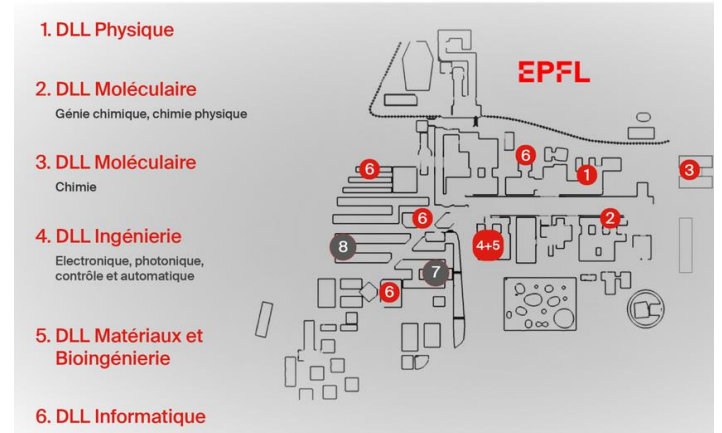


A close-up photograph of a person wearing a white lab coat and white gloves. They are holding a black probe with a white tip, which is touching a small, square microchip on a circular silicon wafer. The wafer is held in a black, ribbed holder. The background is blurred, showing industrial equipment. The text 'MICRO-332' is overlaid in white on a semi-transparent red background at the bottom of the image.

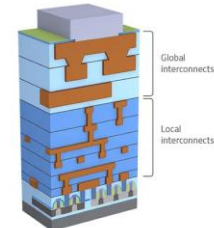
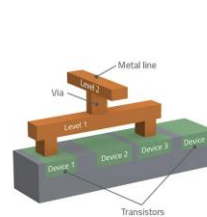
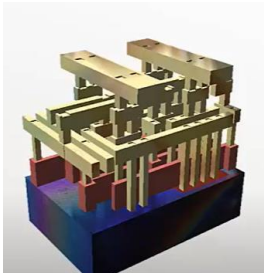
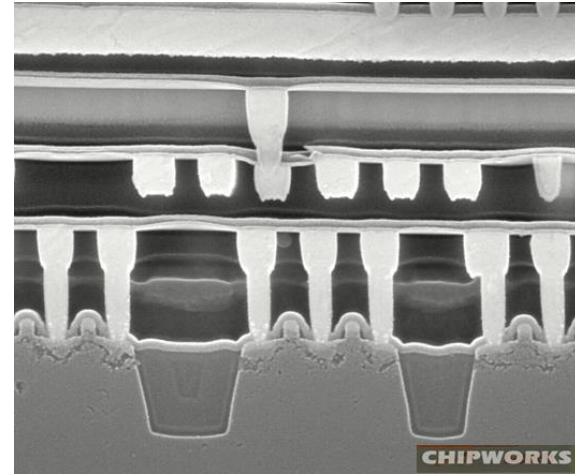
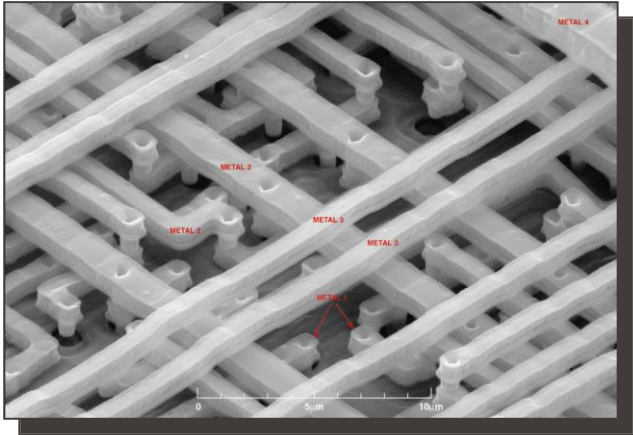
MICRO-332
Microfabrication practicals
Travaux pratiques en Microfabrication

DLL :Discovery Learning Laboratories



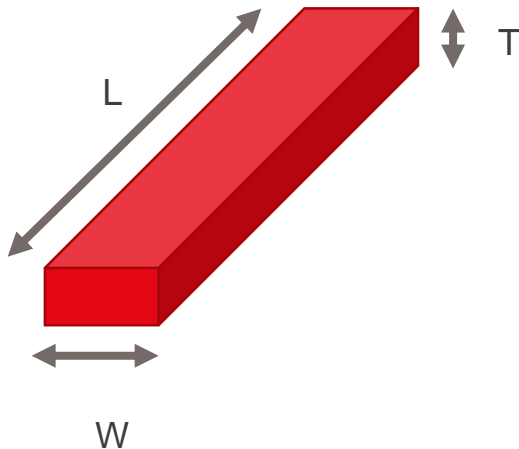


- Composants intégrés = empilement de motifs en films minces: électrodes, zones actives, couches isolantes
- Réalisation nécessite plusieurs étapes successives **de photolithographie**



Résistance électrique

Fil métallique de section rectangulaire

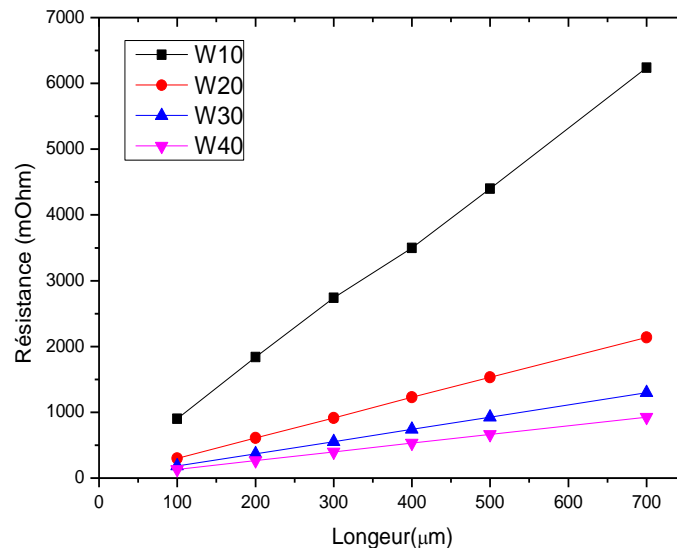


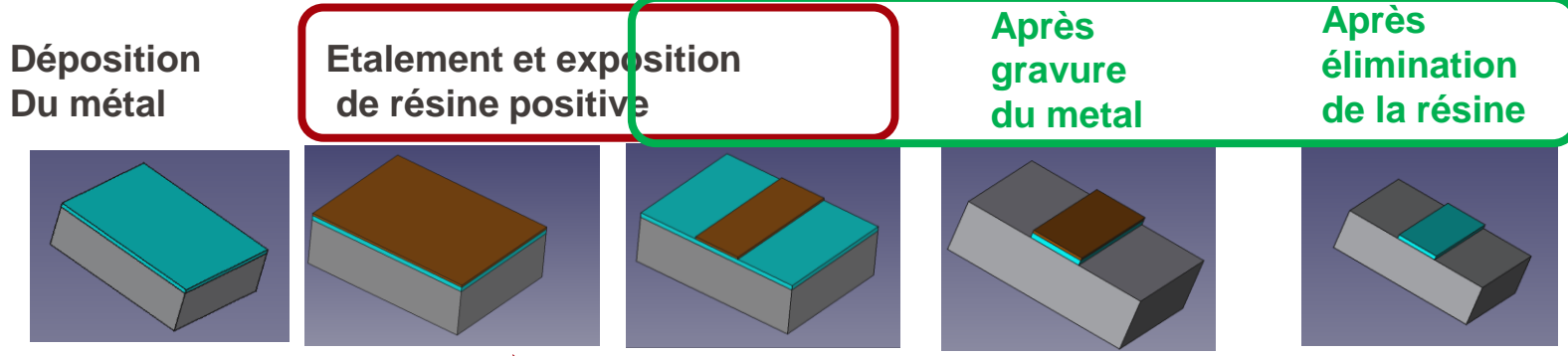
L (longueur) et W (largeur)

ρ Résistivité du film

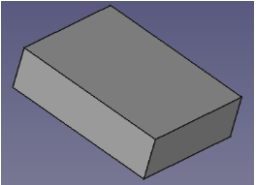
T Epaisseur du film

$$R = \rho \frac{L}{W \cdot T}$$





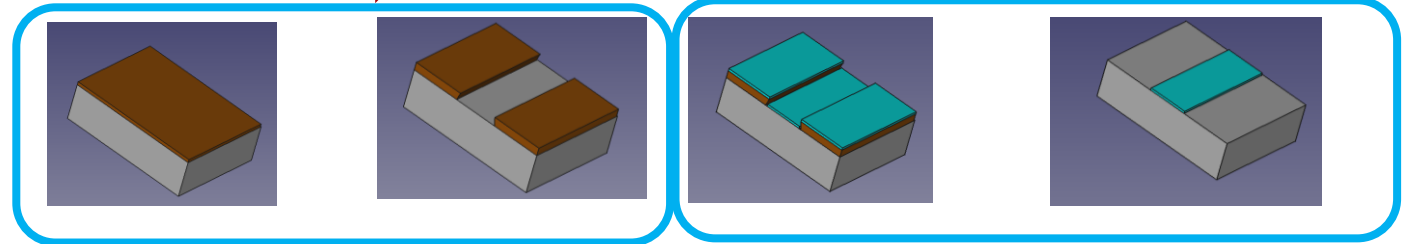
Procédé: Gravure chimique



Substrat



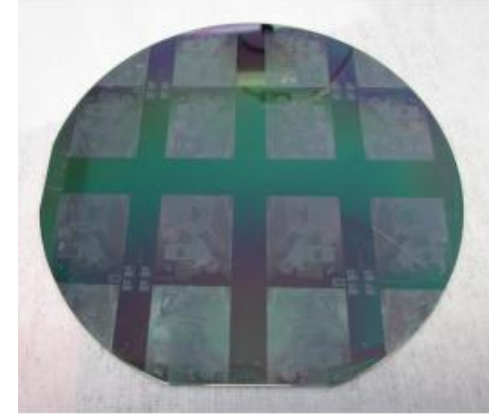
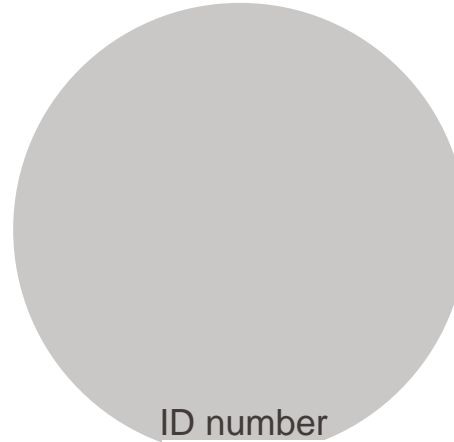
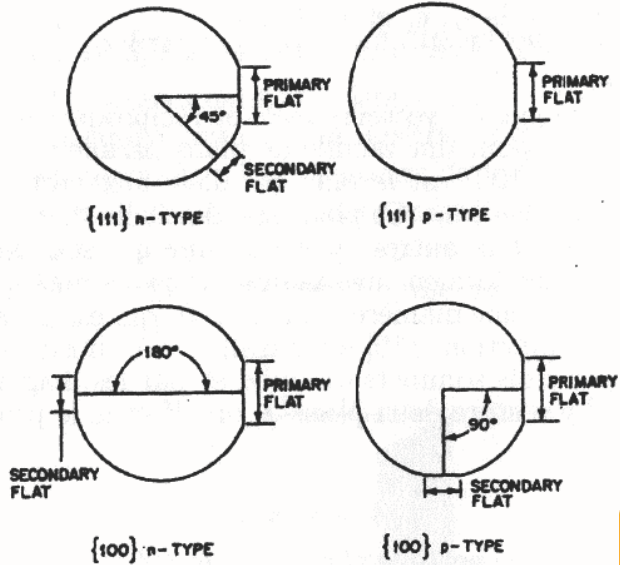
Procédé: Liftoff



Etalement et exposition de résine négative

Identification du substrat

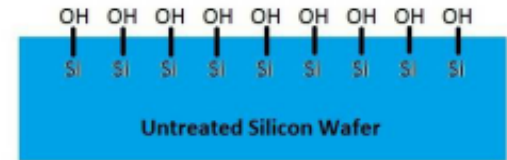
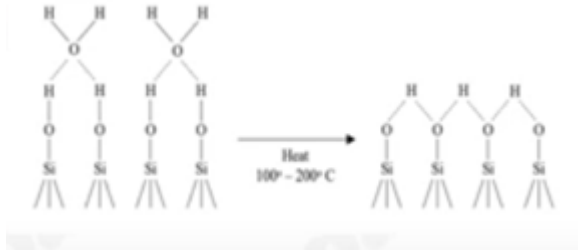
Orientation et dopage, numéro d'identification



Préparation de surface

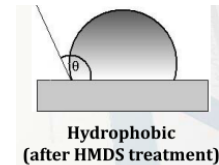
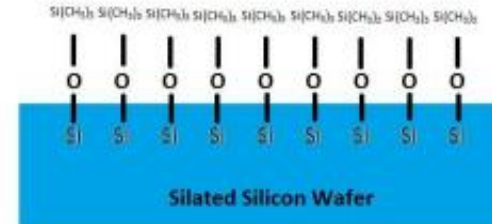
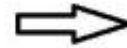
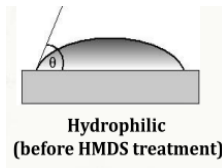
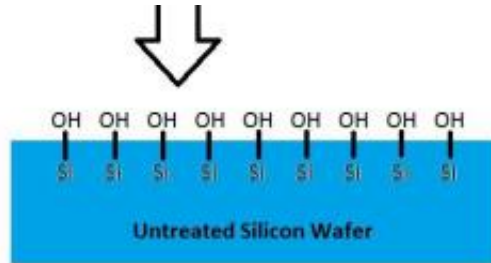
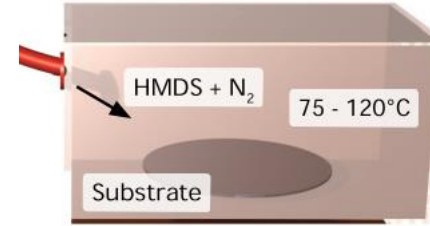
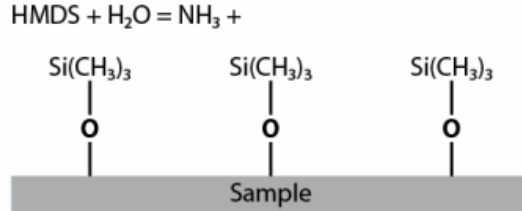
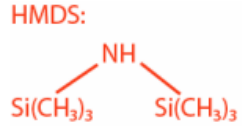
nettoyage et application de promoteur d'adhérence

- But : améliorer l'adhésion et l'uniformité de la couche de résine à la surface du substrat.
- Problème: l'oxyde native du silicium rend la surface hydrophile
 - absorbe humidité

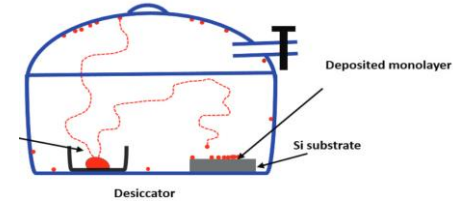
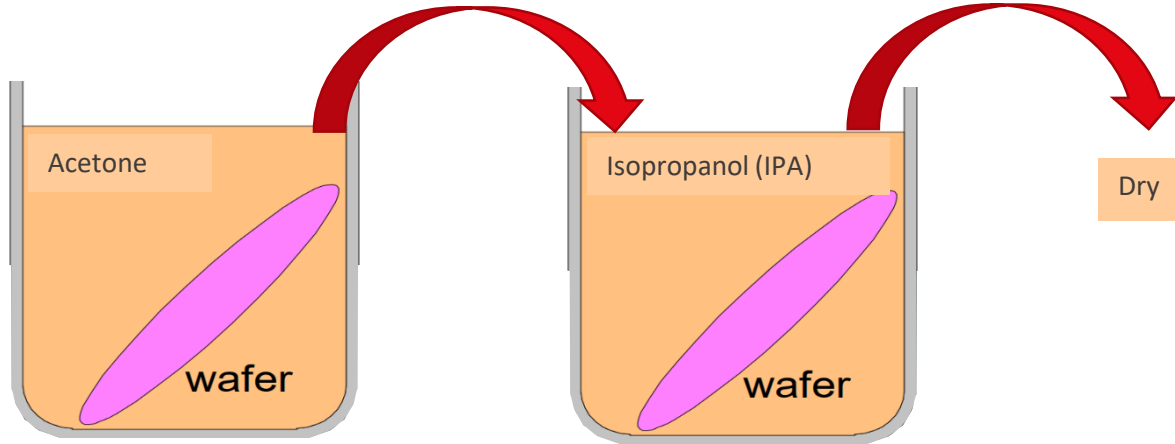


- Solution:
 - Déshydratation: élimination d'humidité à la surface du substrat
 - Recuit thermique à 120 °C pendant quelques min
 - Désorption des liaisons –OH
 - Silanisation: déposition en phase gazeuse du silane hexamethyldisilazane (HMDS) à la surface du substrat

Hexamethyldisilazane (HMDS)



Nettoyage et promoteur d'adhérence



- Les paramètres influençant le dépôt HMDS :
 - la température
 - la pression dans l'enceinte pendant le dépôt
 - la durée du traitement



Angle de contact

L'angle de contact est l'angle entre le substrat et la tangente de la goutte d'eau posée sur le substrat

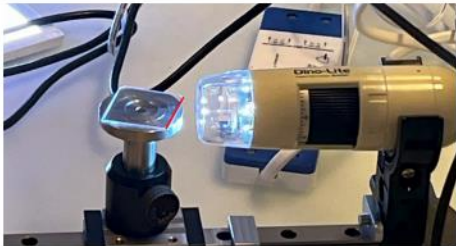
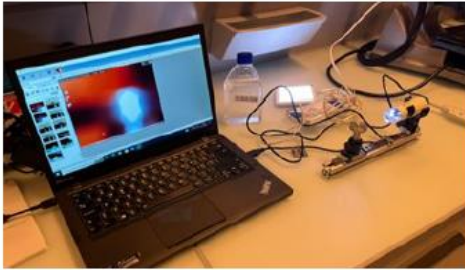
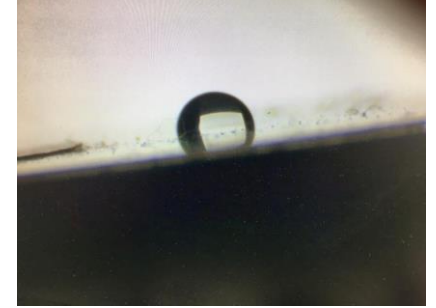
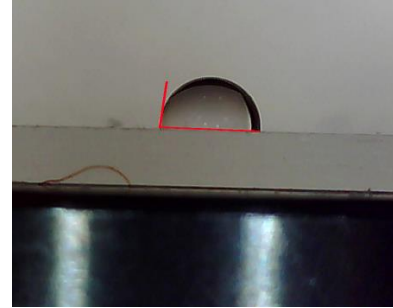
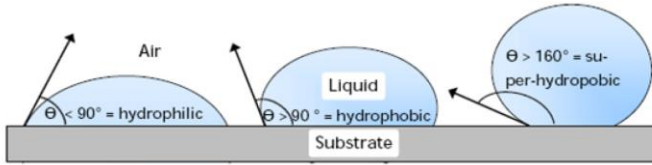
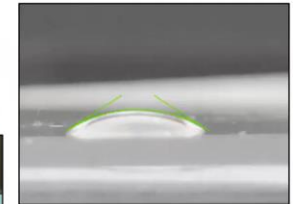
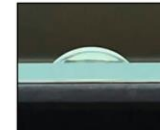
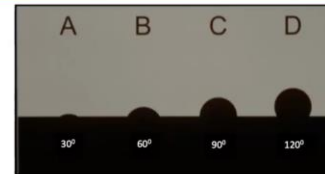
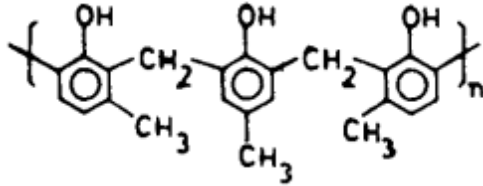


IMAGE QUALITY

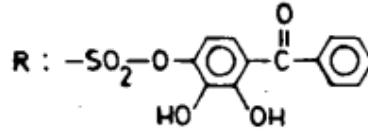
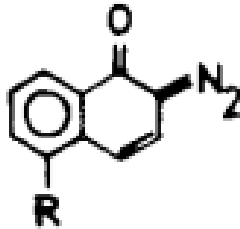


Résine photosensible positive

- Une résine est composée de 3 éléments essentiels :
 - Polymère inactif : matrice du film Novolaque (10-40%)



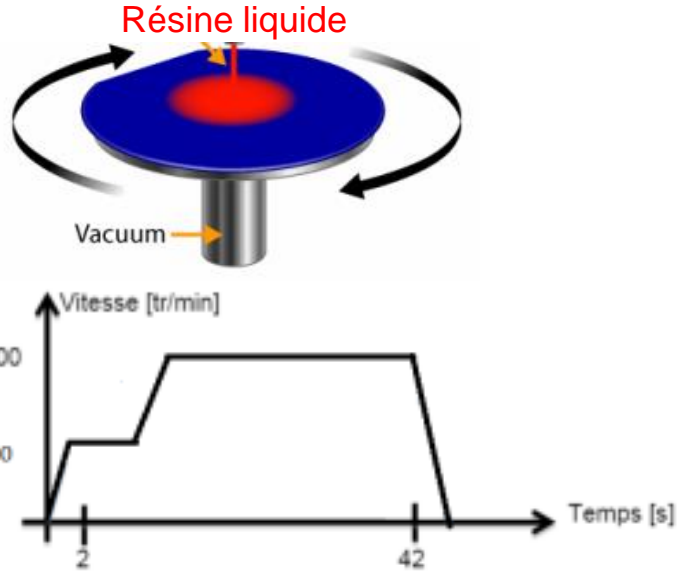
- Élément photo actif (PAC) diazonaphtoquinone (DNQ) (1-5%)



- Solvant: contrôle la viscosité de la résine propylène-glycol-monométhyl-éther-acétate (PGMEA) (50-85%)

Déposition de la couche de résine

- Etalement à la tournette
- Obtenir une couche de résine uniforme



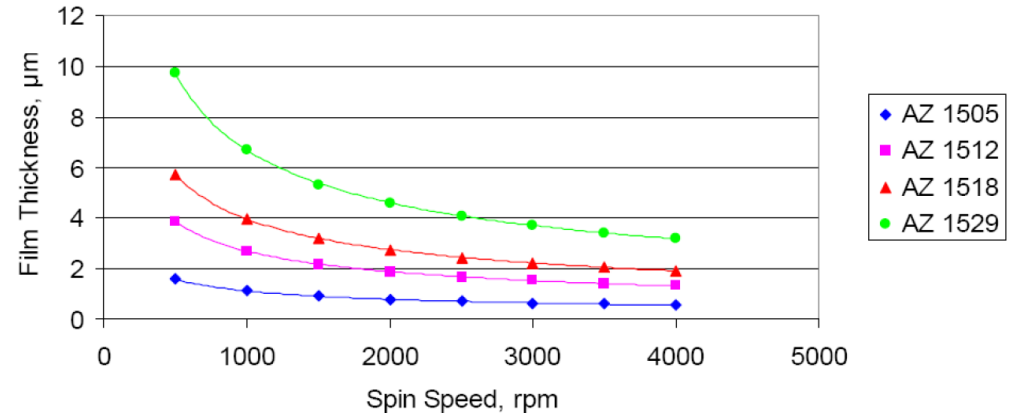
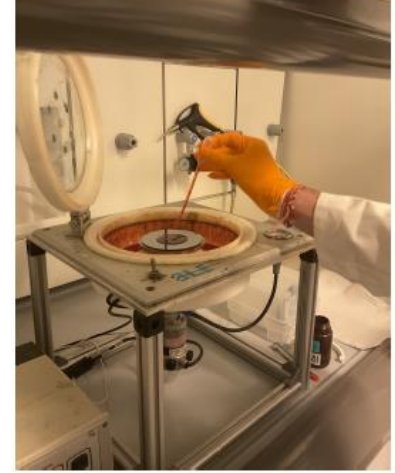
$$e = \frac{kp^2}{\sqrt{v}}$$

e : épaisseur de la résine (μm)

k : constante de la tournette

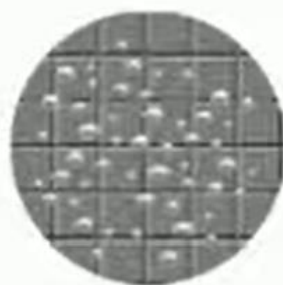
p : viscosité (cP)

v : vitesse de rotation (tr/mn)

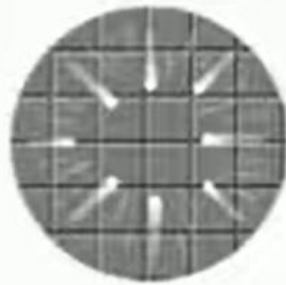


Spincoating – Common issues

Bubbles in solution



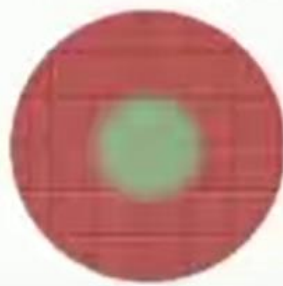
Comets, Streaks



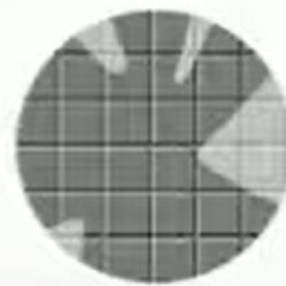
Swirl Pattern



Chuck Mark

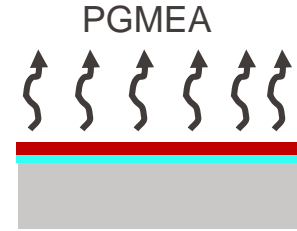


Insufficient dispense

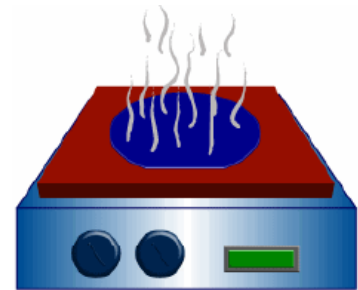


Pinholes





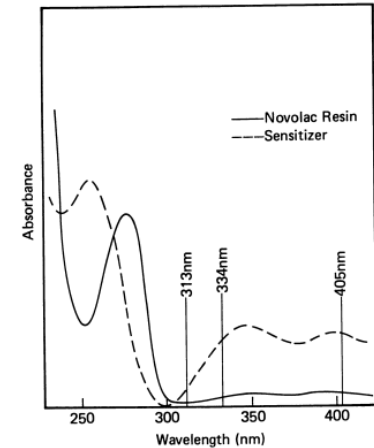
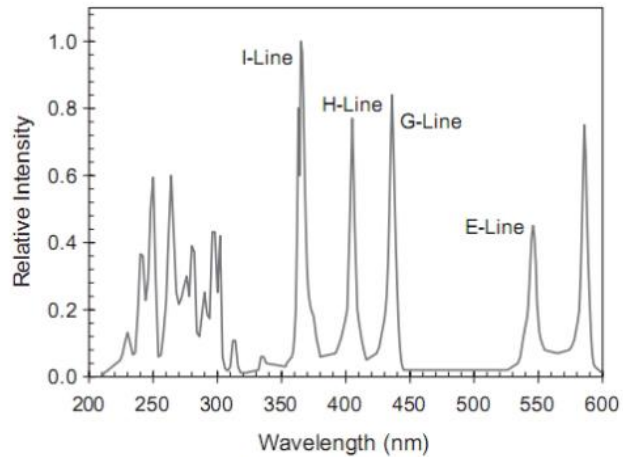
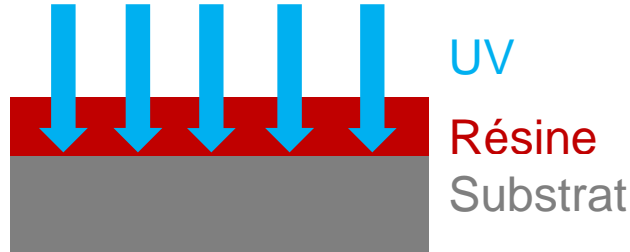
- Elimination des solvants (diminution d'épaisseur).
- Amélioration d'adhésion de résine au substrat
- Réduit les contraintes mécaniques créées dans la résine pendant la centrifugation
- Température de recuit: élément très important
 - A softbake at 100°C on a hotplate for 1 min per μm resist film thickness. At 110°C, halve the softbake time, while for each 10°C below 100°C the time should be doubled
 - Température élevée:
 - la résine réagit avec l'oxygène dans l'air et conduit à la formation de fissures
 - Décomposition du photo-initiateur
 - Température faible:
 - Élimination du solvant n'est pas suffisante
 - Cause des problèmes lors de l'exposition aux UV



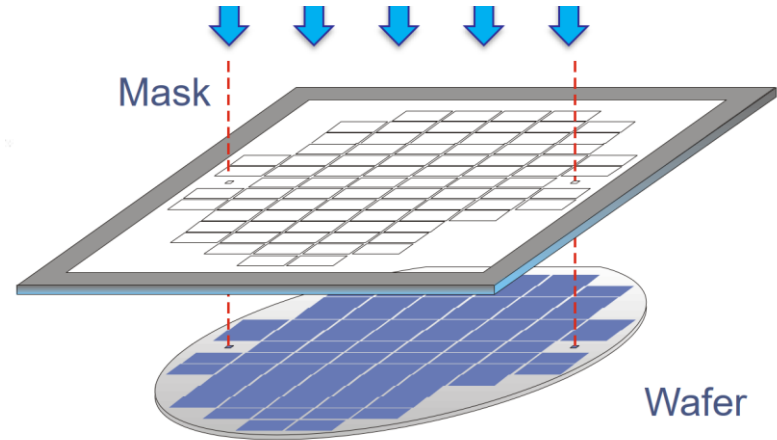
Exposition aux UV

UV light : $\lambda = 365 \text{ nm}$

I_{lamp} # mW/cm^2



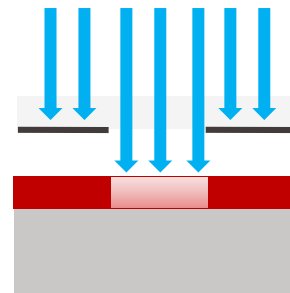
Préparation du masque



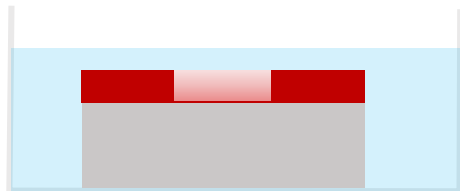
Résine positive et Résine négative



2. Etallement de résine



3. Exposition aux UV



4. Développement

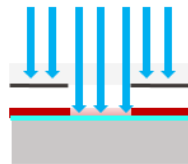
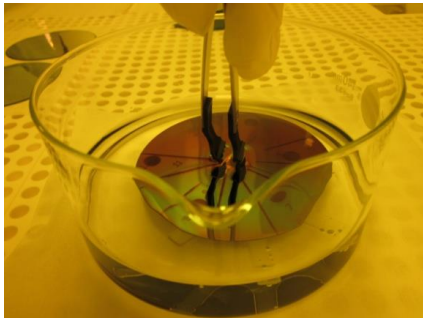
→ Résine négative



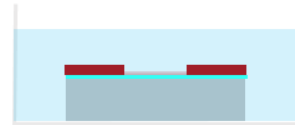
→ Résine positive



- Dissolution de la résine dans une solution de développement
 - MIF (metal ion free) (Souvent TMAH (hydroxyde de tétraméthylammonium)) sans ions Na^+ et K^-
 - Utilisé essentiellement pour les composants électroniques et optiques
 - MIC (metal ion containing) (solution basique; NaOH , KOH)
 - Contient les ions Na^+ et K^- pouvant contaminer les composants électriques.
 - Souvent utiliser dans MEMS et les photomasques
- Concentration de la solution et du temps de développement



6. Exposition aux UV

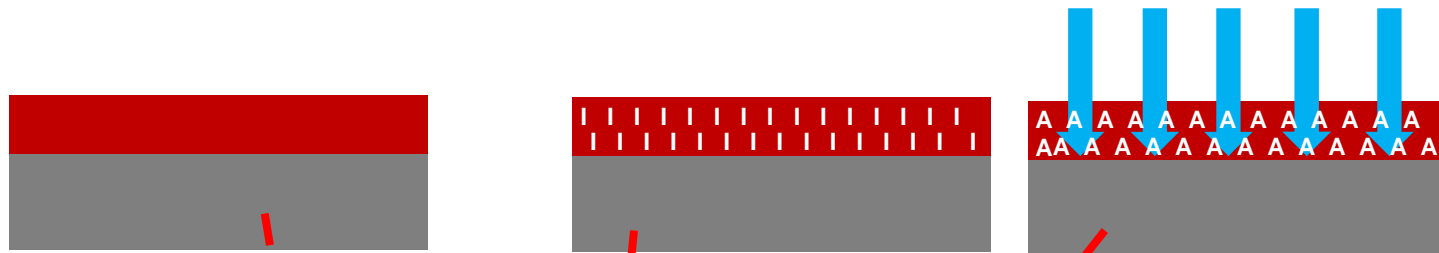


7. Développement



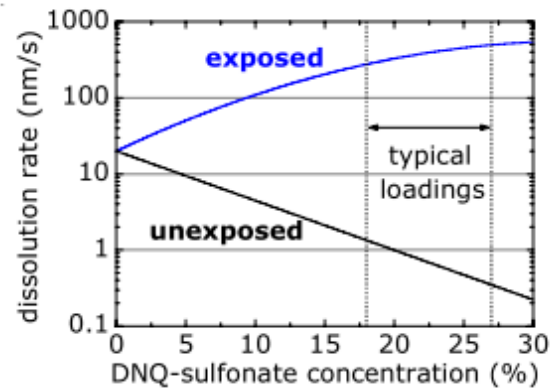
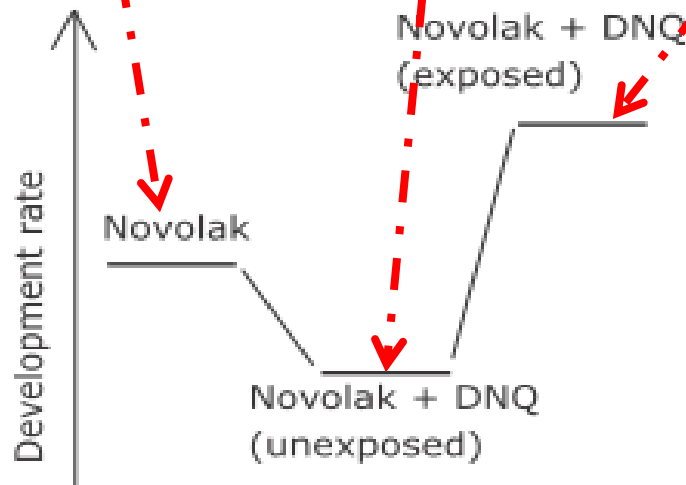
8. Caractérisation

Résine positive: Novolak + DNQ



DNQ: Inhibiteur
de dissolution

DNQ: Accélérateur
de dissolution

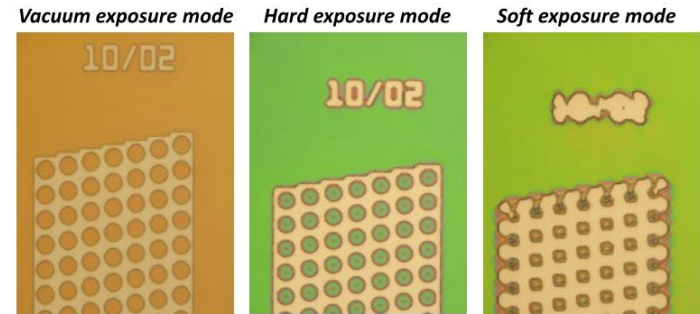
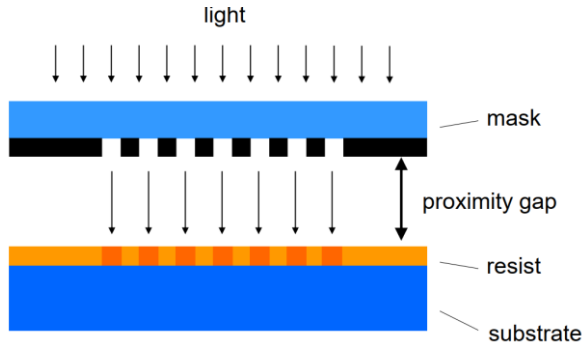
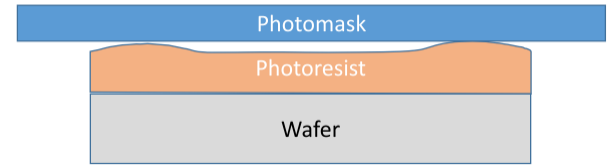
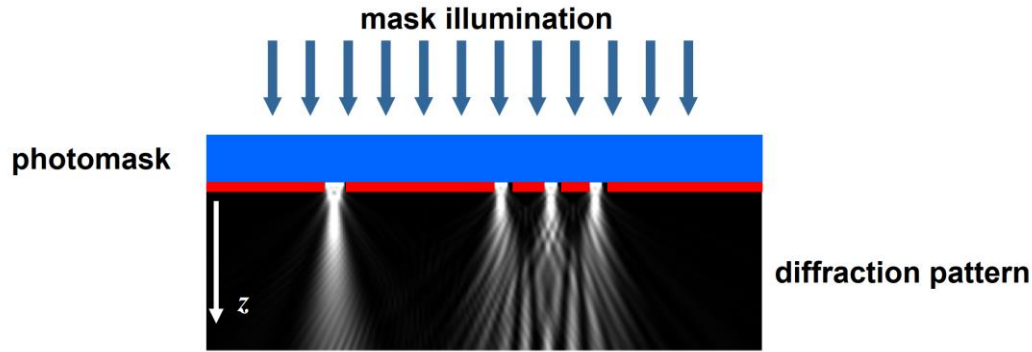


Profile de Résine

- Depends on the application



Techniques d'exposition aux UV



Topic 2 : Résine positive

Objectifs:

- Courbe de contraste
- Epaisseur de résine en fonction de la vitesse de rotation.

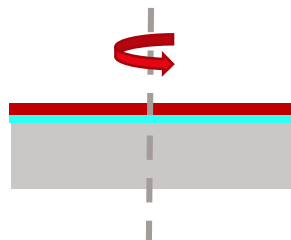
Etapas de fabrication: Résine positive



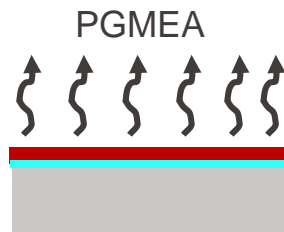
1. Nettoyage de la surface



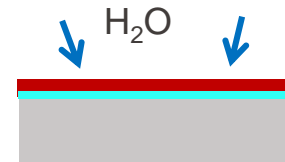
2. Silanisation : HMDS



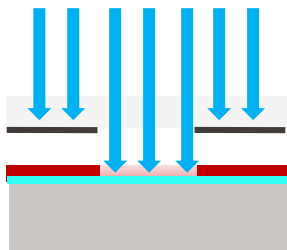
3. **Etalement de la résine**



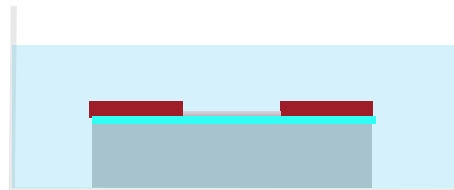
4. Pré-recuit



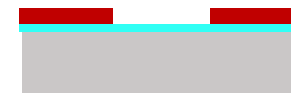
5. Relaxation: rehydratation



▪ 6. **Exposition aux UV**



7. **Développement**



8. Caractérisation

Courbe de contraste

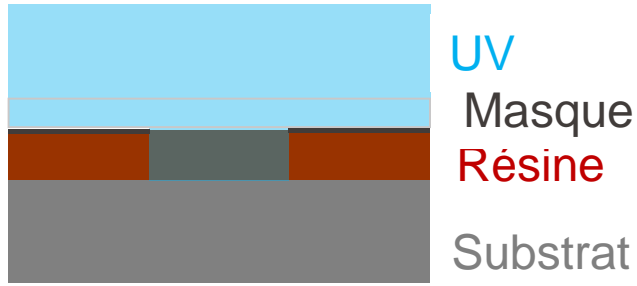
Variation de l'épaisseur normalisée en fonction de la dose d'exposition

$$\text{Epaisseur normalisée} = \frac{E_f}{E_i}$$

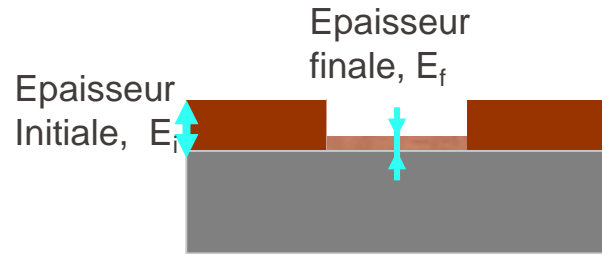
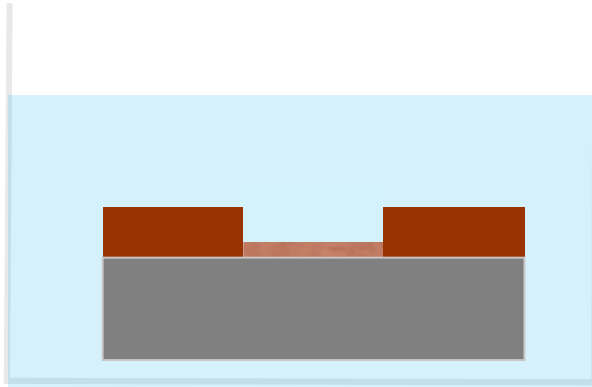
$$\text{Dose d'exposition} = I_{\text{lampe}} \times t_{\text{exp}}$$

I_{lampe} = Intensité de la lampe (mW/cm²)

t_{exp} = temps d'exposition (sec)

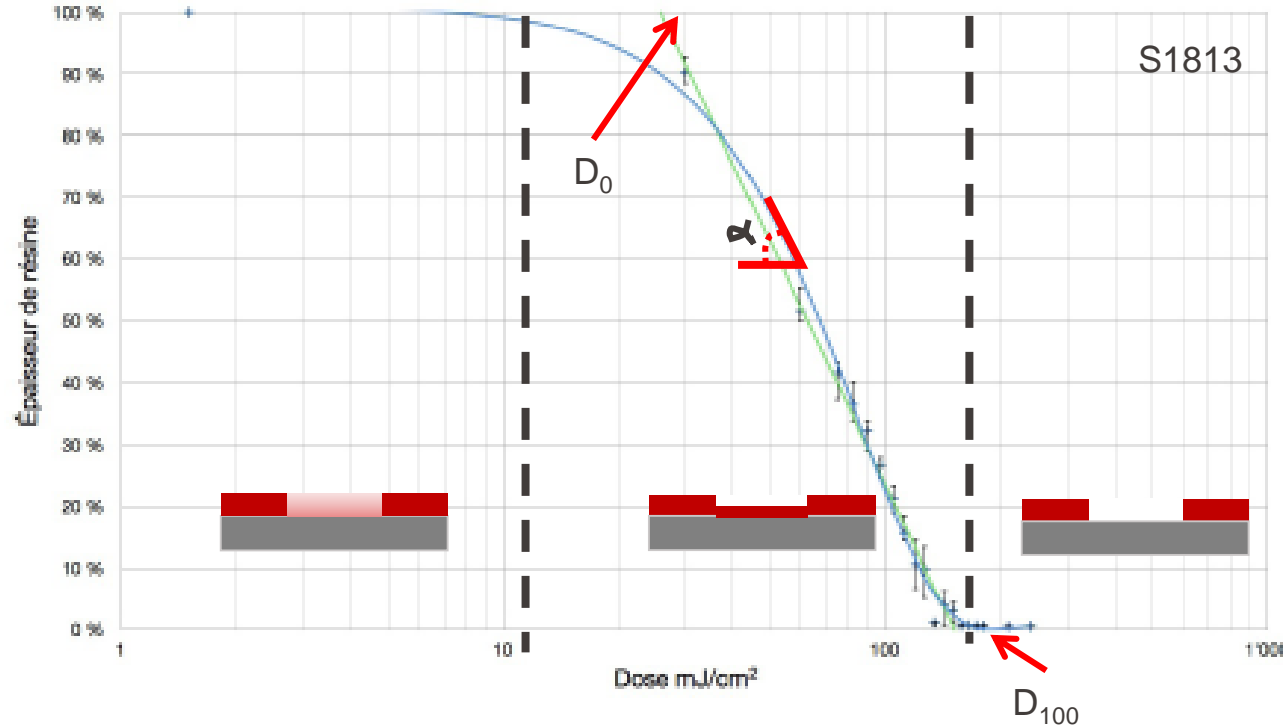


Exposition aux UV, t_{exp}



Développement, t_{dev}

Courbe de contraste: résine positive

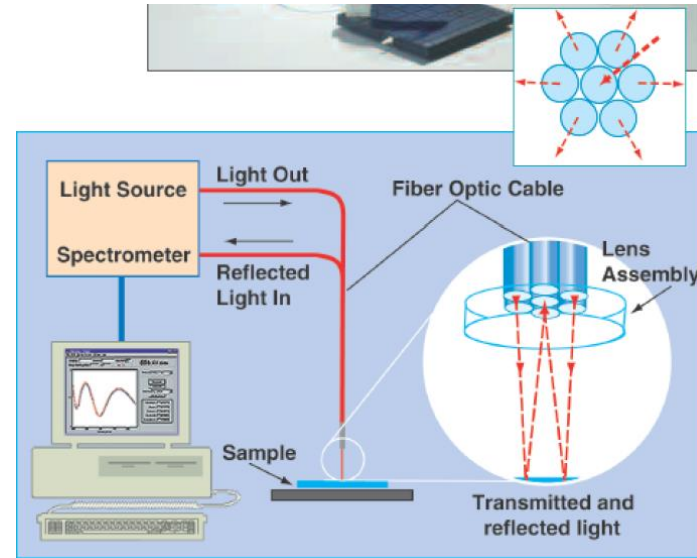
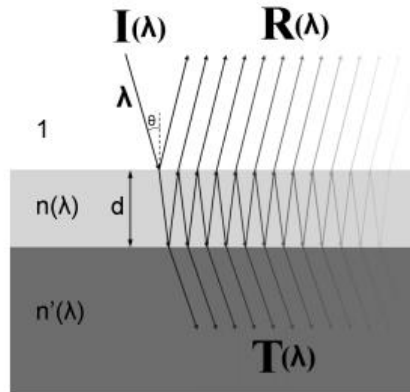


- Sensibilité de la résine: D_{100} (Wafer par heure)
- Contraste de la résine : α (Résolution)
-

$$\alpha = \frac{1}{\log\left(\frac{D_{100}}{D_0}\right)}$$

Spectral reflectance principle

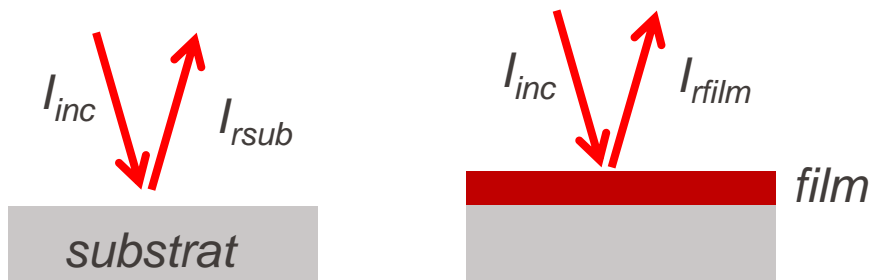
- The light intensity reflected from the sample at a normal incidence is measured over the range of wavelengths
- Computer software uses the property of dispersion of index refraction of the film to determine the film thickness.
- Non-destructive and non-contact
- Simple and relatively low cost



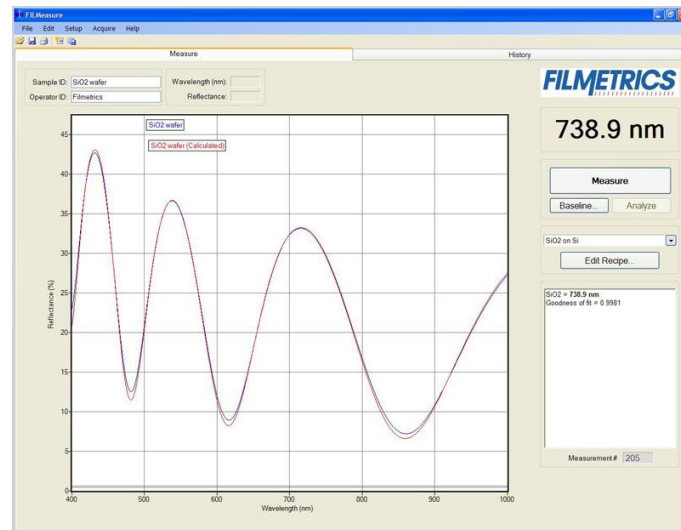
Principle of measurement

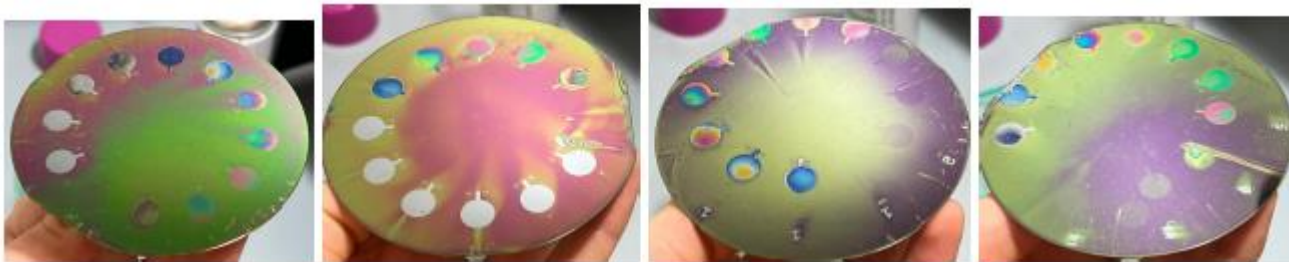
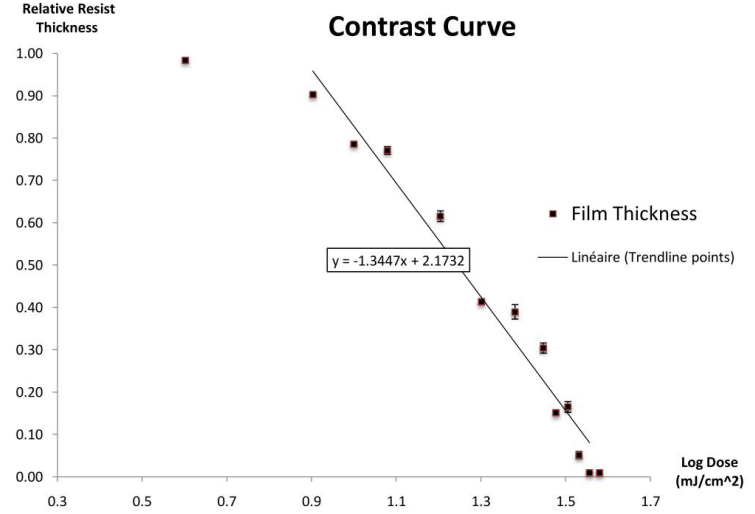
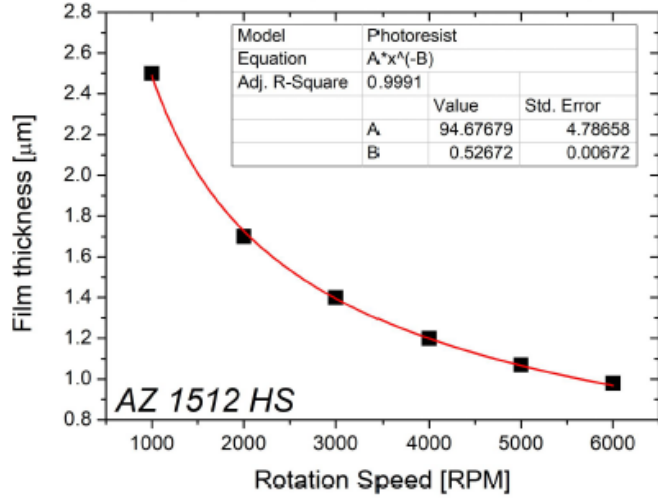
$$R_{film}(\lambda) = \frac{I_{rfilm} - I_{bkg}}{I_{inc} - I_{bkg}} = \frac{I_{rfilm} - I_{bkg}}{I_{rsub} - I_{bkg}} R_{sub}(\lambda)$$

$$R_{sub}(\lambda) = \frac{I_{rsub} - I_{bkg}}{I_{inc} - I_{bkg}}$$

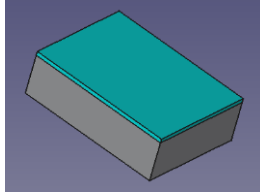


$$R(\lambda) = \frac{r_{01}^2 + r_{12}^2 + 2r_{01}r_{12} \cos\left(\frac{4\pi n_1(\lambda)d}{\lambda}\right)}{1 + r_{01}^2 r_{12}^2 + 2r_{01}r_{12} \cos\left(\frac{4\pi n_1(\lambda)d}{\lambda}\right)}$$

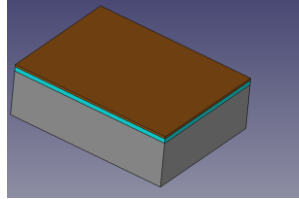




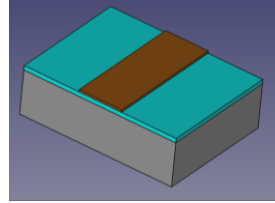
Déposition
Du métal



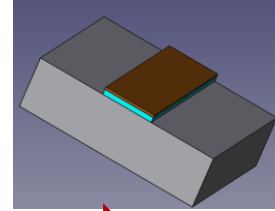
Déposition
de la résine



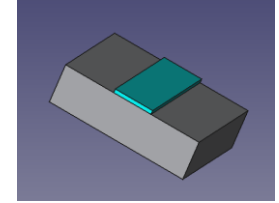
Résine après
exposition UV
et développement



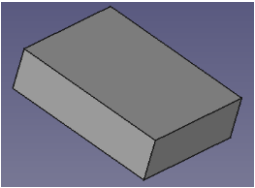
Après gravure
du metal



Après élimination
de la résine



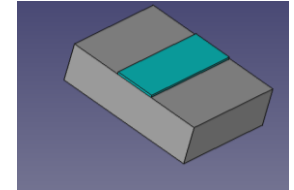
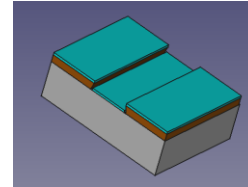
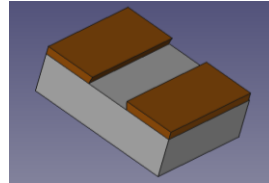
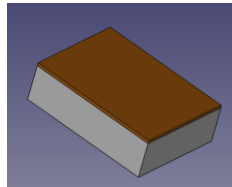
Procédé: Gravure chimique



Procédé: Liftoff



Substrat



Après déposition
du metal

Topic 3 :

Liftoff avec une simple couche de résine

Liftoff avec bicouche de résine

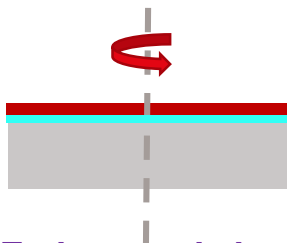
Etapas de fabrication : Résine négative



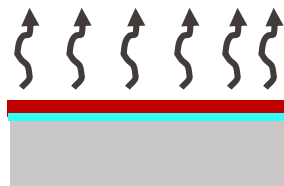
1. Nettoyage de la surface



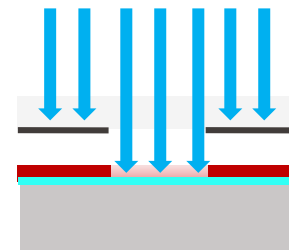
2. Silanisation : HMDS



3. Etalement de la résine



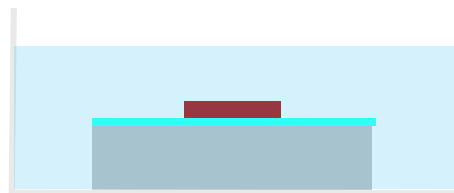
4. Pré-recuit



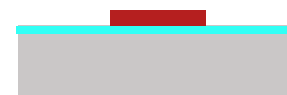
6. Exposition aux UV



5. Post-recuit (PEB)

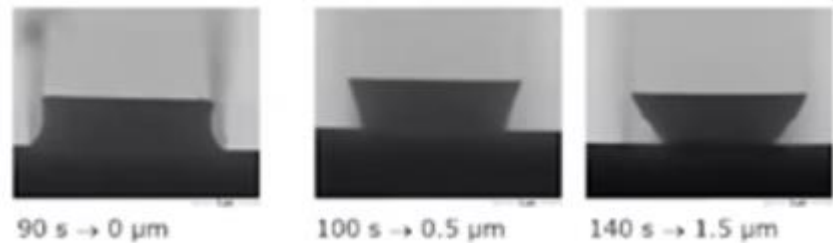
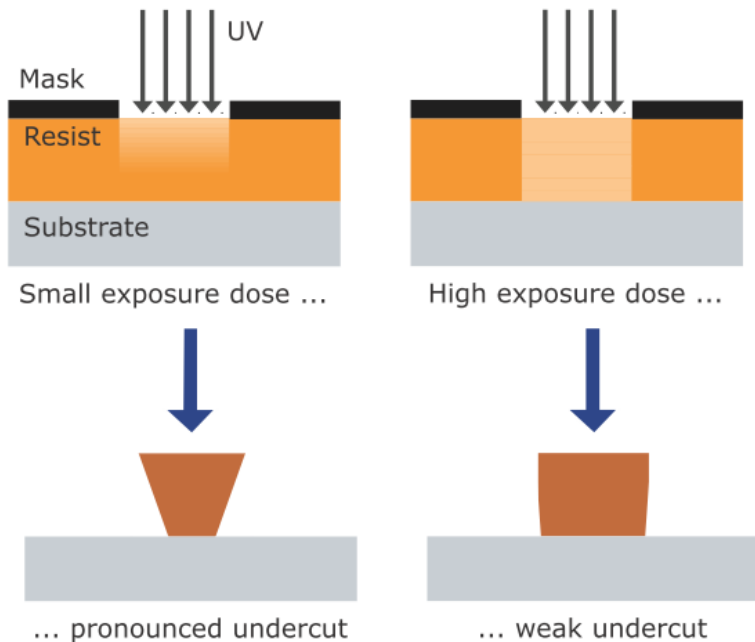


7. Développement




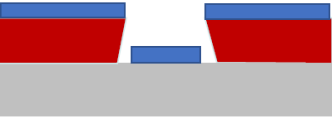


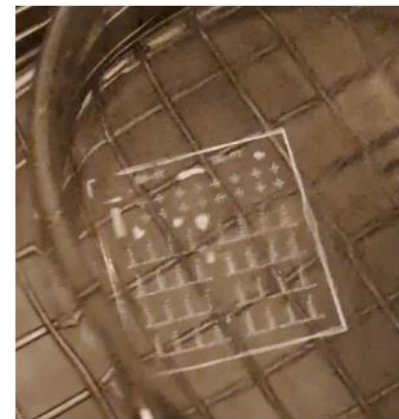
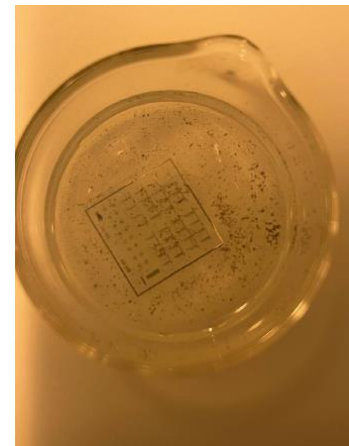
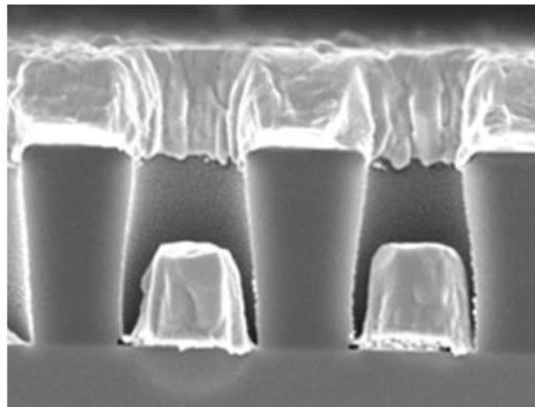
8. Caractérisation

Liftoff : résine négative

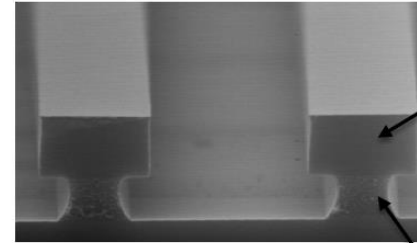


	PEB: 105C/60s	PEB: 110C/60s	PEB 115C/60s
Dose: 60mJ/cm ²			
Dose: 70mJ/cm ²			
Dose: 80mJ/cm ²			
Dose: 90mJ/cm ²			

Step	Process description	Cross-section after process
01	Substrate: Glass wafer <ul style="list-style-type: none"> <i>Teply O₂ plasma treatment,</i> 	
02	<i>Photolith PR coat</i> <ul style="list-style-type: none"> <i>1.4 um AZ nLOF 2020 coating in ACS200,</i> 	
03	<i>Photolith expo+ develop</i> <ul style="list-style-type: none"> <i>4.7 sec exposure with MJB4 (94 mJ/cm²)</i> <i>Developing in ACS200,</i> 	
04	<i>Metal deposition</i> <ul style="list-style-type: none"> <i>20/200 nm Ti/Al in EVA760, 450 mm WD, dep. rate: 5 A/s</i> 	

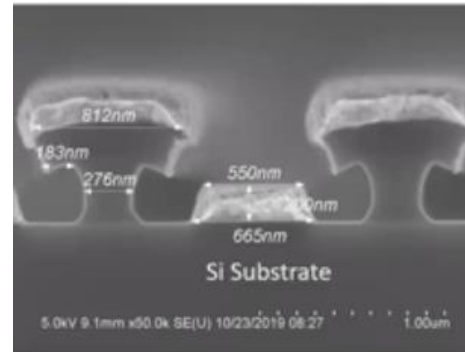


EPFL lift-off avec une bicouche de résine

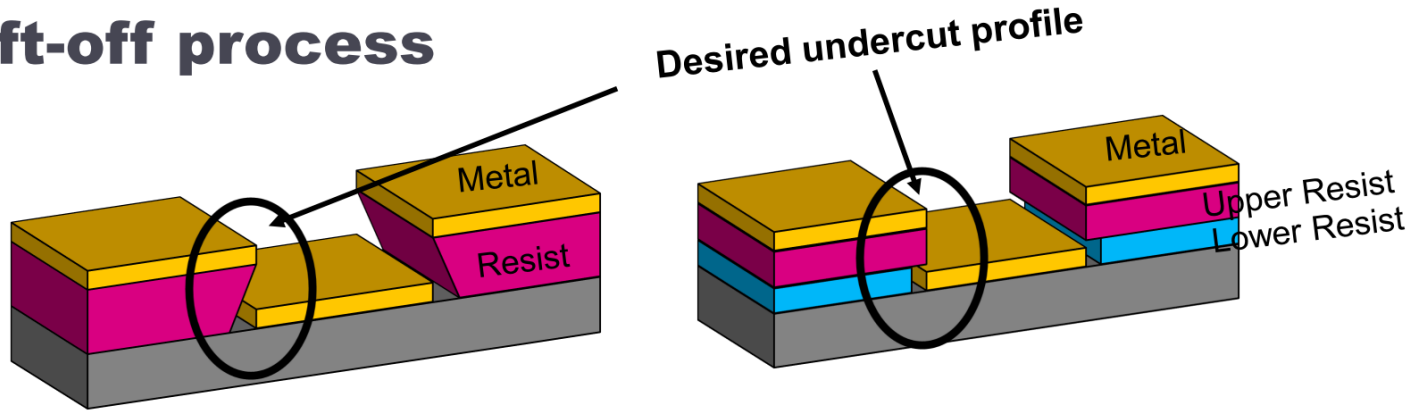


A positive PR
S1805, S1813 etc.

LOR 1A, 5A

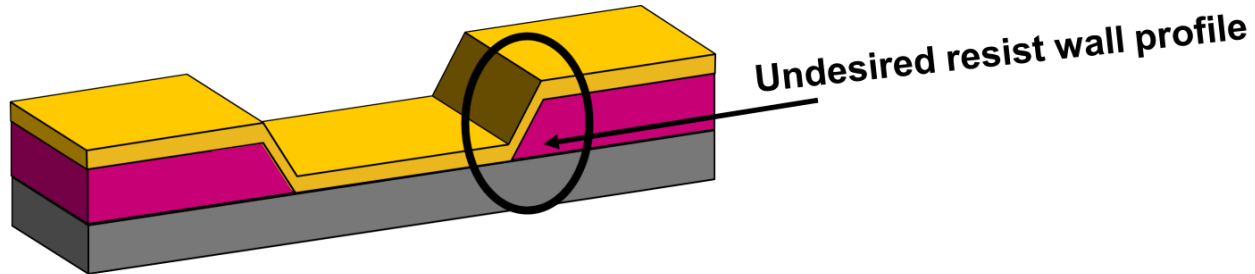


Lift-off process



Good negative or IR resist process

Bilayer process

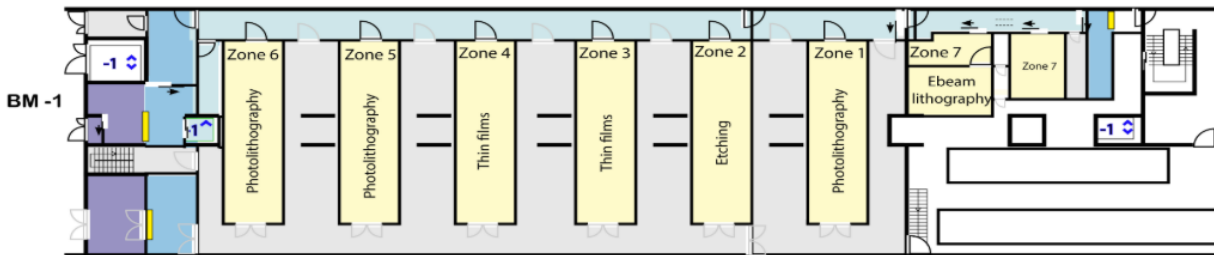
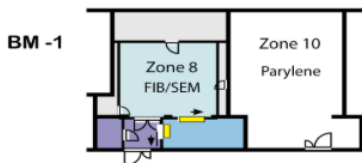
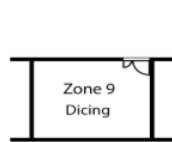
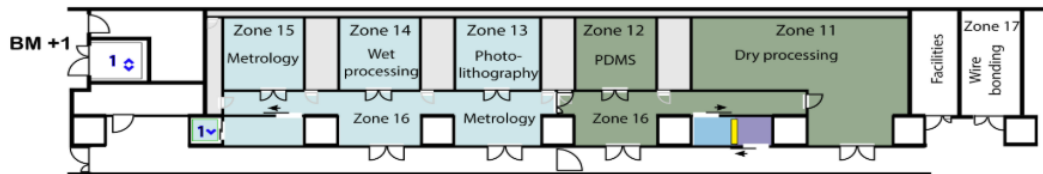


Topic 4:
Salle blanche
Alignement
Gravure chimique

Topic clean room



CMI: Centre of MicroNanoTechnology



Entrance	
Changing room	
Clean room	370 m ² ISO 5 / Class 100
Clean room	280 m ² ISO 6 / Class 1'000
Clean room	150 m ² ISO 7 / Class 10'000
Technical area	509 m ² ISO 7 / Class 10'000



Habillement

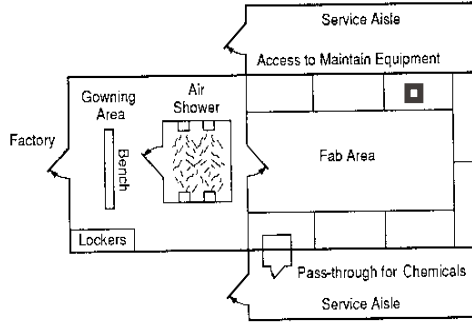
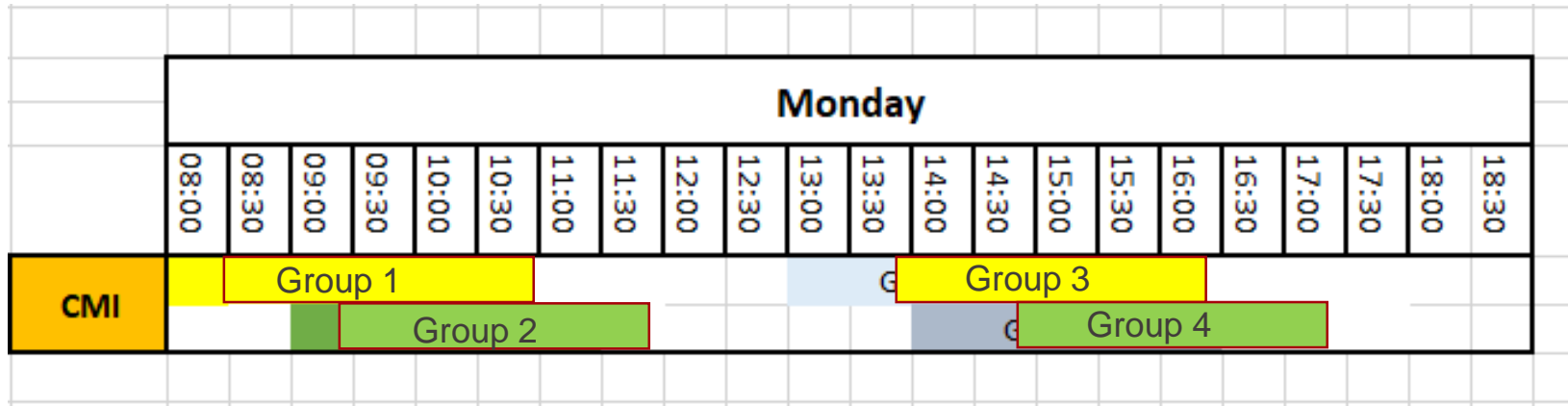


Figure 4.12 Fab area with gowning area, air showers, and service aisles.



- Surchausses
- combinaison
- bottes
- masque facial
- gants vnyil
- lunettes de sécurité
- carte camipro





➤ Z16: MLA 150 1

➤ PR EXPOSURE

➤ Z6: EVG 150

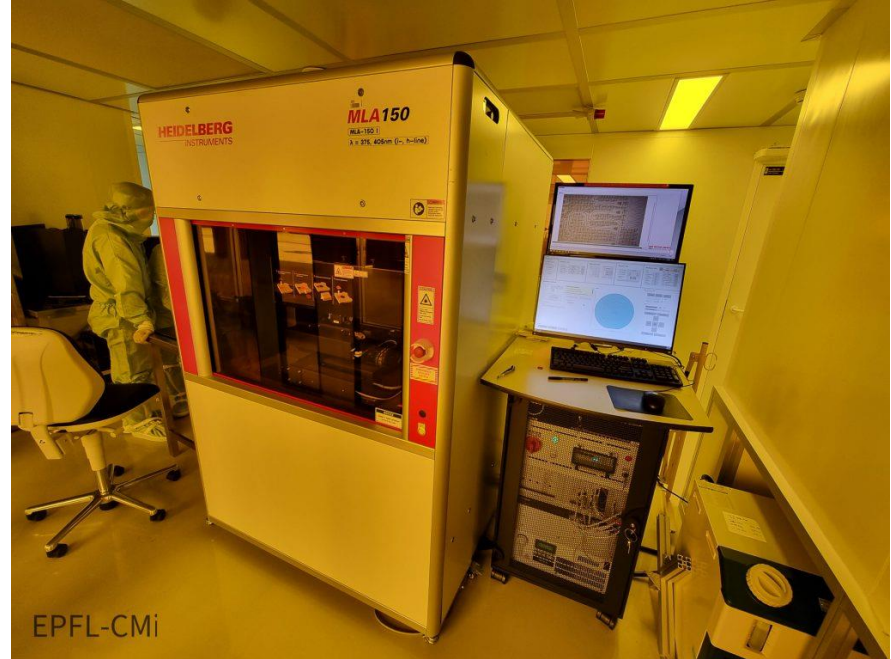
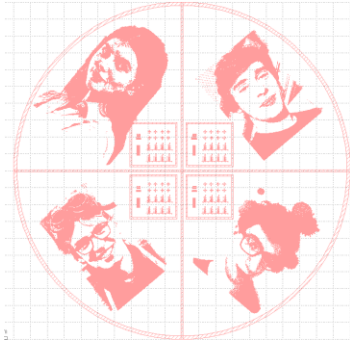
- Development
- PR coating

- Z2: Al etching
Plade Metal
- Z2: Resist stripping
Bain remover 1165

- Al etch
- Resist stripping

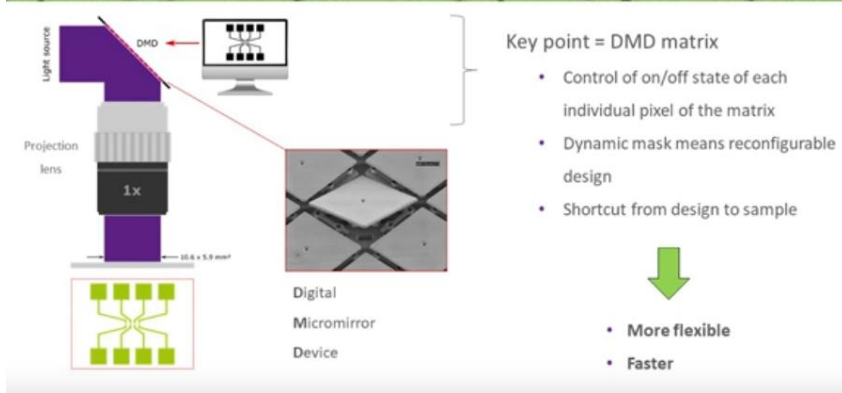
➤ Z15: DekTak

➤ Thickness measurement



EPFL-CM_i

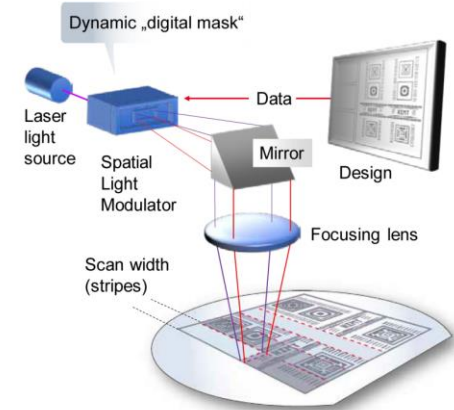
Maskless lithography: how does it work?



Digital age – “film to digital photography”

▶ Maskless lithography

- ▶ Eliminates the need of fabrication of a mask
- ▶ Fast and dynamic
- ▶ Suitable for prototyping and rapid optimization



- Développement
- Etalement de la résine

EVG 150, cluster for i-line photoresists



- Al etching
- Time ~5 to 10 min

Plade Metal, wet bench, metal etch



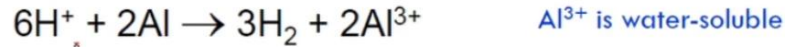
Chemical product: **ANP** **T=35 °C** **ER= 300 nm/min**
 $\text{H}_3\text{PO}_4 : \text{HNO}_3 : \text{CH}_3\text{COOH} : \text{H}_2\text{O} = 73 \% : 3.1 \% : 3.3 \% : 20.6 \%$
ratio in volume (83:5.5:5.5)

<https://cmi.epfl.ch/organisation/materials.php>

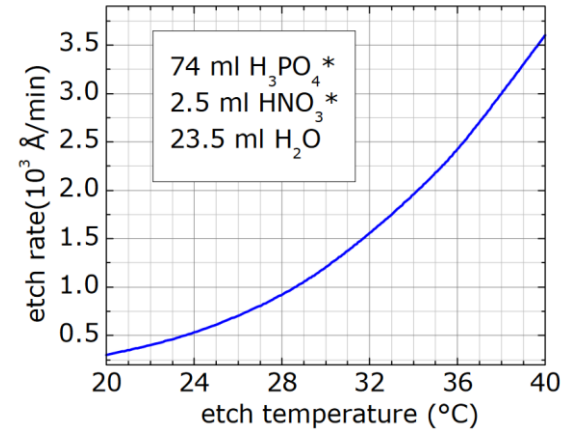
Gravure chimique d'aluminium

<https://cmi.epfl.ch/organisation/materials.php>

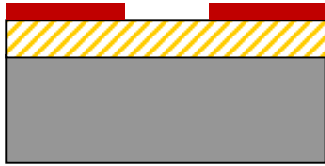
Typical Aluminium etchants contain mixtures of 1-5 % HNO_3^* (for Al oxidation), 65-75 % H_3PO_4^* (to dissolve the Al_2O_3), 5-10 % CH_3COOH^* (for wetting and buffering) and H_2O dilution to define the etch rate at given temperature.



- Aluminum etches in water, phosphoric, nitric and acetic acid mixtures.
- Converts Al to Al_2O_3 with nitric acid (evolves H_2).
- Dissolve Al_2O_3 in phosphoric acid.
- Gas evolution leading to bubbles.
- Local etch rate goes down where bubble is formed, leading to non-uniformity.

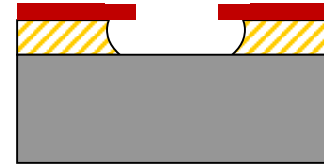


- **Masque** en résine photosensible

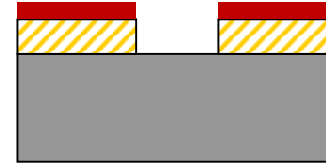


- Résine
- ▨ Couche mince
- Substrat

- **Gravure chimique**
 - Gravure humide
 - Gravure sèche

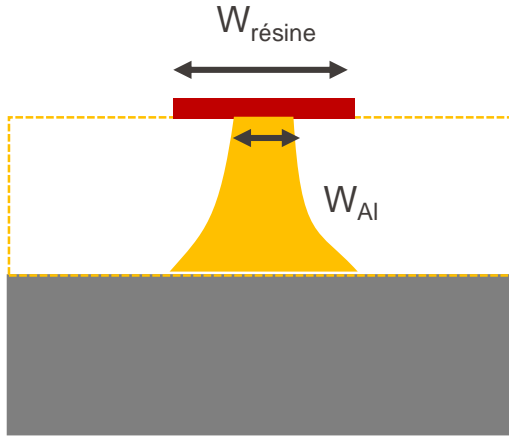


Gravure isotrope

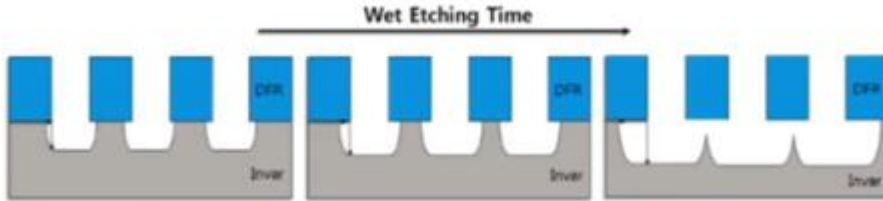


Gravure anisotrope

Gravure chimique d'aluminium



$$V_l = \frac{W_{résine} - W_{Al}}{2 * T_{gravure}}$$



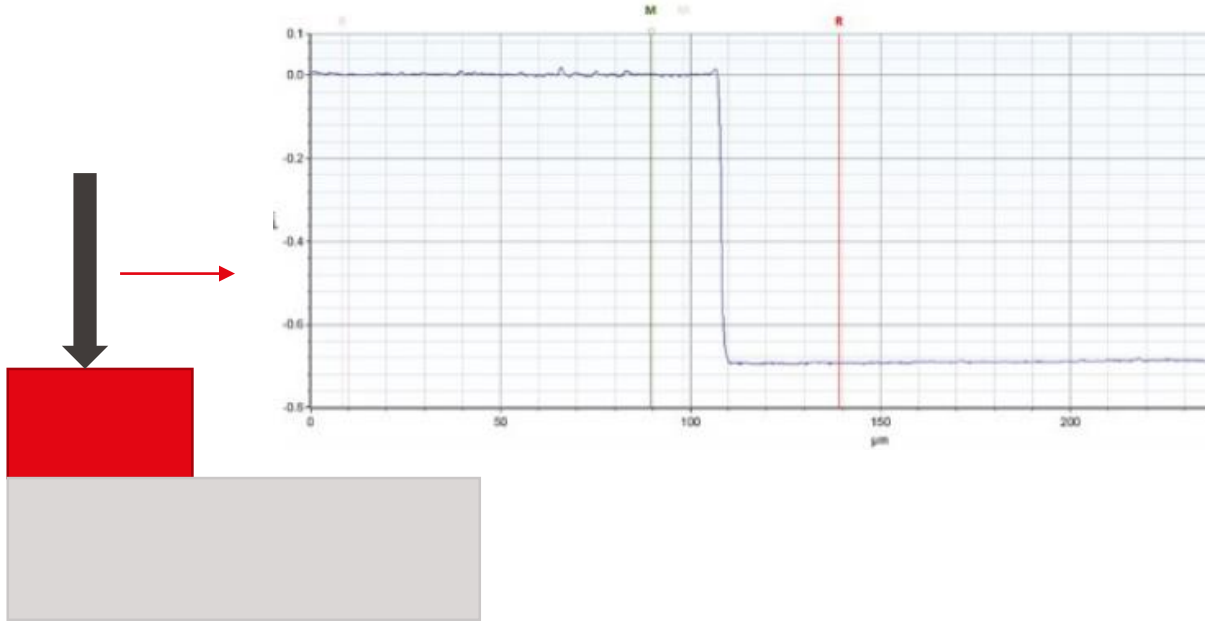
$$Selectivité = \frac{vitesse\ de\ gravure\ d'Al}{vitesse\ de\ gravure\ du\ résine}$$



Over Etch and Resist Lifting

EPFL Mesure d'épaisseur: profilomètre mécanique

La mesure se fait grâce à une pointe très fine en diamant se déplaçant sur une marche de la couche d'aluminium.

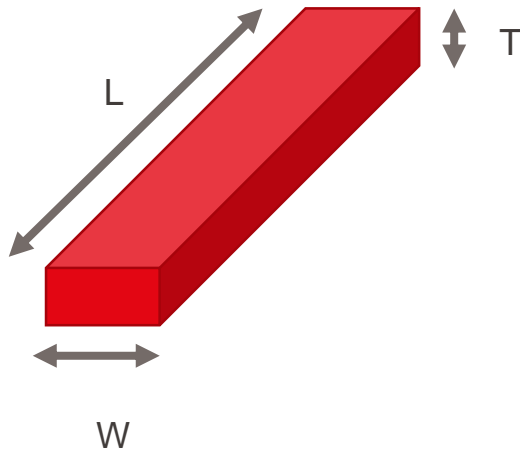


Bruker Dektak XT, surface profiler



Topic 5 :
mesure électrique
mesure optique
SEM OBSERVATION

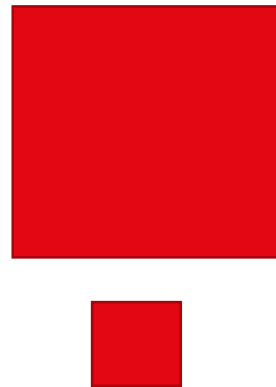
Piste de section rectangulaire



$$R = \rho \frac{L}{W \cdot T}$$

$$L = W \quad \rightarrow \quad R = \frac{\rho}{T} = R_{\blacksquare}$$

$$R = R_{\blacksquare} \frac{L}{W}$$

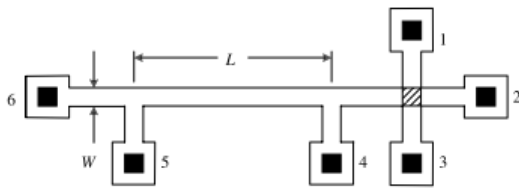


L (longueur) et W (largeur): caractérisent la géométrie du masque

R_{\blacksquare} Résistance par carrée : caractérise la technologie

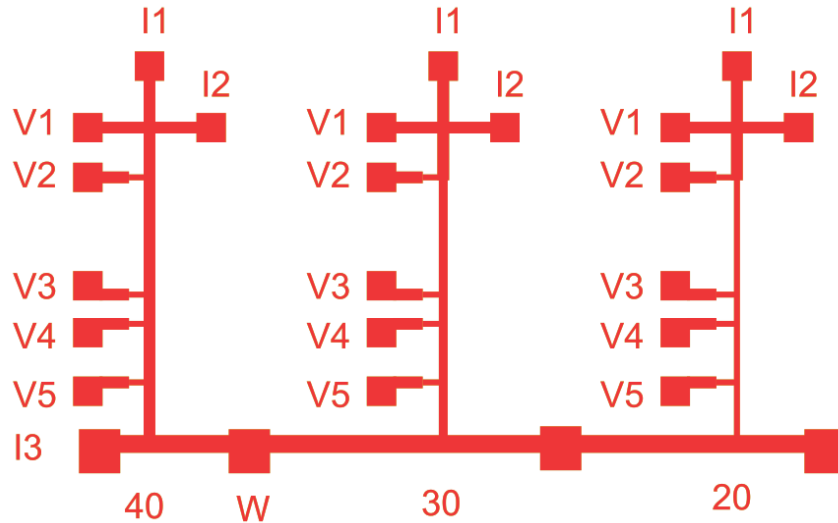
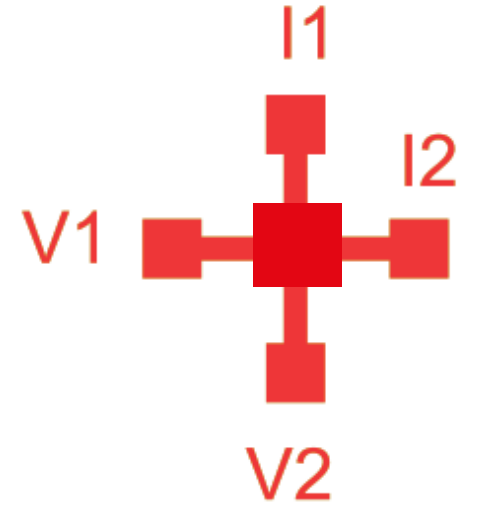
ρ Résistivité du film

T Epaisseur du film

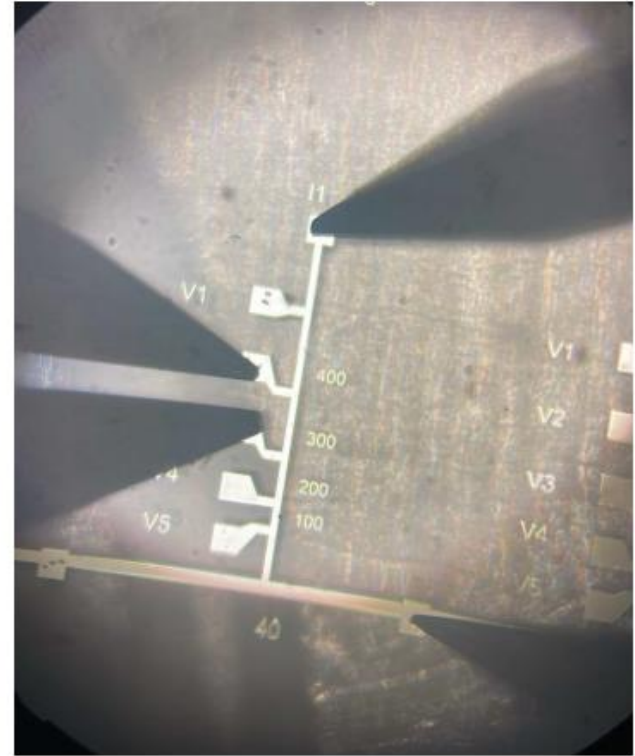


$$R_{\blacksquare} = R_{sh} = \frac{\pi}{\ln(2)} \frac{V_{34}}{I_{12}}$$

$$V_{45} = \frac{R_{sh} L I_{26}}{W}$$

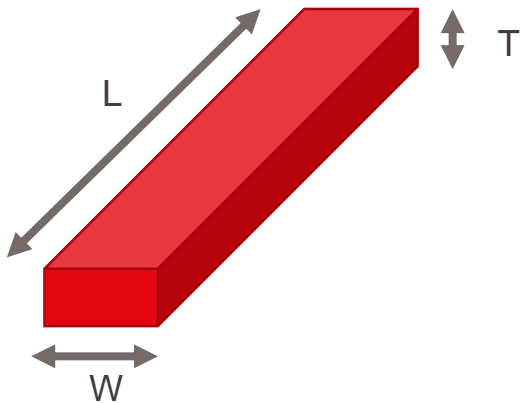


contact	V1-V2	V1-V3	V2-V3	V2-V4	V3-V4	V4-V5	W (unit)
L(μm)	400	750	300	550	200	100	
R(unit)							
R(unit)							
R(unit)							
R(unit)							



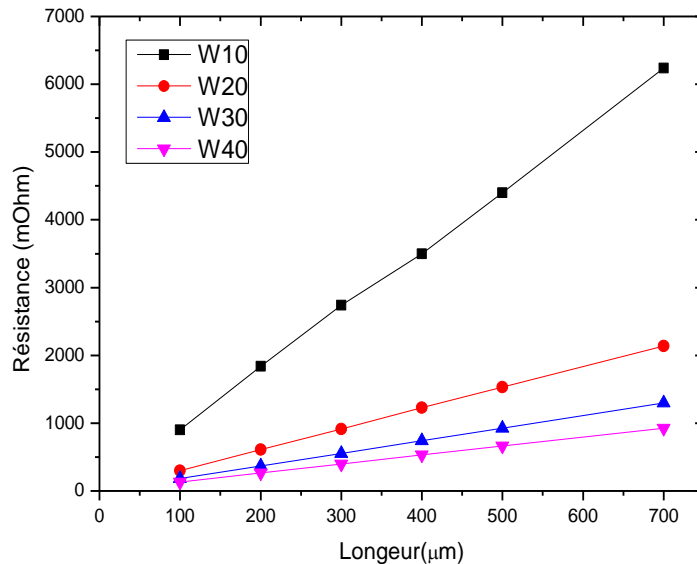
Résistance électrique: calcul

Motif de section rectangulaire

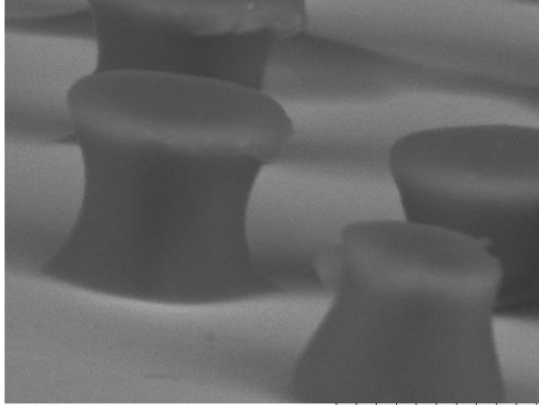


$$R = R_{\blacksquare} \frac{L}{W} \quad \text{pente} = \frac{R_{\blacksquare}}{W}$$

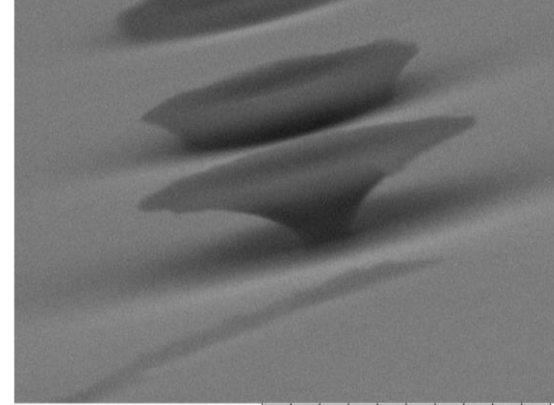
contact	V1-V2	V1-V3	V2-V3	V2-V4	V3-V4	V4-V5	W (unit)
L(μm)	400	750	300	550	200	100	
R(unit)							
R(unit)							
R(unit)							
R(unit)							



MEB observation



EPFL-DLL0385 2022.10.23 17:22 D2.3 x7.0k 10 um



EPFL-DLL0335 2022.10.11 16:18 D2.3 x10k 10 um

	PEB: 105C/60s	PEB: 110C/60s	PEB 115C/60s
Dose: 60mJ/cm ²			
Dose: 70mJ/cm ²			
Dose: 80mJ/cm ²			
Dose: 90mJ/cm ²			



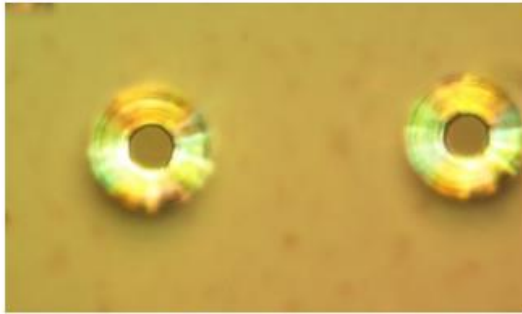


Figure 27 : motif rond cercle supérieur

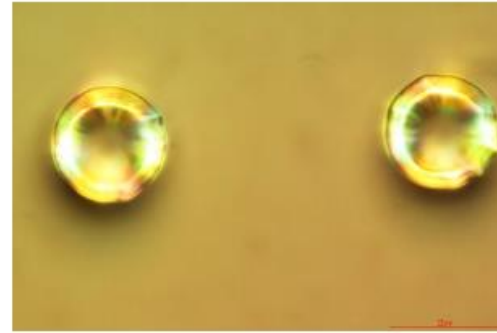
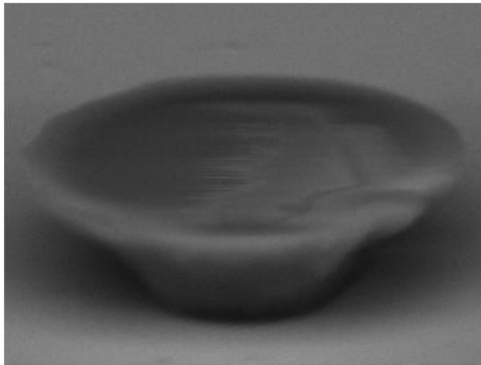
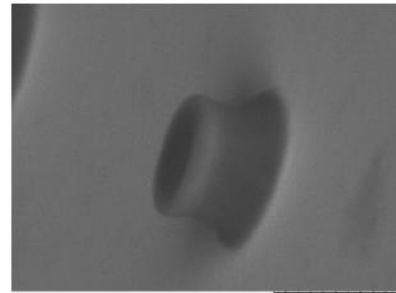


Figure 28 : motif rond cercle inférieur

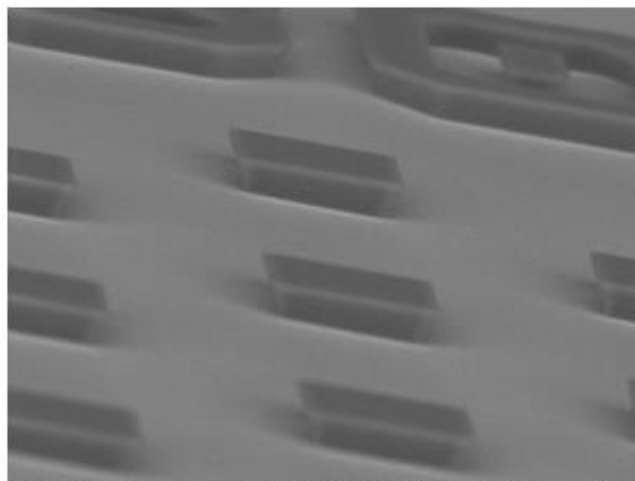


EPFL-DLL0908 2024.12.02 16:05 D5.2 x8.0k 10 um

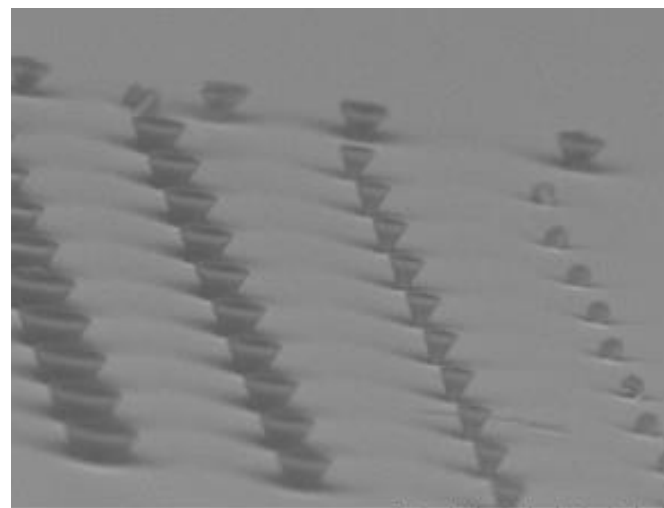


EPFL-DLL0909 2024.12.02 16:21 D8.3 x6.0k 10 um

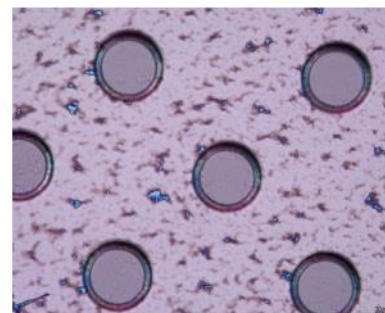
Figure 35 : wafer paramètres 4



EPFL-DLL0721 2024.10.14 15:30 D5.1 x1.8k 50 um



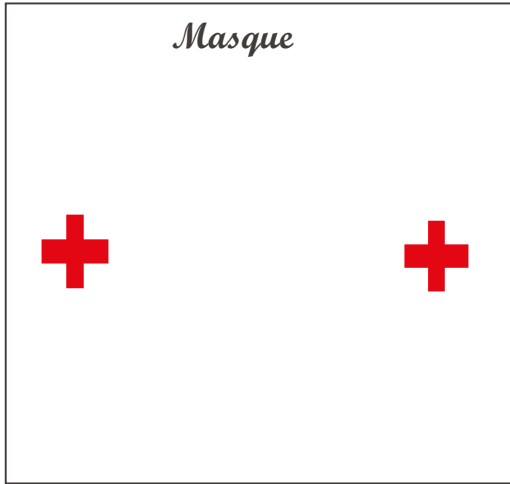
EPFL-DLL0719 2024.10.14 15:22 D4.0 x1.5k 50 um



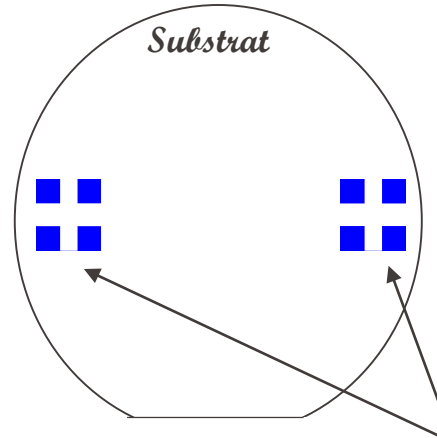
Topic 6 :
Observation profile
Résine négative

Procédé d'alignement

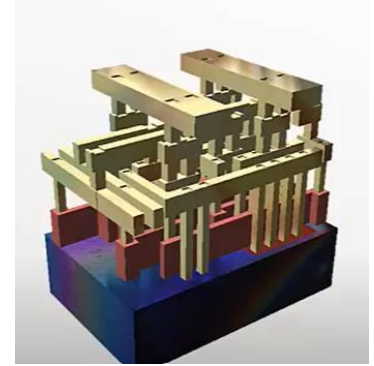
Nécessaire d'aligner le masque et le substrat afin que les motifs soient situés à l'endroit voulu.



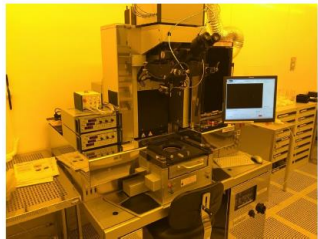
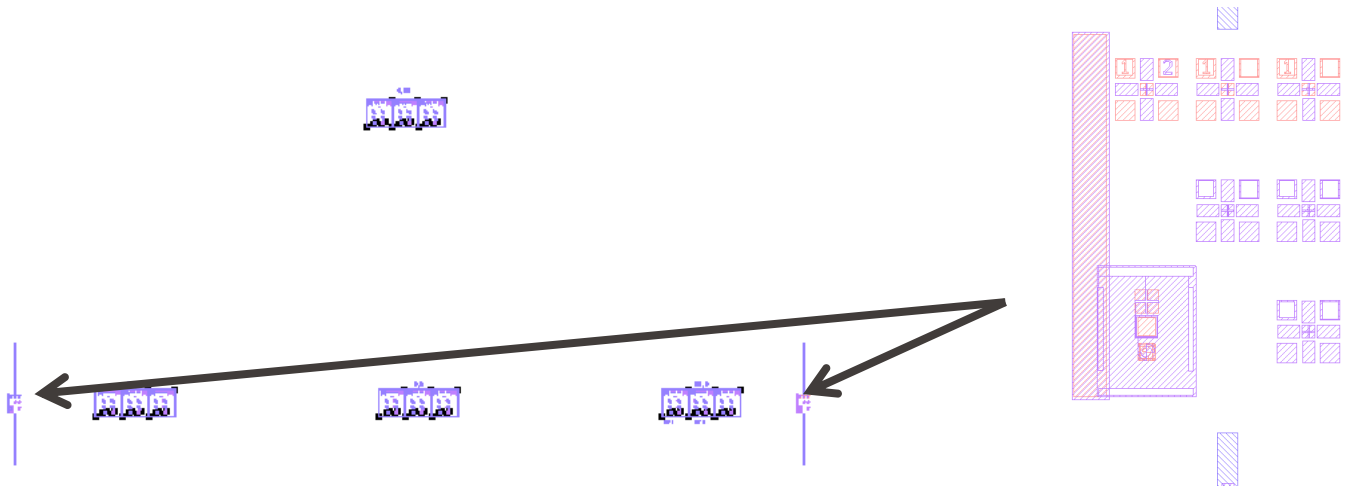
Masque pour le niveau à réaliser



Marques d'alignement de l'étape précédente

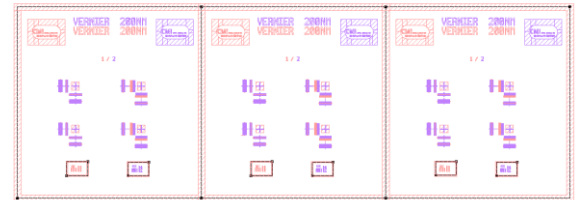


Photomasque



Coordonnées
(x,y) en mm

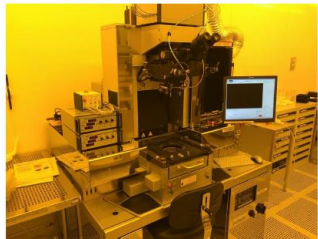
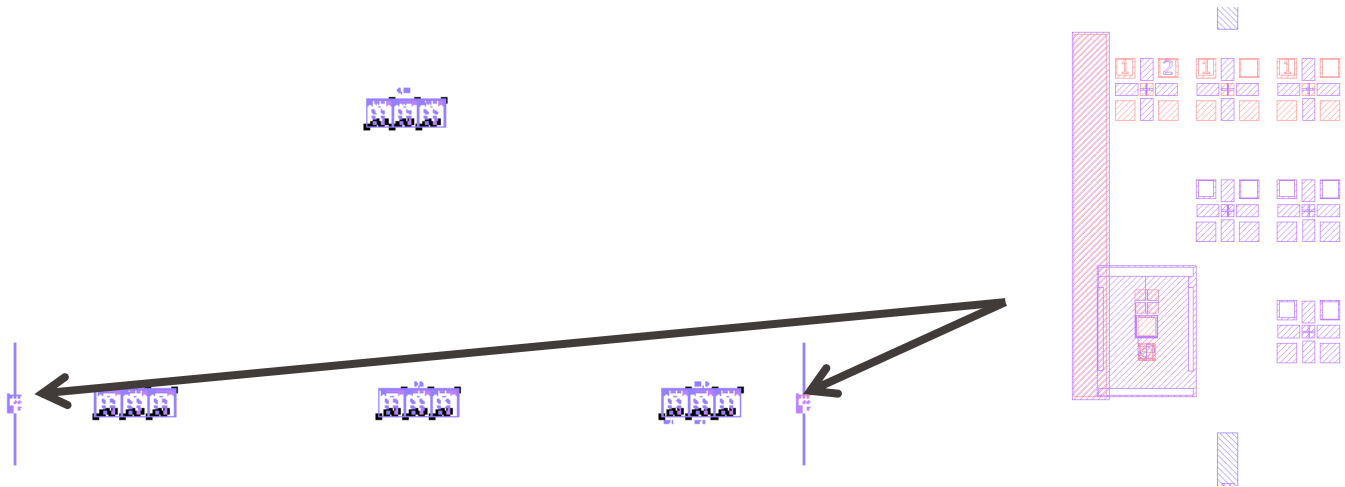
28, 0



REF 1

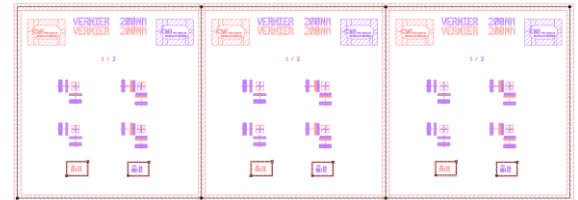
REF 2

Photomasque



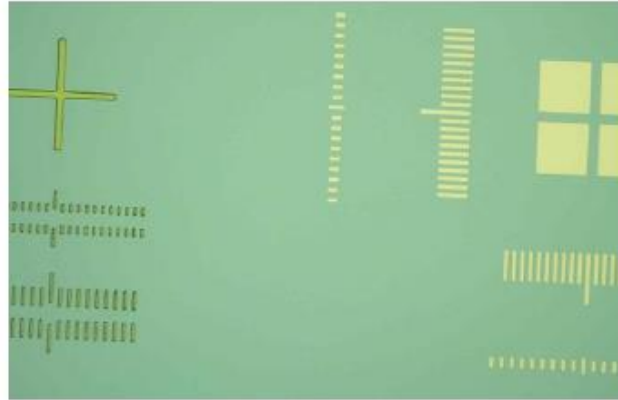
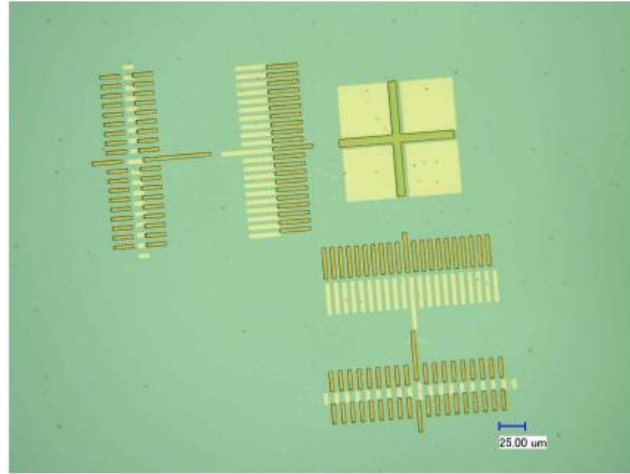
Coordonnées
(x,y) en mm

28, 0

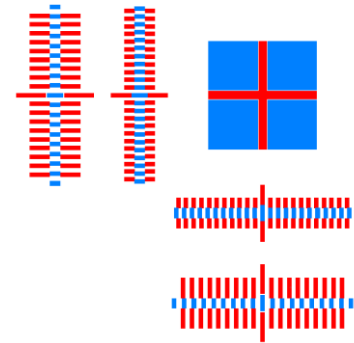
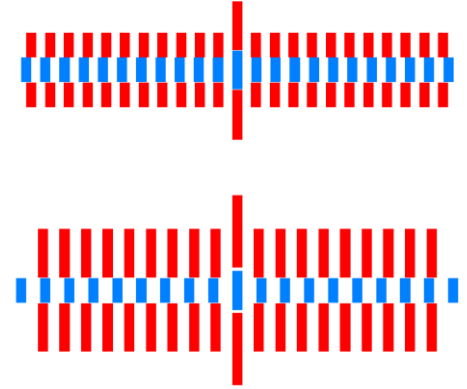


REF 1

REF 2



BM3 229/ BM3 231





Choisir votre groupe



Liste des groupes

Caché pour les étudiants



Programme 1er semestre_2025



Consignes pour rapport TP Micro 332

Caché pour les étudiants

Note : Vous avez le choix de rédiger votre rapport soit en français soit en anglais et à me l'envoyer en format pdf 2 semaines après votre dernière séance pratique.

Exemple de figures et tableaux avec numéros et légendes (Juste pour avoir une idée)

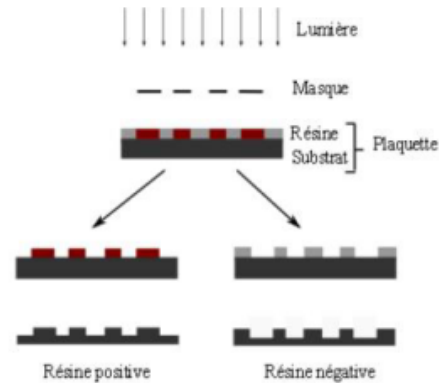


Figure 1.2 : Polarité des résines utilisées en microélectronique

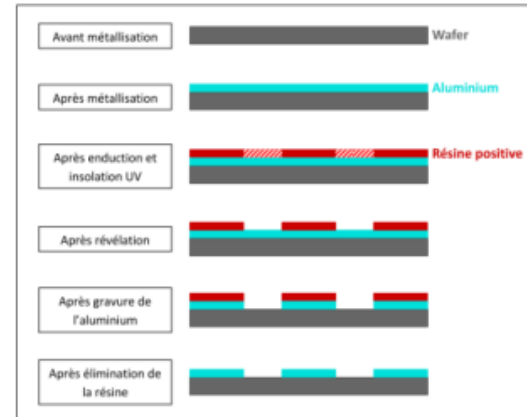


Figure 15 : Représentation schématique d'une structuration d'aluminium par photolithographie et gravure

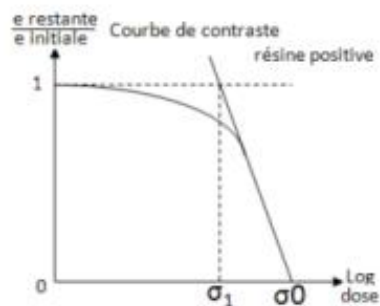


figure 62 : exemple d'évolution de l'épaisseur normalisé en fonction de la dose d'insolation (rapportée à une durée d'exposition sur cette exmple) pour une résine positive

Les mesures d'épaisseurs sont réalisées au profilomètre mécanique Tencor, elles sont regroupées au tableau 1 :

Tableau 1 : mesure de l'épaisseur en fonction de la dose

Dose mJ.cm^{-2}	25	35	45	50	65	75	85	95
Epaisseur μm	18,6	18,25	19,06	18,35	19,29	18,7	18,5	18,95

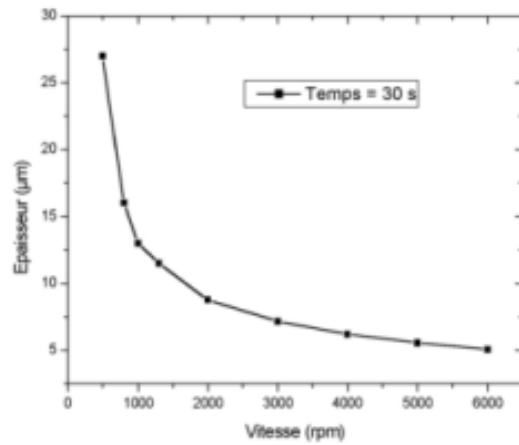


Figure 5 : Courbe d'étalement de la résine AZ-4562 en fonction de la vitesse de rotation pour une durée constante de 30 s.

TABLE 1
SPIN COATING RECIPE FOR CREATING A 1.4 µm PHOTORESIST LAYER USING AZ1512 HS

Step	Speed (rpm)	Ramp (rpm/s)	Time (s)
1	800	1,000	3
2	1,500	1,500	3
3	3,000	3,000	30

4.1 qualité des bordures

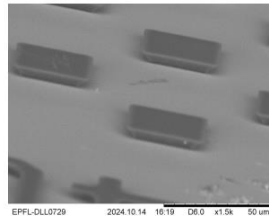


figure 5.1 : student 2, échantillon 4

4.2 taille limite

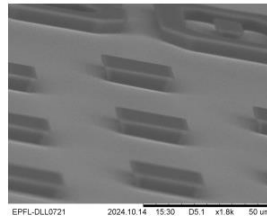


figure 5.2 : student 1, échantillon 2

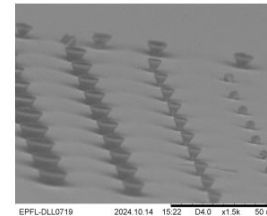


figure 5.3 : student 1, échantillon 2



Sécurité en salle blanche



Centre de microtechnologie, EPFL

Habillement

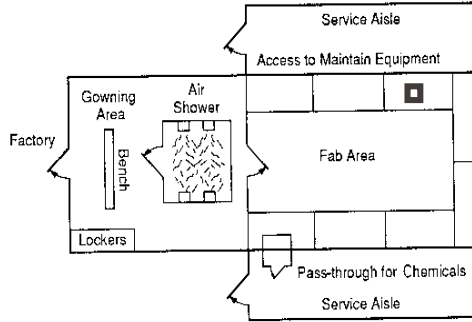
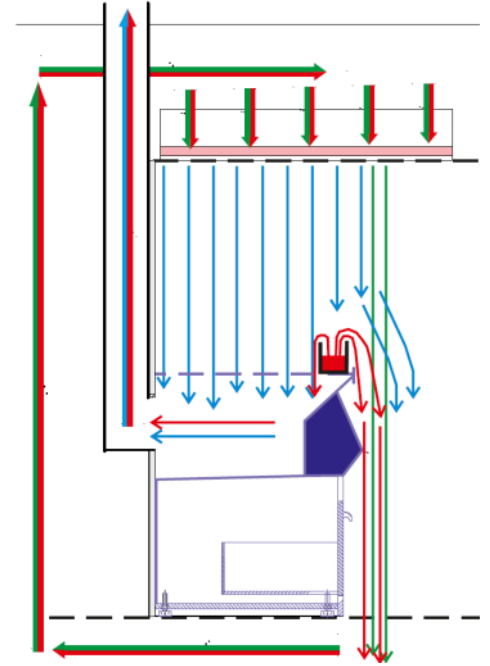
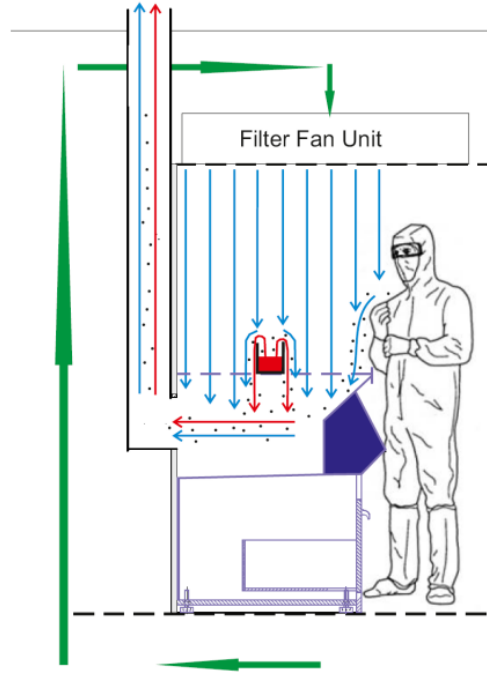


Figure 4.12 Fab area with gowning area, air showers, and service aisles.



- Surchausses
- combinaison
- bottes
- masque facial
- gants vynil
- lunettes de sécurité
- carte camipro









CMI cleanroom concept

Standard ISO 14644-1

Concentration max allowed of particles (particles/m³ of air)
 Particles sizes equal or superior to that given below

Classe ISO	0,1 µm	0,2 µm	0,3 µm	0,5 µm	1 µm	5 µm	Classe US FS209
ISO 1	10	2	0	0	0	0	
ISO 2	100	24	10	4	0	0	
ISO 3	1 000	237	102	35	8	0	1
ISO 4	10 000	2 370	1 020	352	83	0	10
ISO 5	100 000	23 700	10 200	3 520	832	29	100
ISO 6	1 000 000	237 000	102 000	35 200	8 320	293	1 000
ISO 7	∞	∞	∞	352 000	83 200	2 930	10 000
ISO 8	∞	∞	∞	3 520 000	832 000	29 300	100 000
ISO 9	∞	∞	∞	35 200 000	8 320 000	293 000	

CMI BM -1 ⇒ ISO 5
 CMI BM +1 { ISO 6
 ISO 7