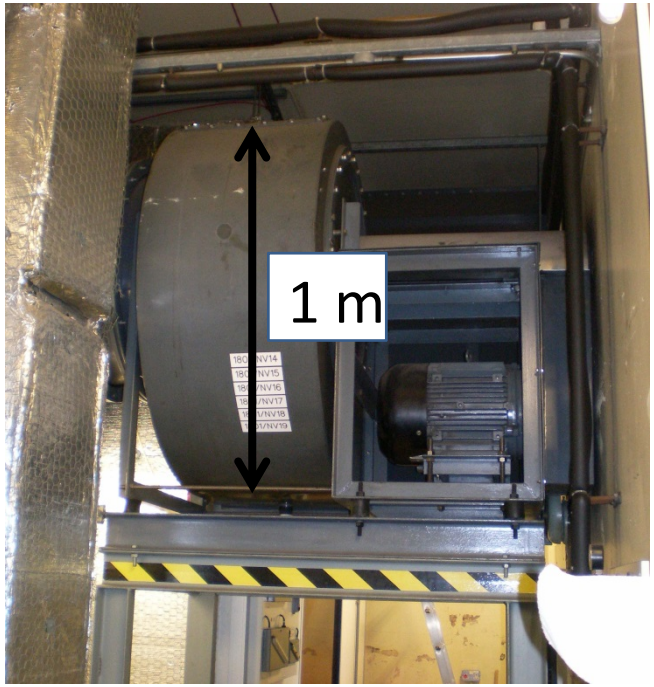
Ideal vertical airflow



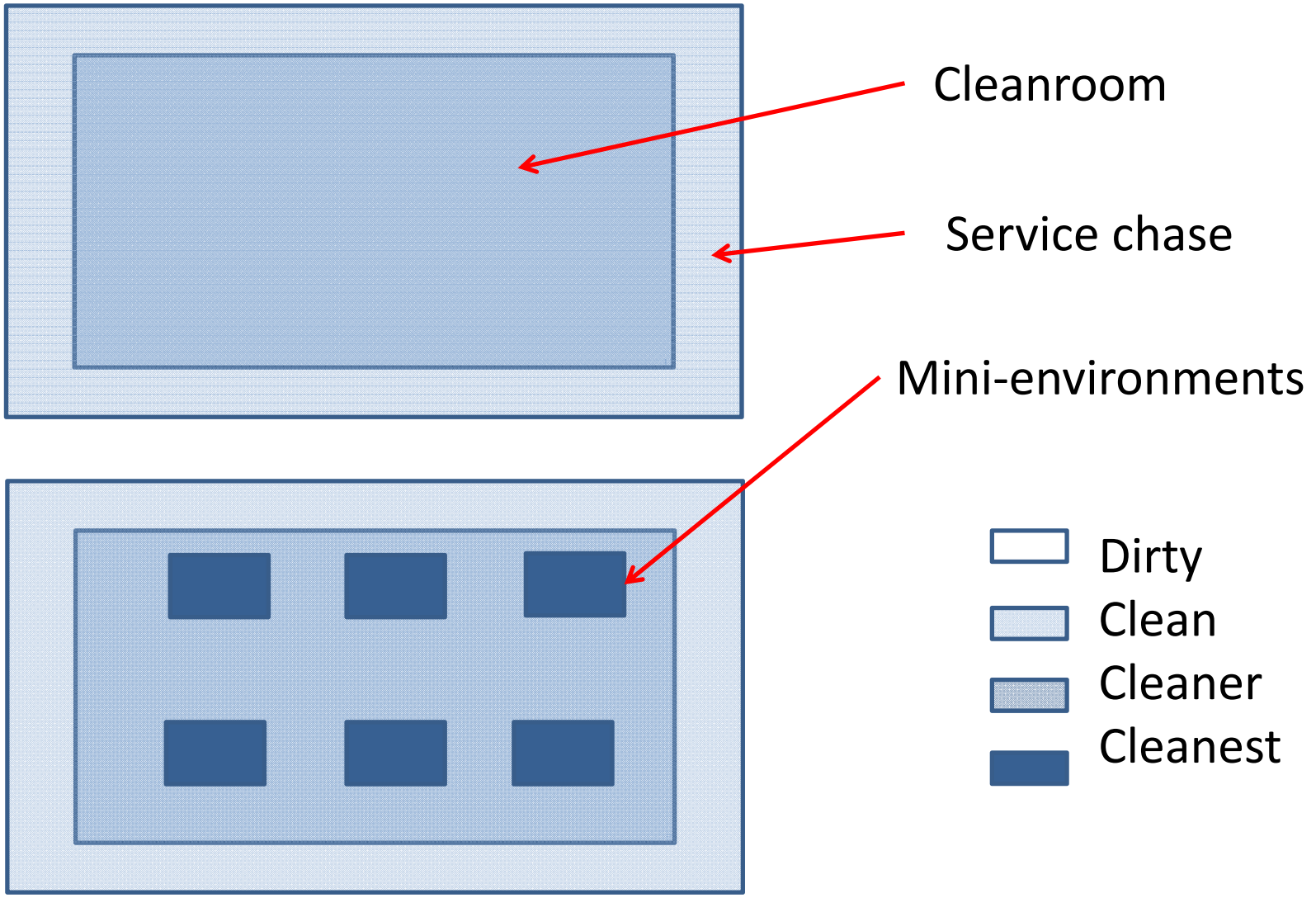
- Clean air enters through roof
- Dirty air exits through floor
- Vibration isolation for cleanroom floor
- Cleanroom occupies just 25% of building

Fans

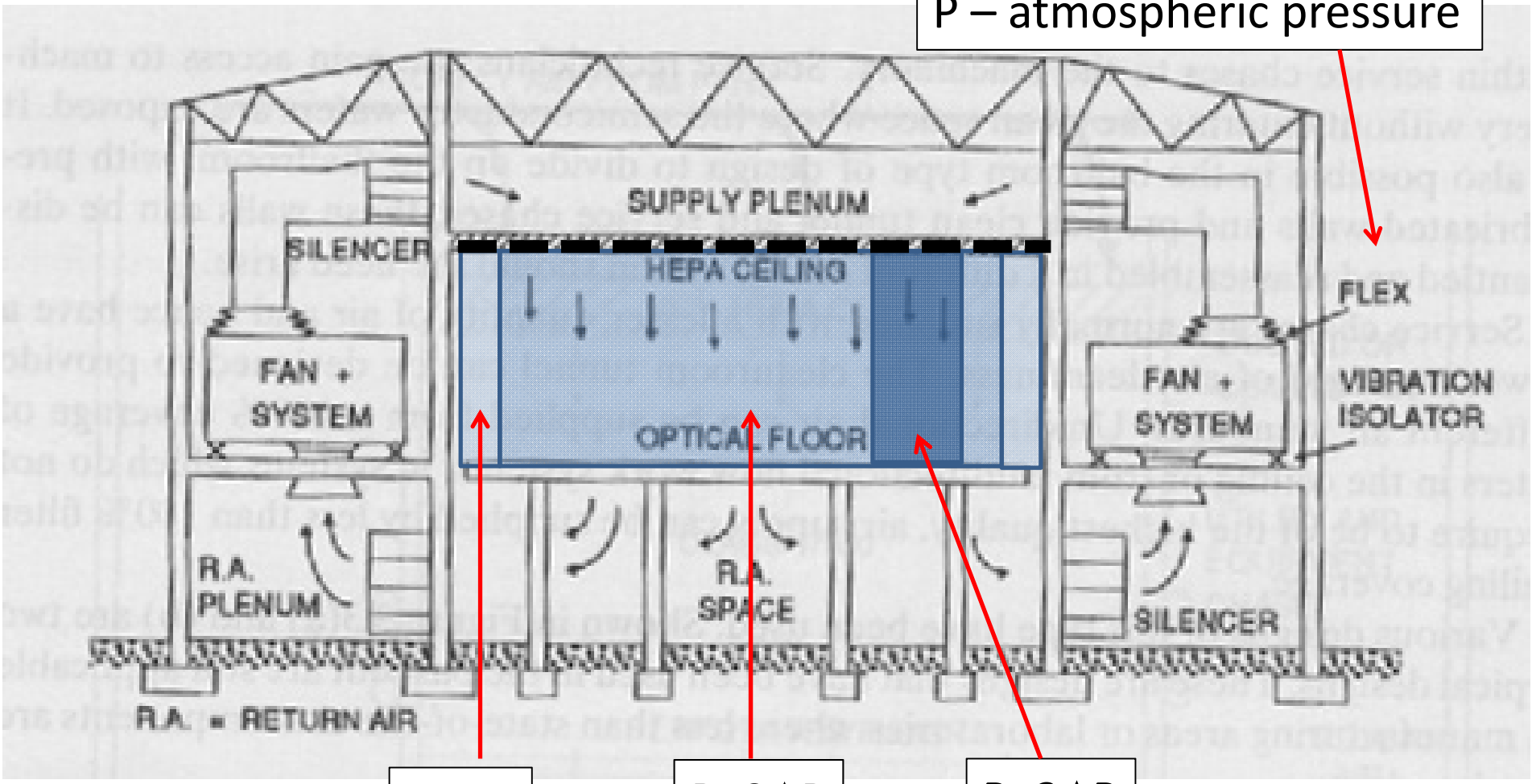
- Axial vane
- Vibration isolation from lab
- Sound attenuation
- EM isolation
- Consume a lot of power



Cleanroom floor plans



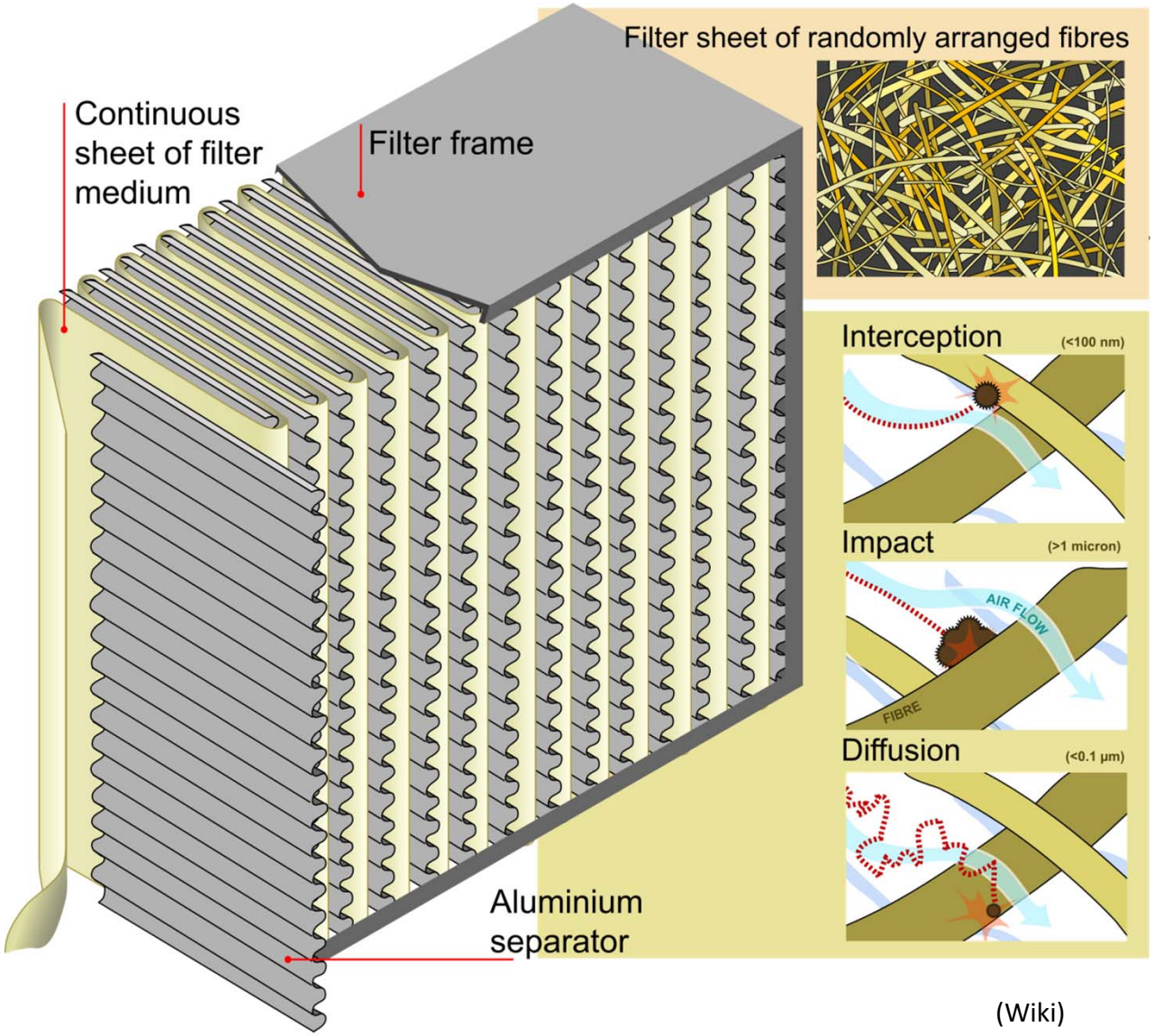
Pressure differences



Cleanest area at highest positive pressure

$\Delta P \sim 15$ Pa (0.15 mbar)

High-efficiency particulate air (HEPA) filter



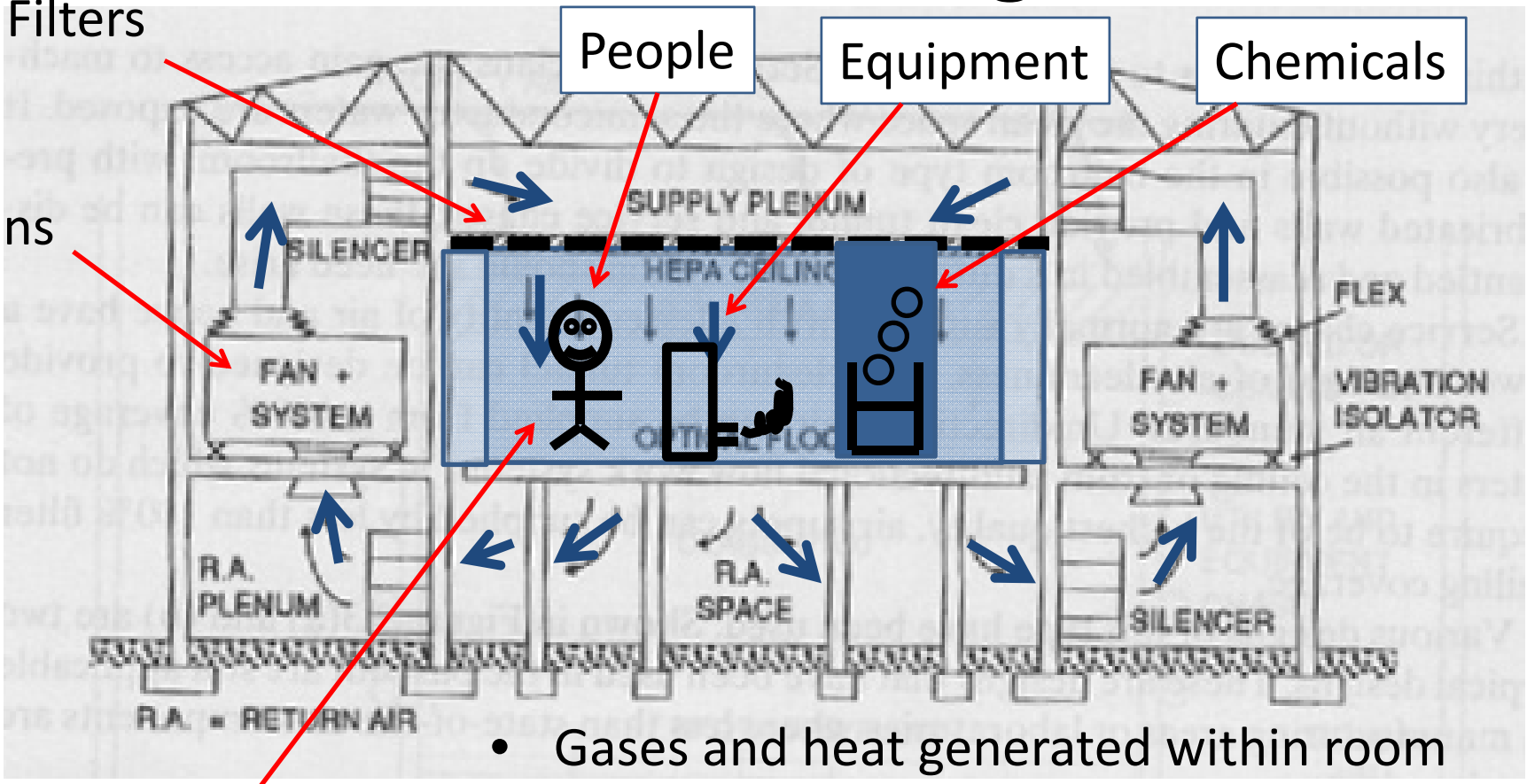
(Wiki)

Dense mat of randomly-arranged fibres

Removes >> 99 % of particles > 0.3µm

Does *not* remove gases (e.g. acid or organic vapour)

What's missing?

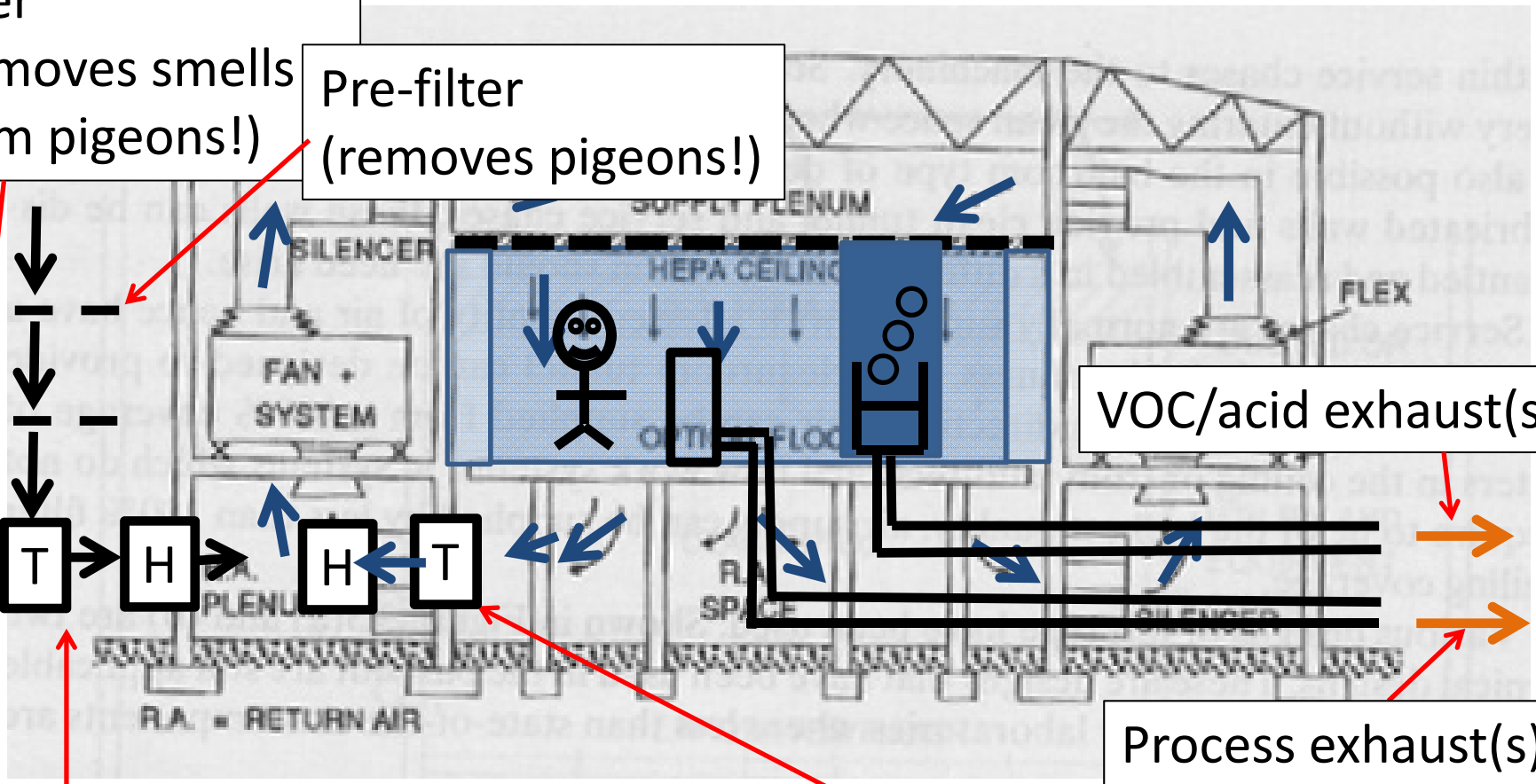


- Gases and heat generated within room

Therefore:

- Temperature control
- Humidity control
- Volatile organic compound (VOC) and process-gas control

Solution:



Activated-carbon filter (removes smells from pigeons!)

Pre-filter (removes pigeons!)

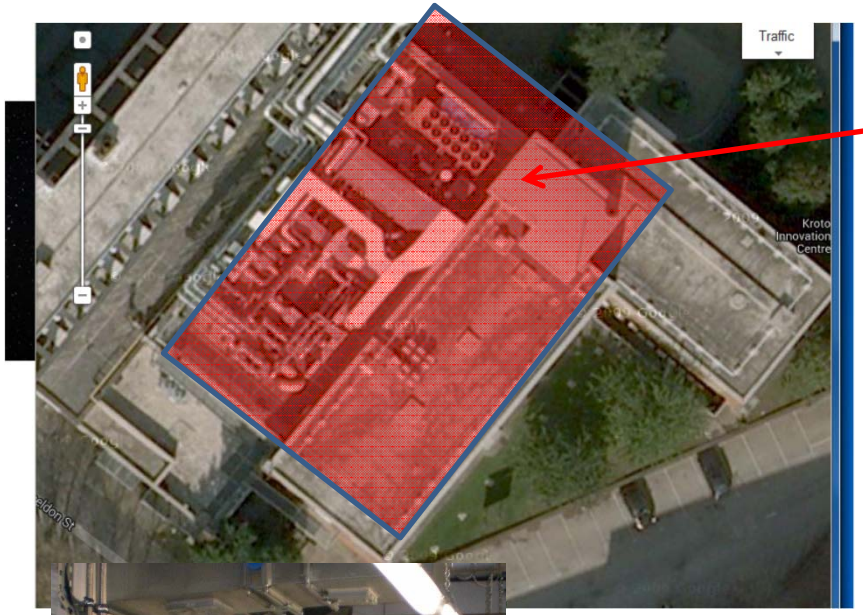
VOC/acid exhaust(s)

Process exhaust(s)

Temperature and humidity conditioning of ‘fresh’ air

Temperature and humidity conditioning of circulating air

Photos of plant



Sheffield III-V building
Air handling plant (same size as cleanrooms!)

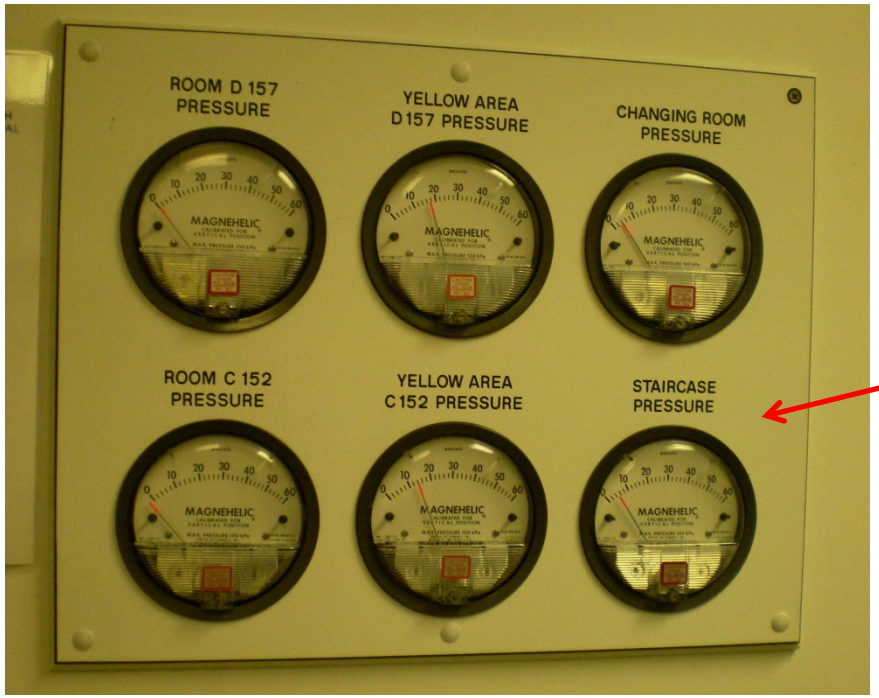
Vacuum pumps in service chase

Exhaust pipes (above roof level)

Measurements

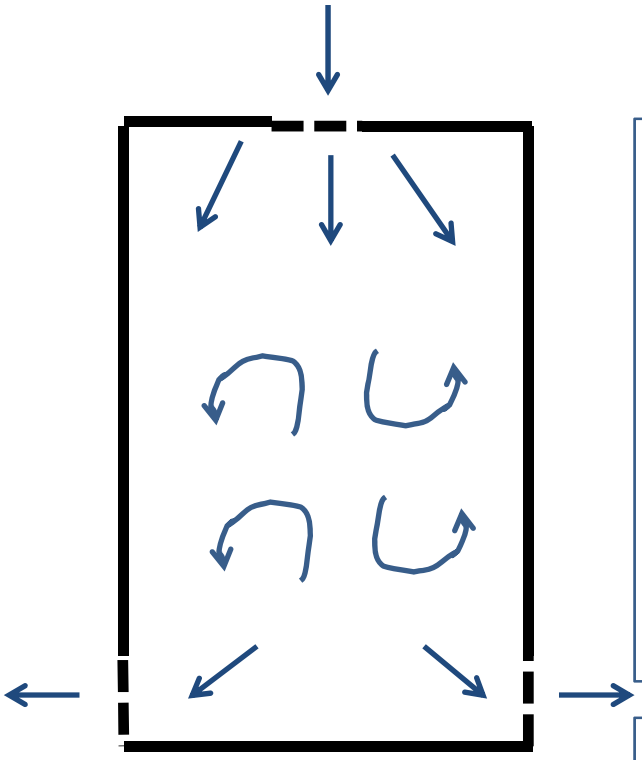
Anemometer
(measures air velocity)

Particle counter
(measures the light scattering from dust in air)



Pressure gauge (‘Magnehelic’)
(measure pressure difference ΔP by using a diaphragm)

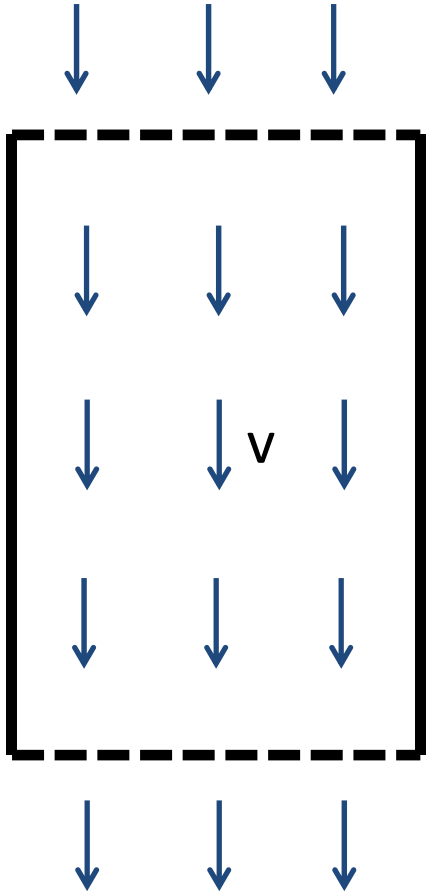
Air flow



E.g. for a 20x20x2m room:

Class	m^3/h (min)
8	1,600
7	8,000
6	80,000
5	432,000
4	720,000

Huge!
Must be delivered at constant T and RH



Turbulent flow

Class	Air changes/hour
8	2-10
7	10-100
6	>100

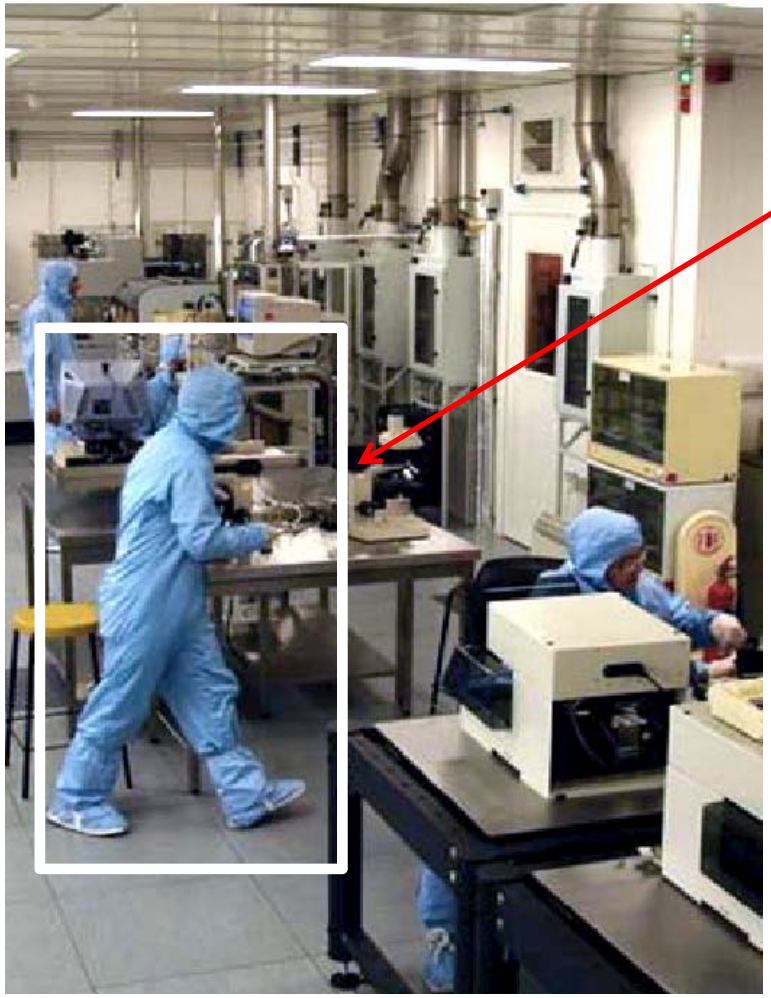
Uni-directional ('laminar') flow
Class 6 and below
Velocity v = 0.3-0.5 ms^{-1}

Materials and design

Plasterboard	No!	Plastic	Yes (but avoid outgassing)
Wood	No!	Metal	Yes
Paint	No!	Coated-metal	Yes
Carpet	No!		

- Avoid corners and crevices where dust can hide
- Add draft-proofing to doors
- Add windows to allow viewing – for visitors and for safety

Clothing



- Full body cover (tight-weave polyester) – shoes the hat then suit then over shoes
- Gloves (latex, nitrile)
- (Glasses)
- (Face mask)

- Minimise dust
- Eliminate static

- Does *not* provide chemical protection

Cleanroom Discipline

Person walking sheds ‘more than *one million* >0.5 µm particles per minute’!

Who counted them?!

Avoid:
sneezing, dandruff, talcum powder, hairspray, cosmetics, food, drink, smoke, paper, pencil, cardboard,…

Use: gloves, tweezers for handling

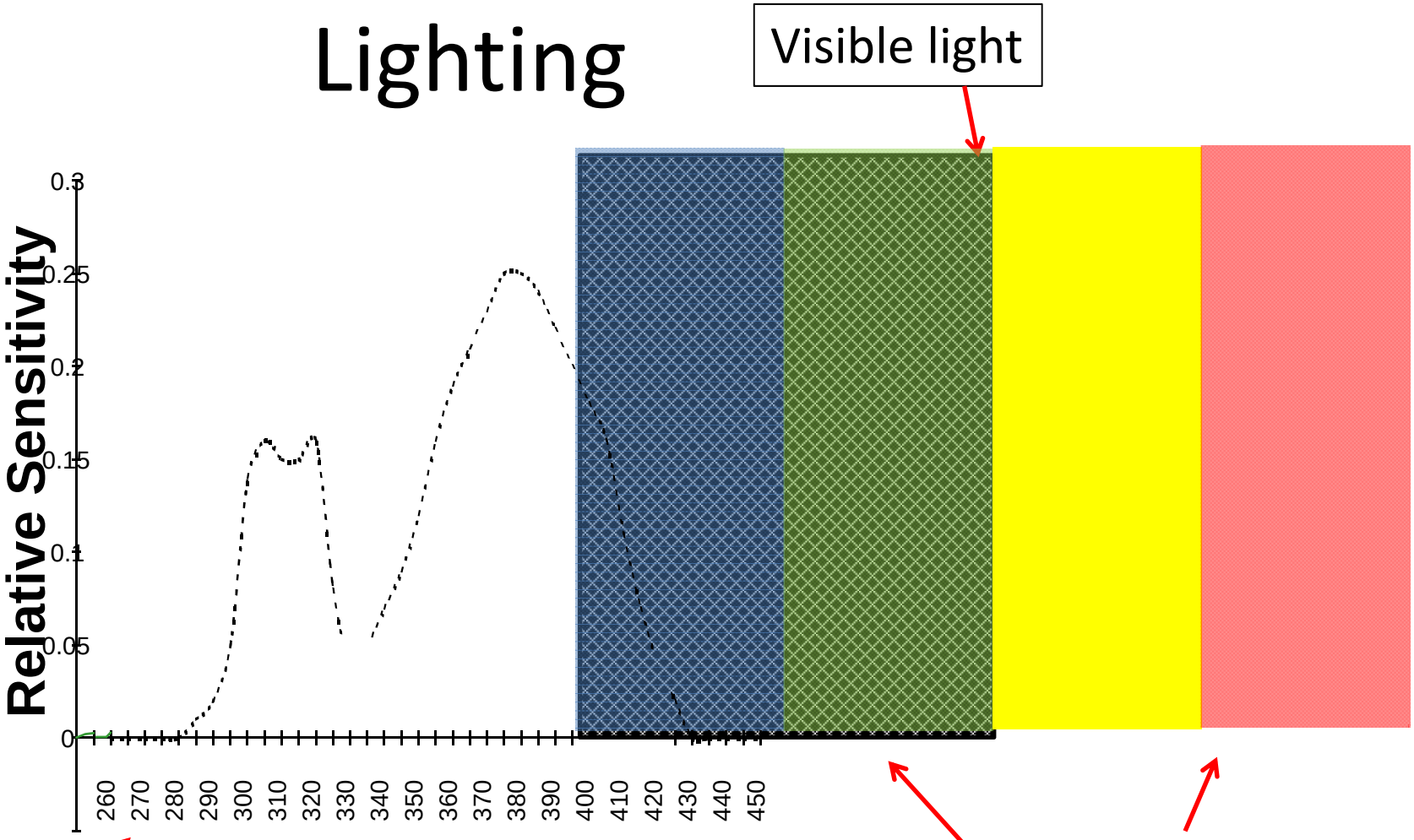
Clothes washing: avoid fabric conditioners!

Class	Changes/week
7	2
6	3
5	5
<5	per entry

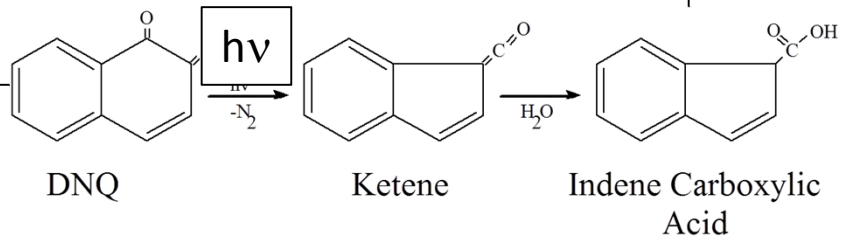
Services

Lighting
Power - 240 V AC
- 415 V AC (three phase)
Water - mains
- chilled
- potable
- ultrapure
- hot
Compressed air (pneumatics)
Nitrogen - liquid (-193 °C)
- gas
Process gases – for (plasma-assisted)oxidation, etching, growth, etc.
Chemicals – acid
- alkali
- organic solvents
- toxic materials

Lighting

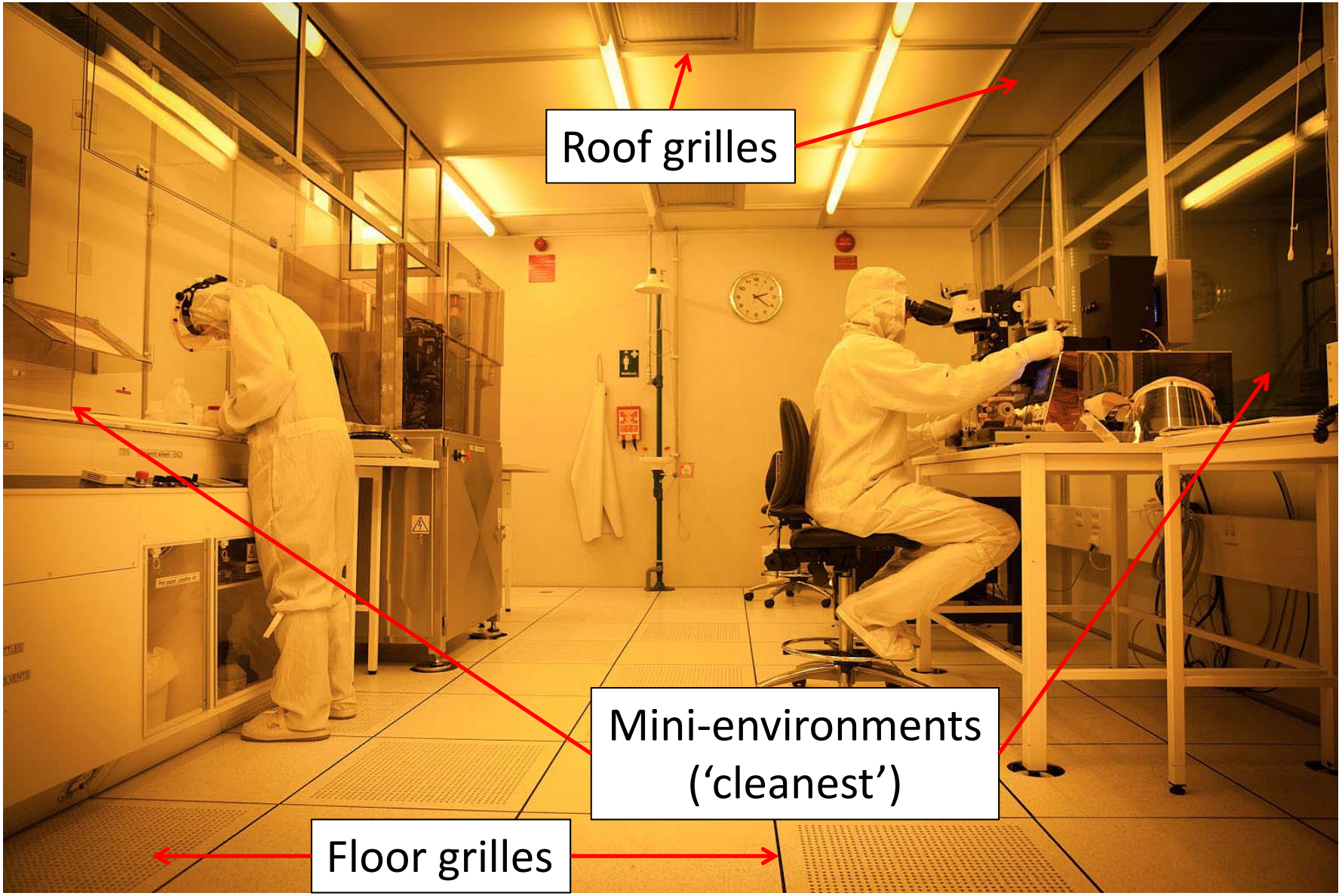


Example photoresist response function (PEPR® 2400)



- Block blue light
- Leave yellow light

‘Yellow room’ for photolithography



Water

- Mains

Supply to cleanroom

- Deionised ('ultrapure') resistivity $\rho > 18 \times 10^6\ \Omega$-cm

Contaminants: ionic, non-ionic, organic, bacteria, dissolved gas
Used for all wet-chemistry procedures

- Chilled

Used in a closed-loop where temperature control is important and to minimise wastage (e.g. cooling coil on thermal evaporator)

- Potable (i.e. drinking-quality water)

Used for emergency shower
(note: no drinking in cleanroom!)

- Hot water

Hand washing

Nitrogen

Delivered and stored as liquid (-183 °C)

Used in *vast* quantities
(~10,000 litres/week!)

Liquid used *directly* within oil diffusion vacuum pumps (‘diff pump’)

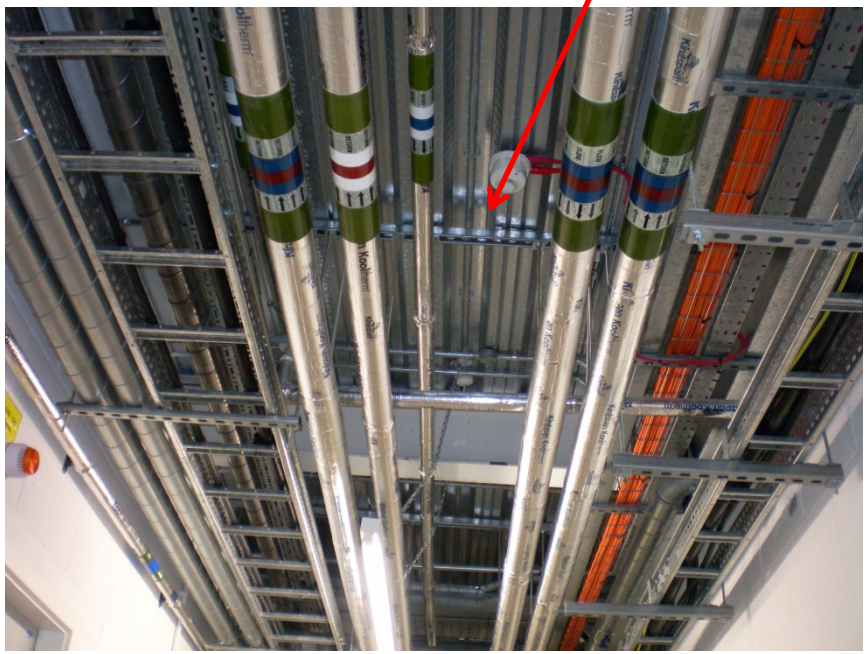
Gas (‘boil-off’) used in many processes and for pneumatics

Process gases

- Ar N_2 O_2 H_2 Cl_2 CHF_3 SF_6 AsH_3 $Ga(CH_3)_3$ PH_3 SiH_4 etc…

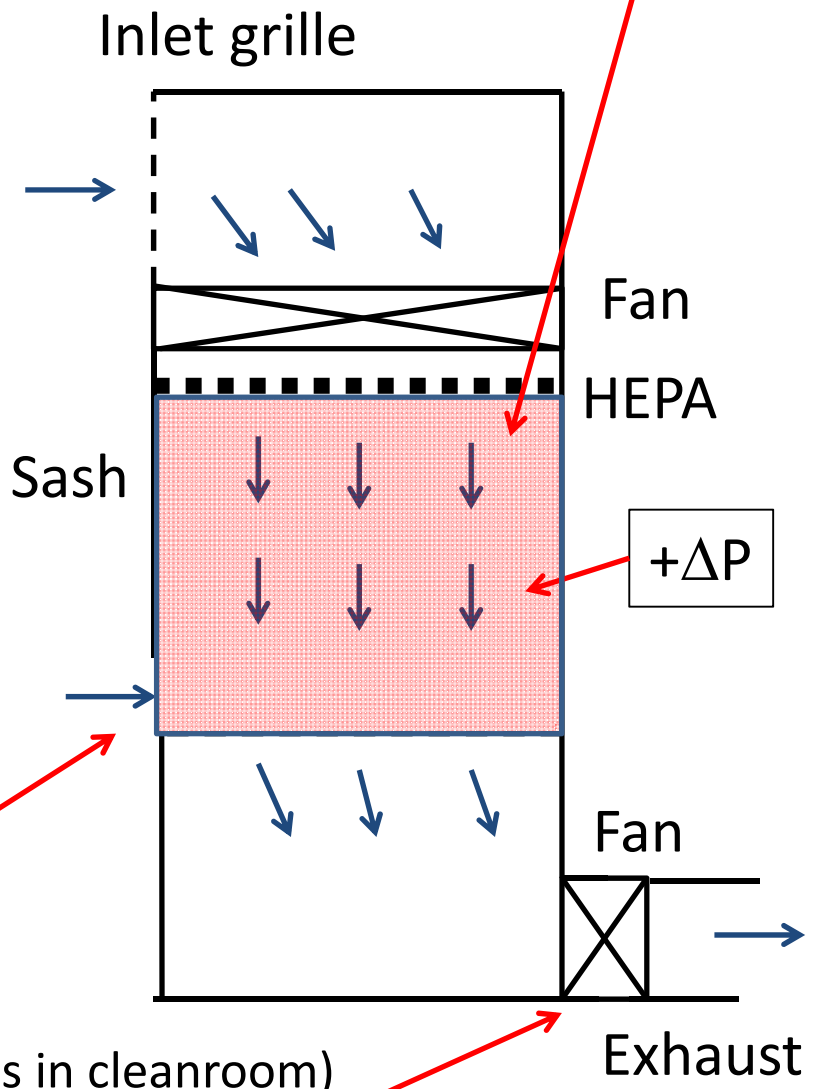
- Used in smaller quantities
- Delivered as high-pressure gas
- Stored outside (reduced fire risk)

- Much pipework necessary!



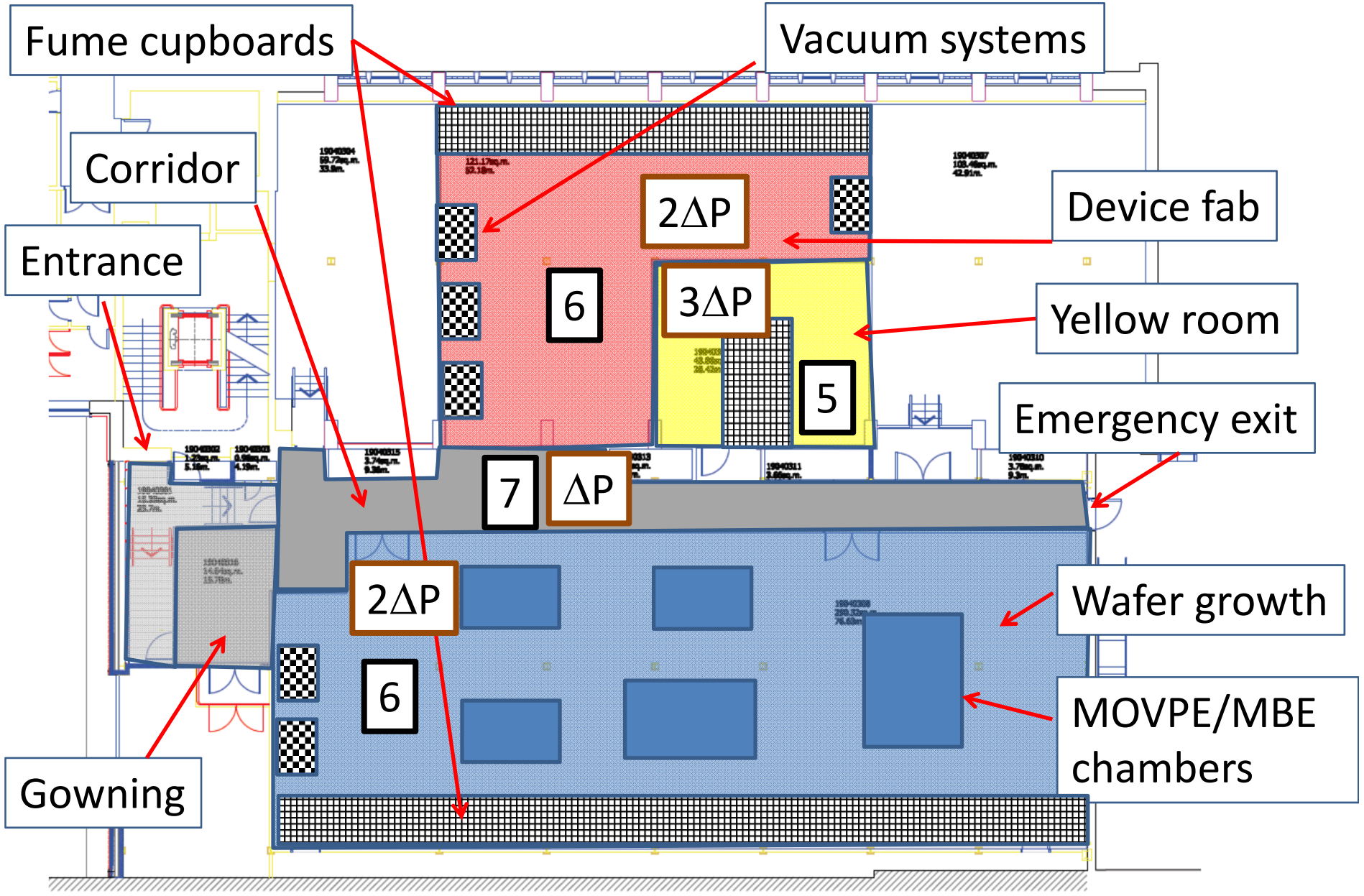
Uni-directional ('laminar') flow fume hood

All wet-chemistry done here (acids, alkali, solvents, photoresist,…)



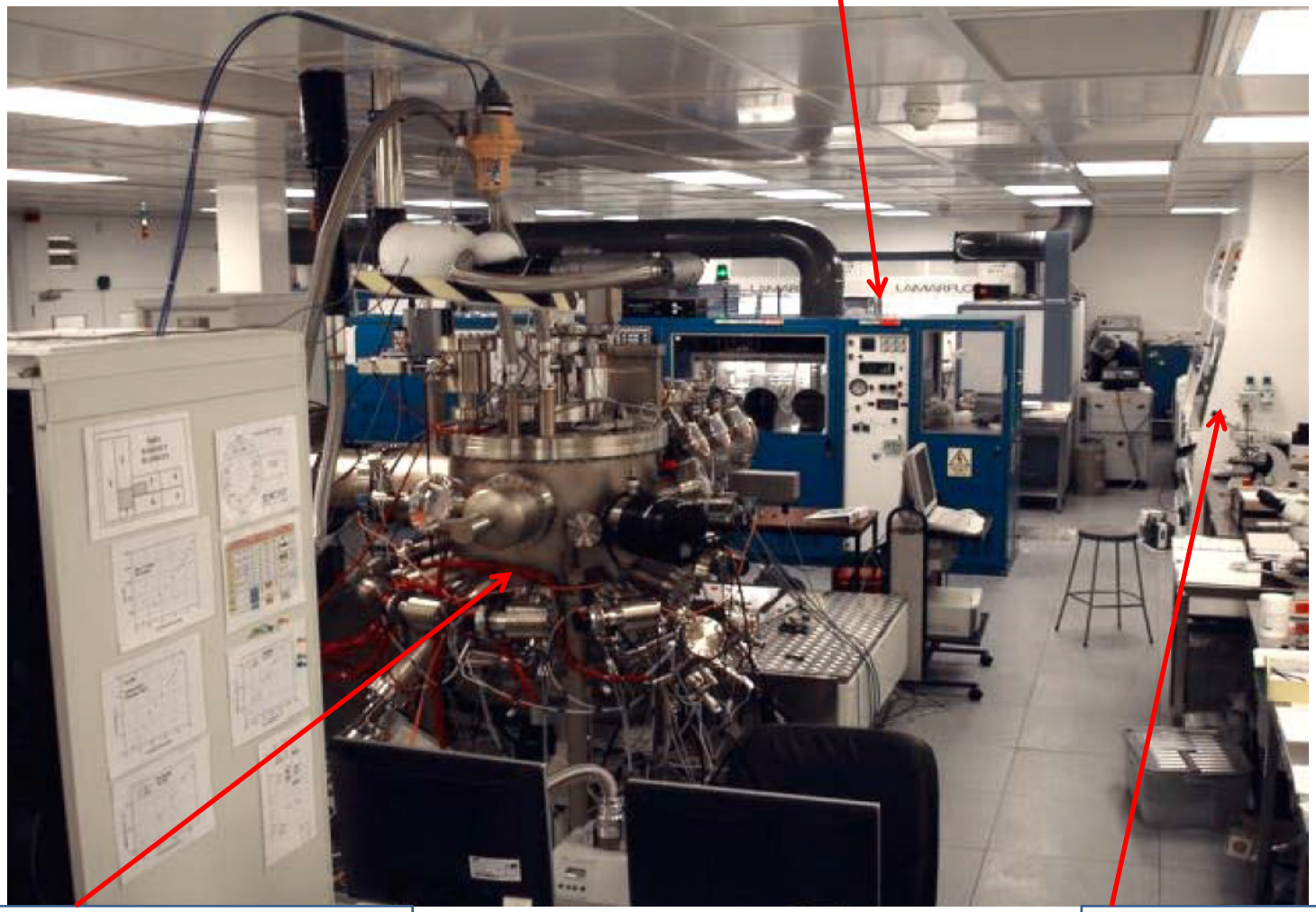
- Positive velocity below sash (to avoid fumes in cleanroom)
- Fan speeds adjusted to ensure positive pressure within hood

Practical layout – Sheffield III-V suite



Sheffield III-V wafer growth lab

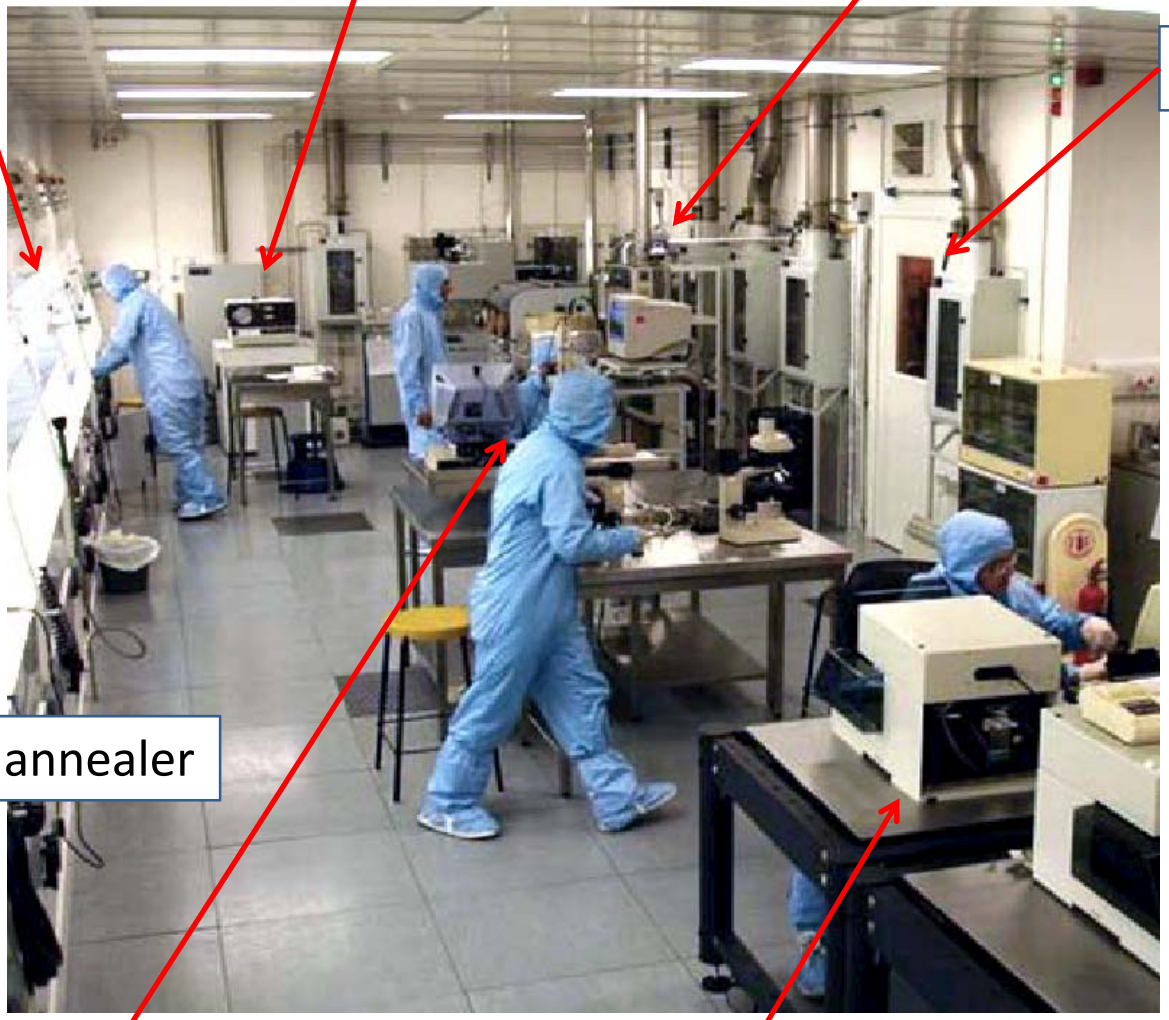
Metal-organic vapour phase epitaxy (MOVPE)



Molecular beam epitaxy

Fume cupboards

Sheffield III-V device fab lab



Fume cupboards

Plasma asher

Plasma deposition

Yellow room

Thermal, e-beam and sputter deposition

Wire bonding
Electrical test

Ellipsometer

Stylus surface profiler

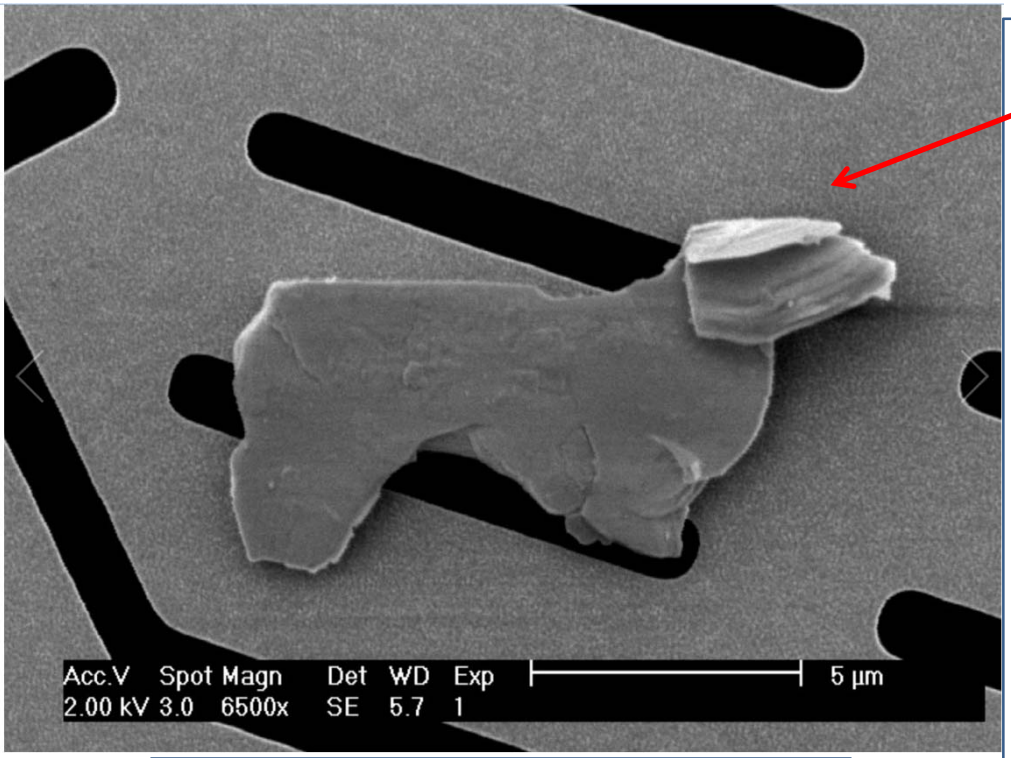
Microscopes

Rapid thermal annealer

Safety

- O_2 depletion sensor
- Toxic gas alarms
- Gas cylinders
- Fire
- Electrical faults
- Spillage

Summary



Joanna Grace V. De La Cruz, Analog Devices
IEEE Spectrum 'Art of Failure' competition

This tiny dog may look cute -
But he will destroy your device!

Dust control is *vital* for semiconductor fabrication

Cleanroom is a very complex system…

…even before you start to make anything…