Les puces optiques

ou

Circuits intégrés photoniques

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Contenu

1. Présentation.

2. Fabrication.

3. Principes fondamentaux:
    1. Confinement de la lumière.
    2. Propagation de la lumière dans un guide.

4. Principaux circuits:
    1. Coupleur Y.
    2. Coupleur en X.
    3. Interféromètres.
    4. Réseau de diffraction.

Intérêts de l'optique

Rapidité	Bande passante large
Distance	Faible atténuation
Compatibilité électromagnétique	Haute fréquence
Sûreté	Pas de charge électrique
Sécurité	Piratage difficile
Observation	Imagerie
Analyse	Interaction avec la matière

Applications de la photonique

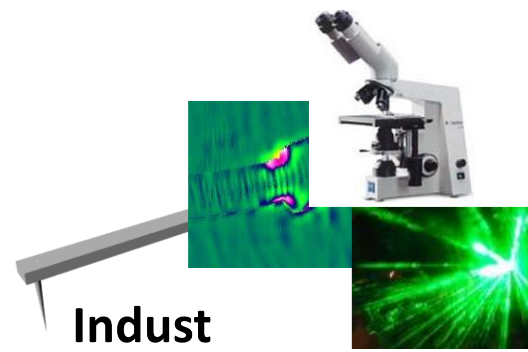
Transports

Biomédical

Informatique Multimedia

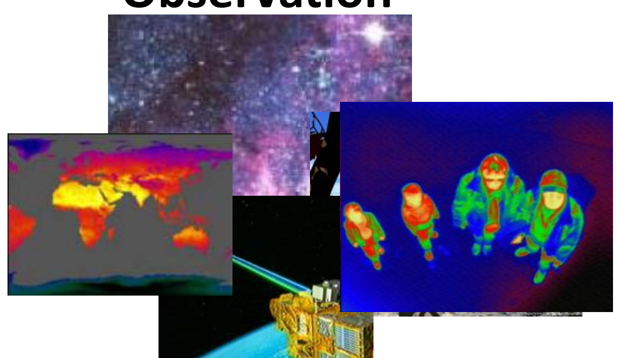
Éclairage Affichage

Sources lasers
Fibres optiques
Circuits intelligents
Photo détecteur



Indust Instrumentation

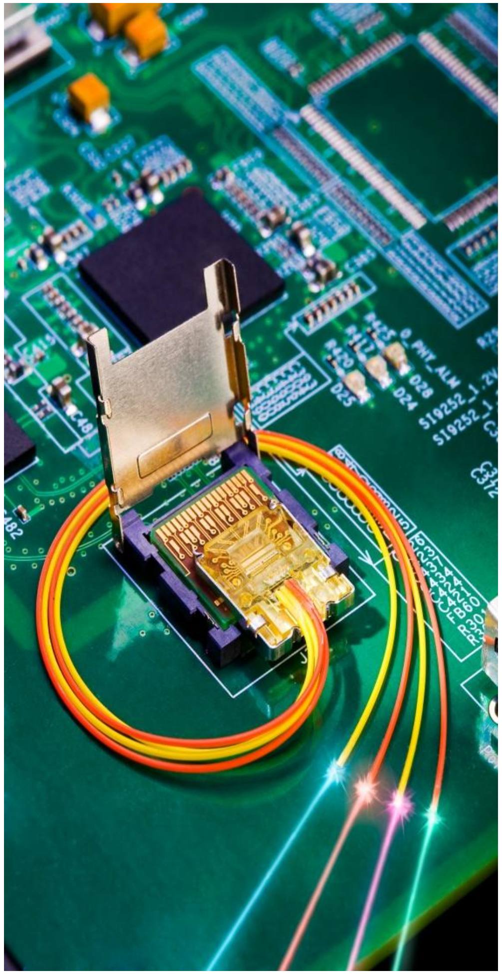
Observation

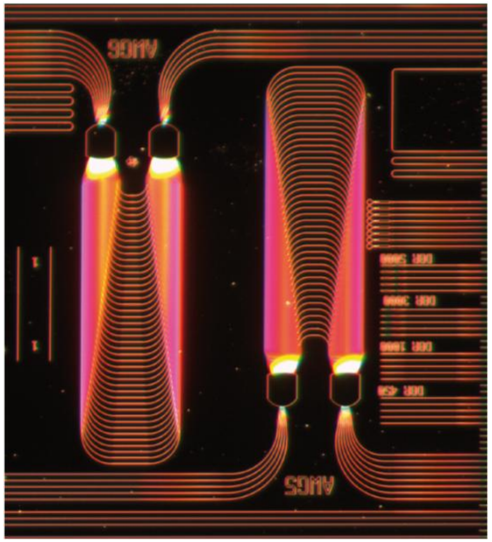


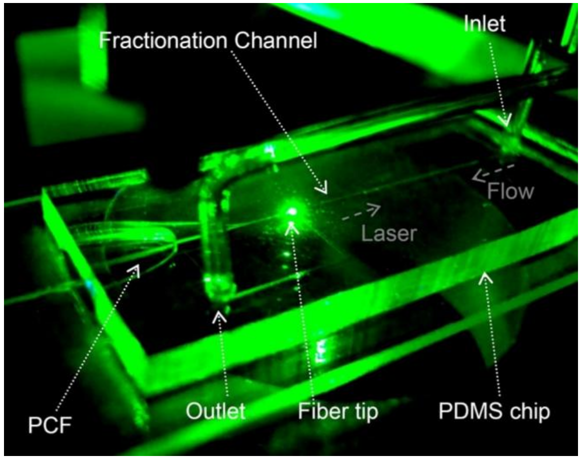
Télécoms

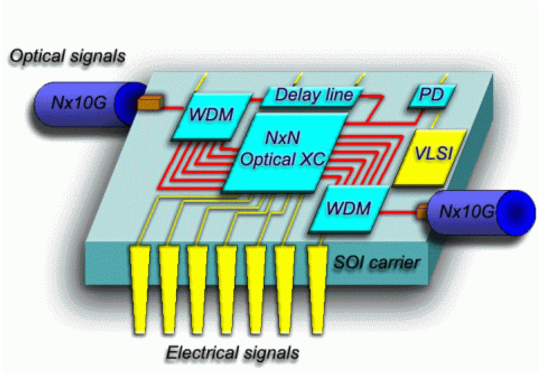
Défense

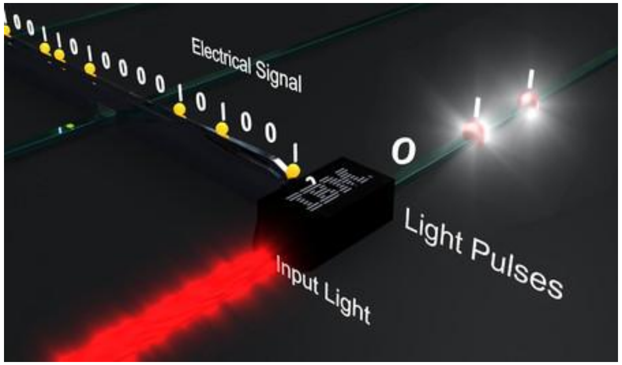
Présentation des puces optiques



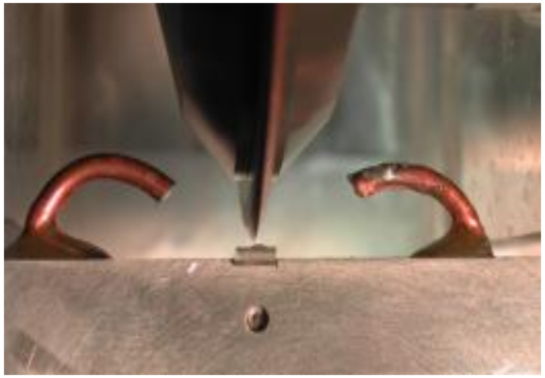


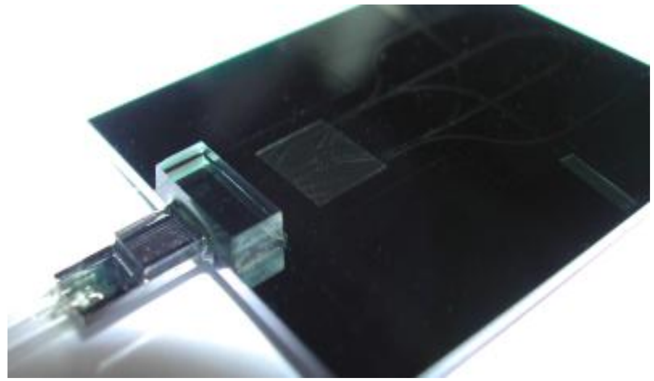


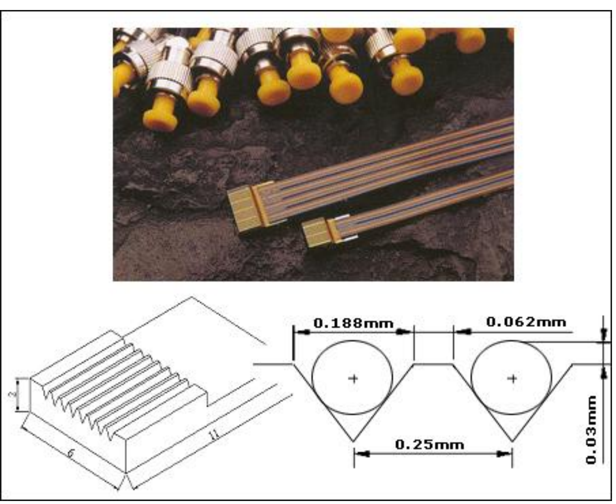


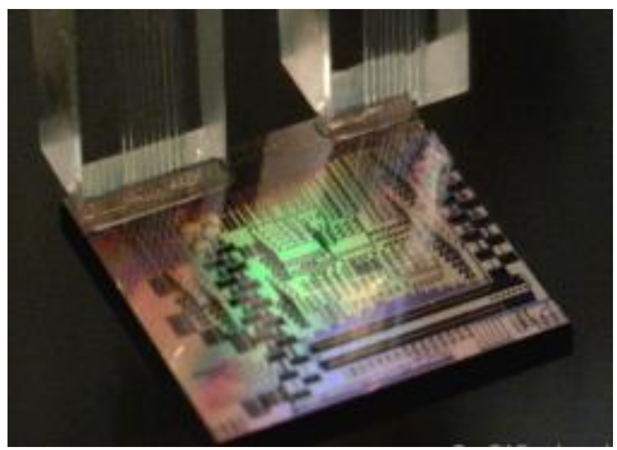


Mise en boîtier de la puce

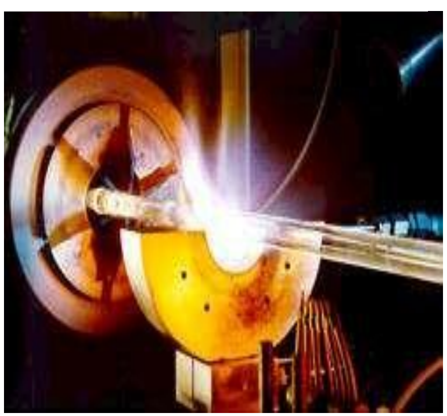


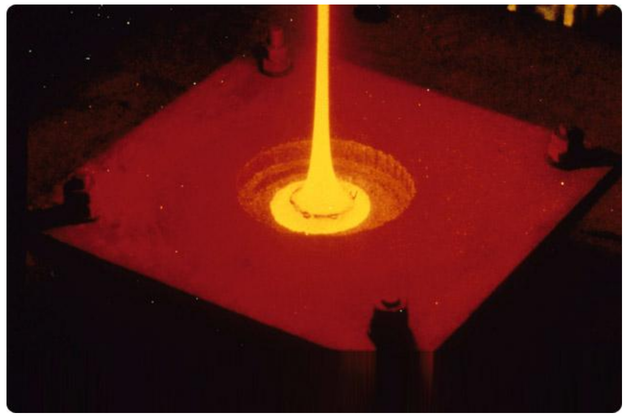






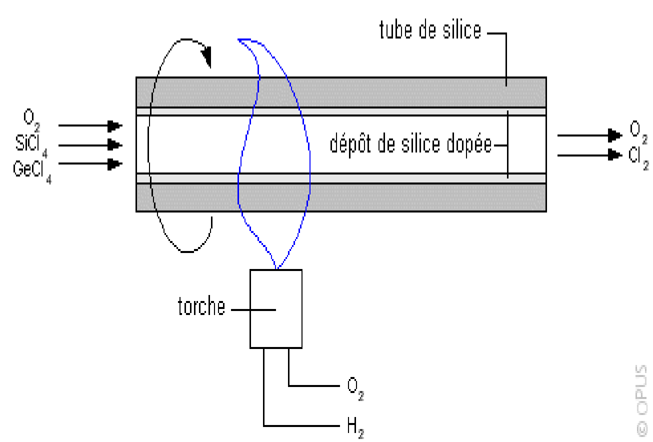
Fabrication d’une fibre optique en verre



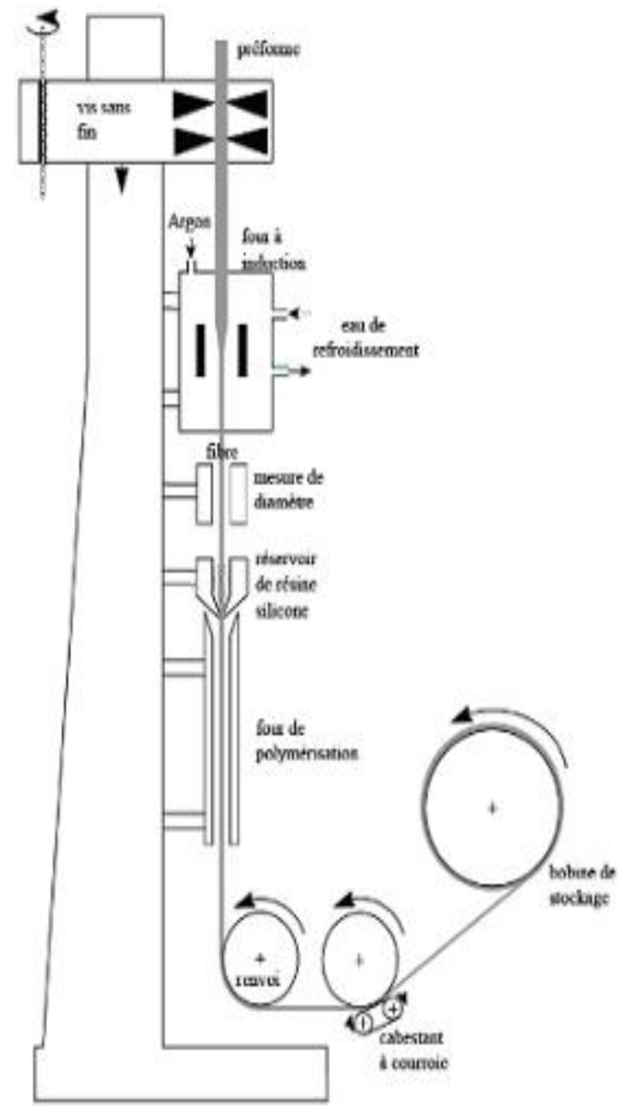


Fusion du sable à 1500°C

Préformation
*(**C**hemical **V**apor **D**eposition)*



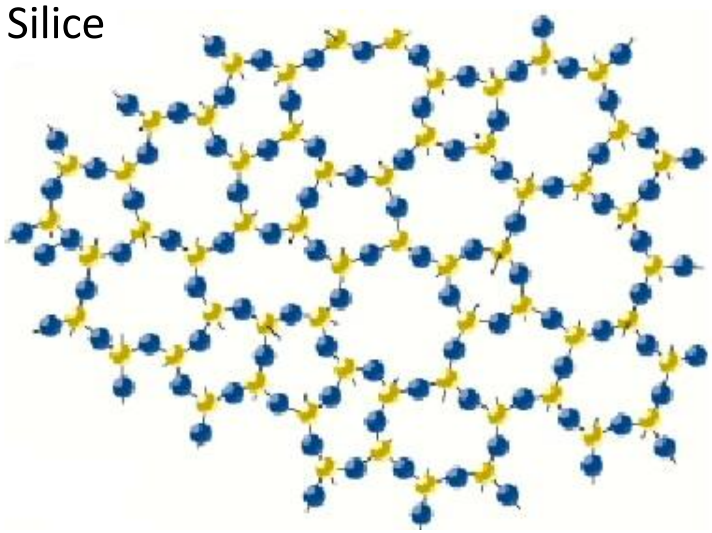
Fibrage

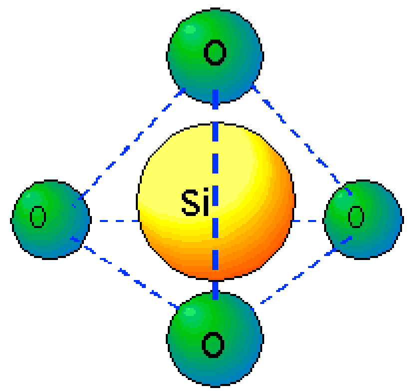


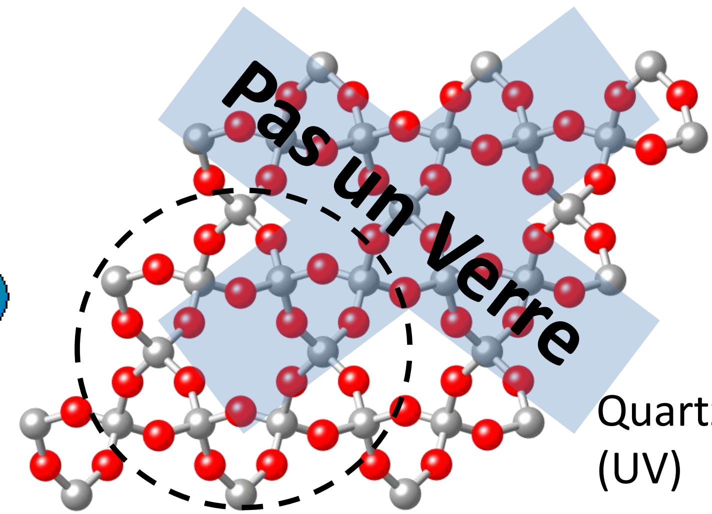
Verres

*Un verre est un **solide non-cristallin** présentant le phénomène de **transition vitreuse**.*

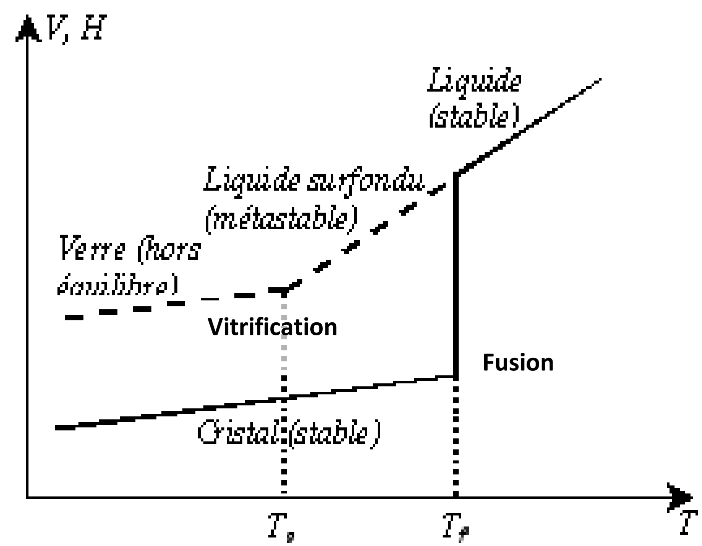
Silice







Quartz (UV)

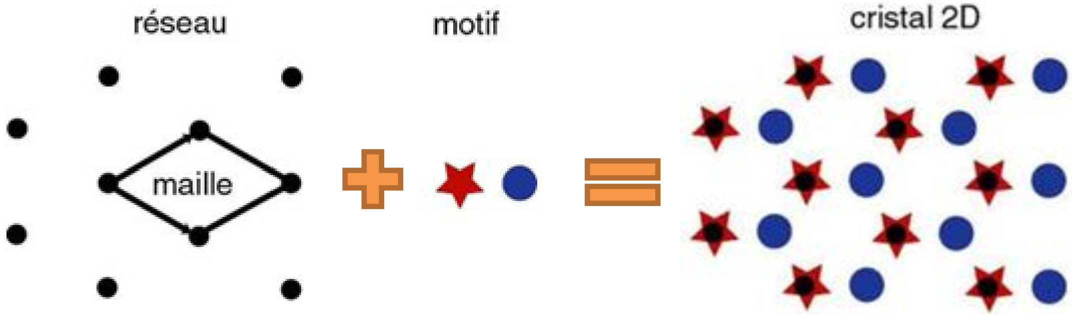


Verres d'oxyde: Visible, proche IR (< 2µm)
SiO_2, GeO_2, TiO_2, … Indice ≥ 1.45 (sauf Verres poreux)

Chalcogénures: Moyen IR (1-2µm → 20µm)
Se, Te, S, … Indice # 2 - 3
+ Cd, Ga, As, Ge, …

(Verres métalliques?) ***Le verre est un solide qui présente le désordre d'un liquide.***

Cristaux

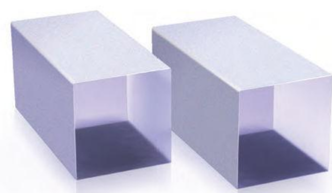


YAG

$Y_3Al_5O_{12}$

Ytterbium **A**luminium **G**renat
Dopé Néodyme: **Nd:YAG**
(inversion population)
Laser @ 1064µm

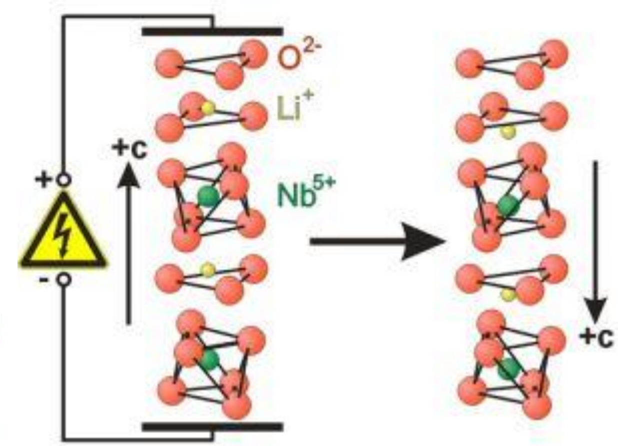
KTP
Phosphate de Potassium titanyl
Doublage YAG



$$\vec{P} = f(\vec{E})$$

Niobate de Lithium

$LiNbO_3$
ElectroOptic, AcoustoOptic



Semi-conductors

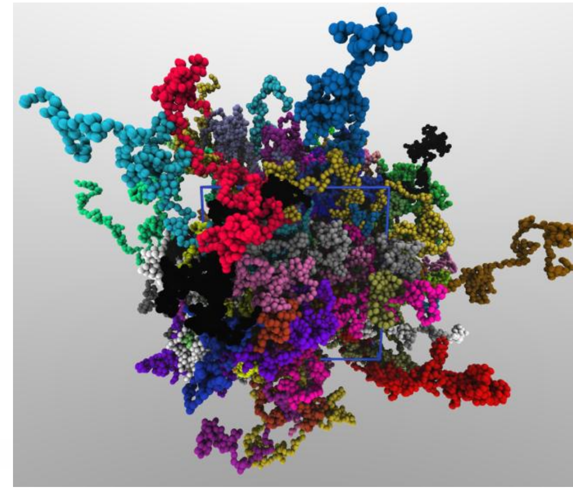
Si, GaAs, Ge, Csi, …

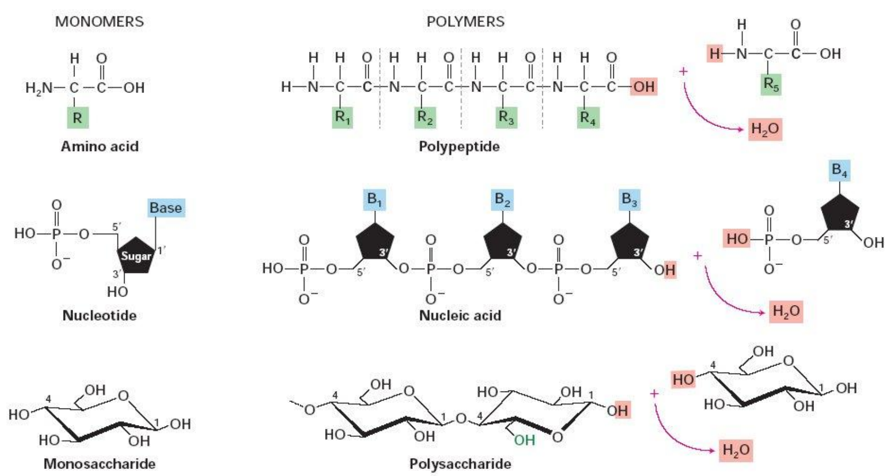
Calcite

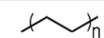
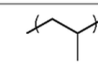
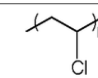
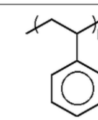
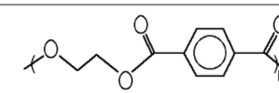
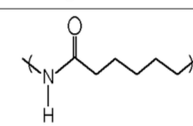
$CaCO_3$ Birefrigent

Polymères

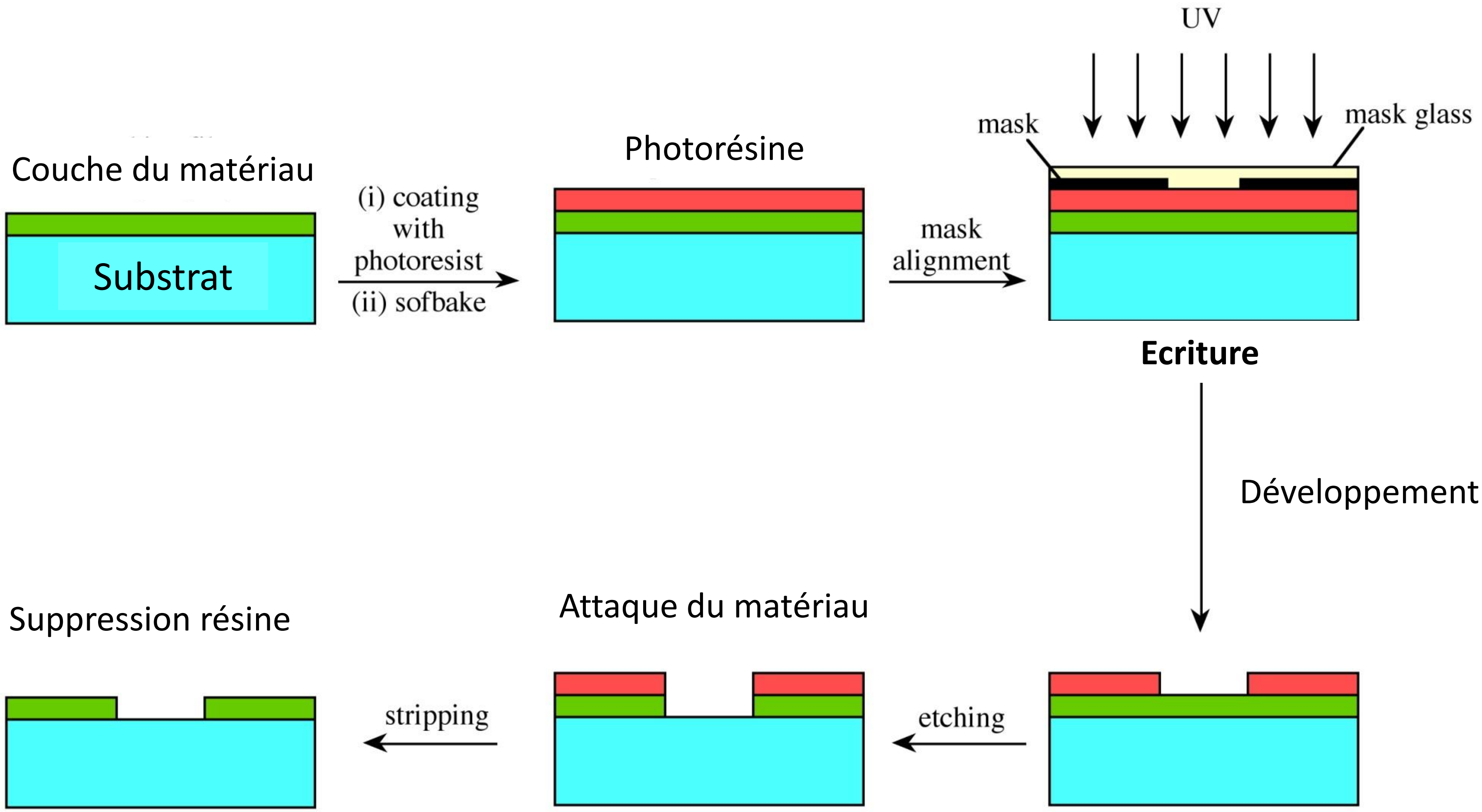
Propriétés ajustables:
Imperméable, poreux, résistance au feu, corrosion, anti-adhésion, transparence, …
Applications variées:
Emballages, isolants, conteneurs, joints, revêtement, optique, médical, textile, …



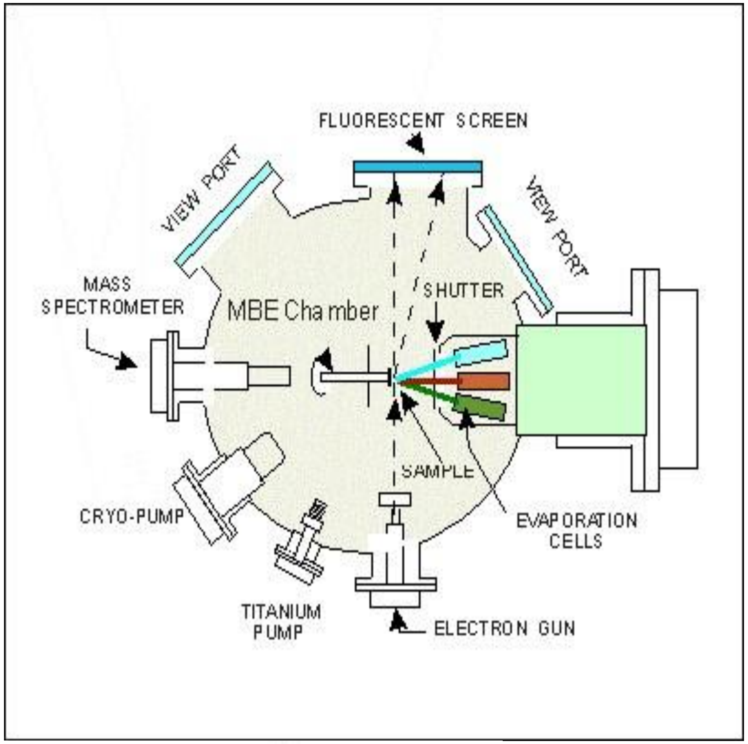


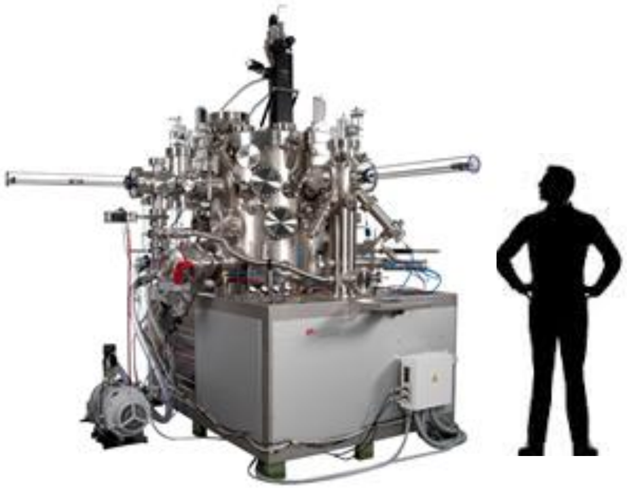
Sigle	Structure moléculaire	Désignation courante
PE		polyéthylène
PP		polypropène
PVC		poly(chlorure de vinyle)
PS		polystyrène
PET		poly(téréphtalate d'éthylène)
PA-6		polycaprolactame

Fabrication de la puce



Croissance d'un cristal





Evaporation des éléments par chauffage

Vide poussé (10^{-8} Pa) évite les perturbations et les impuretés

Dépôt lent (1µm / h) de couches monoatomiques

Pompage cryogénique refroidi le substrat et absorbe les impuretés

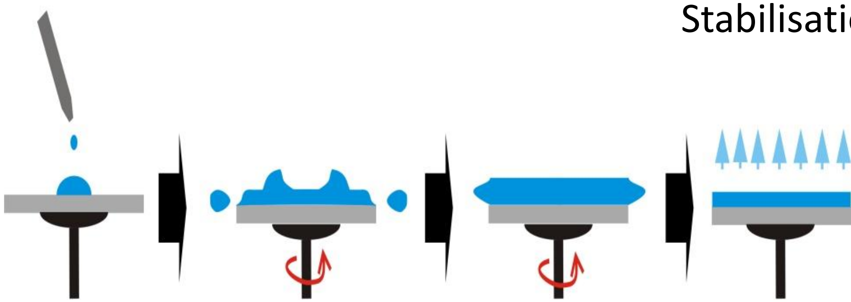
Température du substrat contrôle les réactions

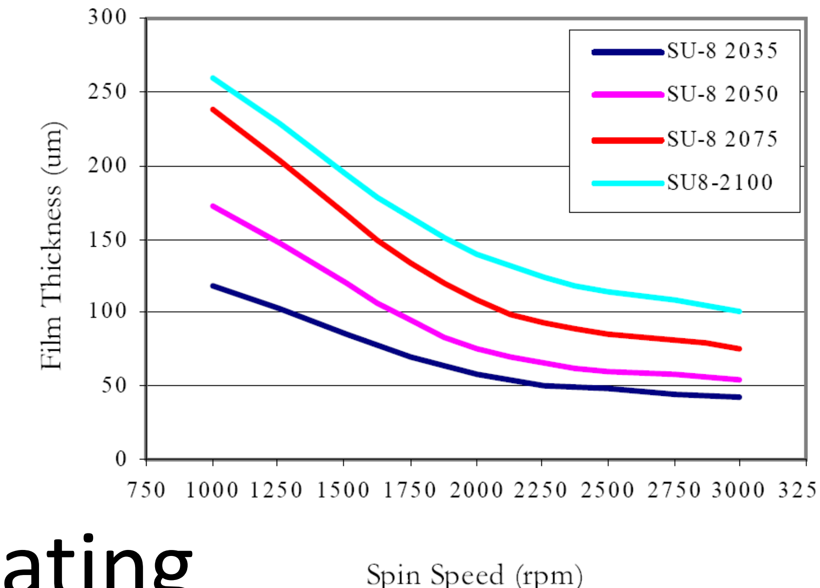
Suivi cristallin par diffraction électronique

Analyse de la composition par spectrométrie de masse

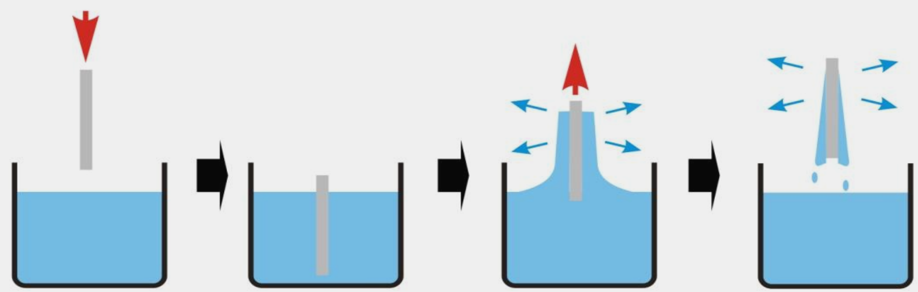
Dépôt de résine polymère par spin coating

1	2	3	4
Arrêt Dépôt	Accélération Ejection	Consigne Etalement	Arrêt Evaporation Stabilisation



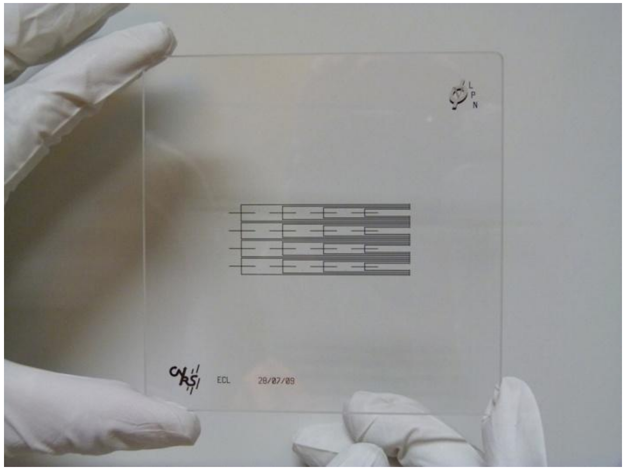


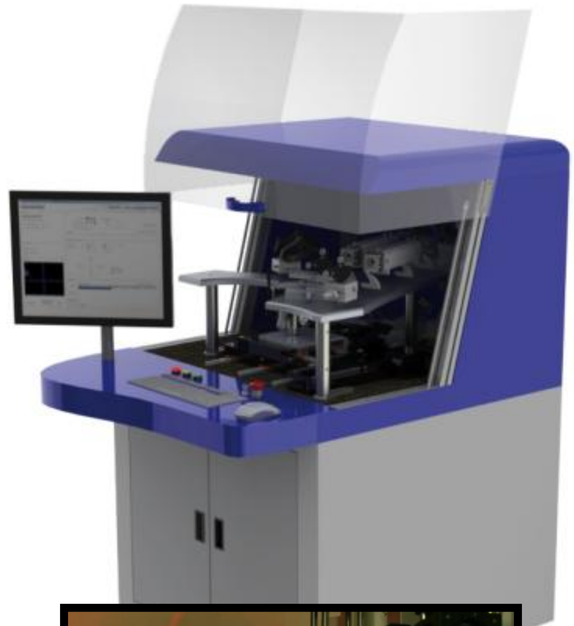
… ou dip coating

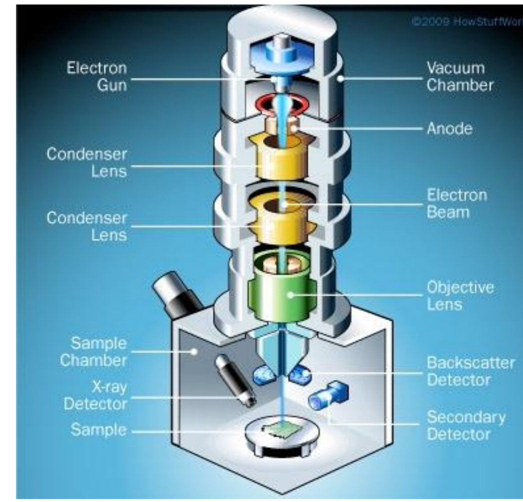


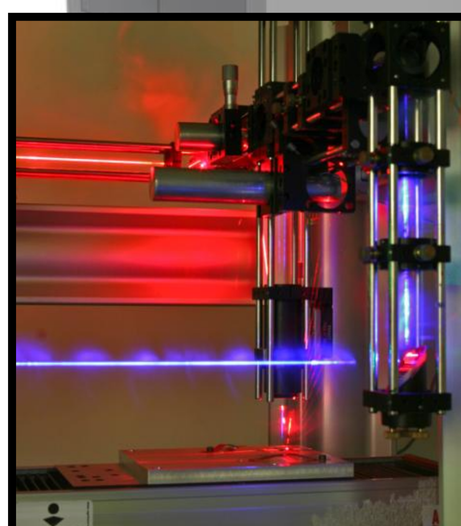
1	2	3	4
Vitesse Trempage	Arrêt Stabilisation	Consigne Dépôt	Décélération Arrêt Evaporation Ejection

Dessin des circuits

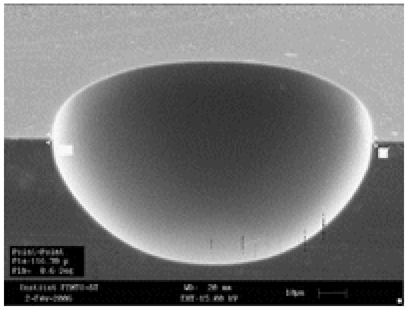


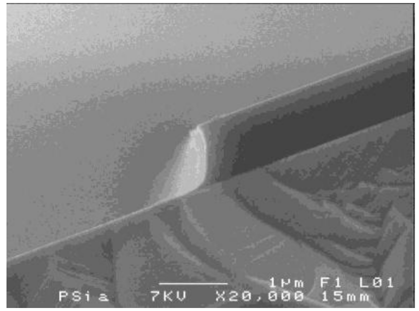


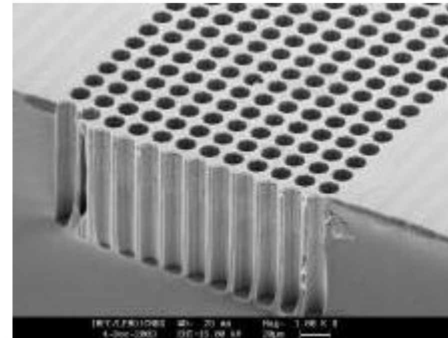


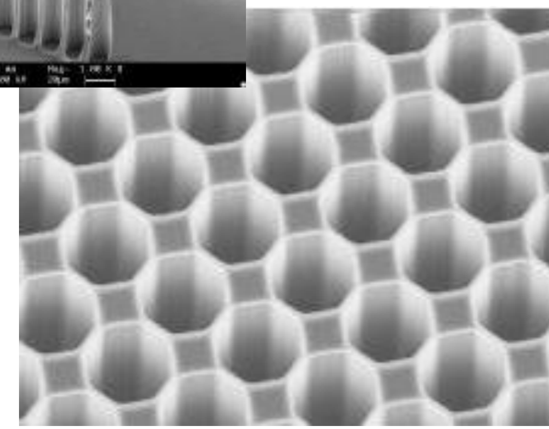


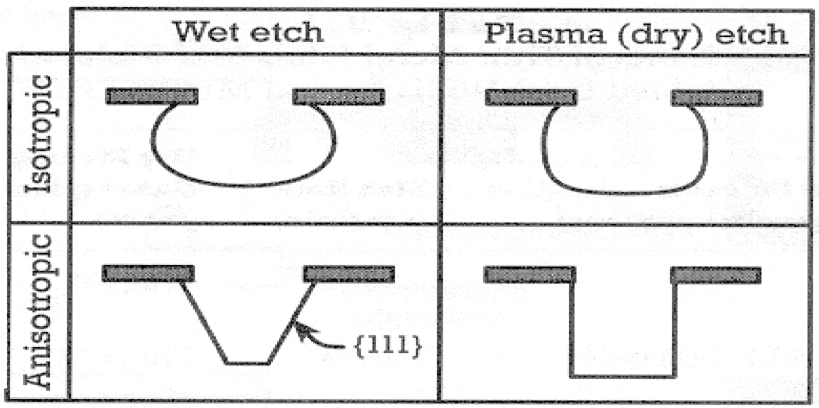
Révélation des images

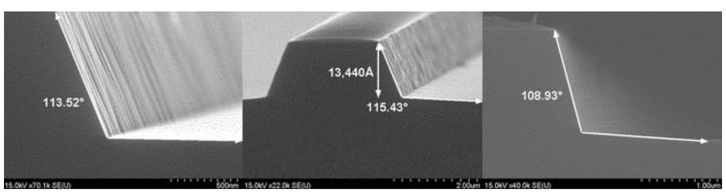


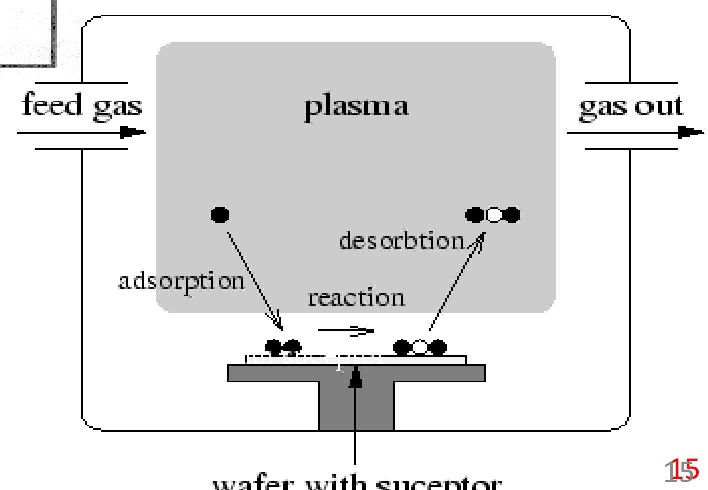




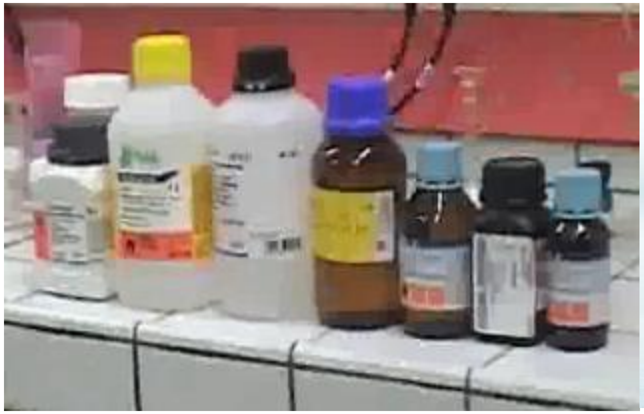






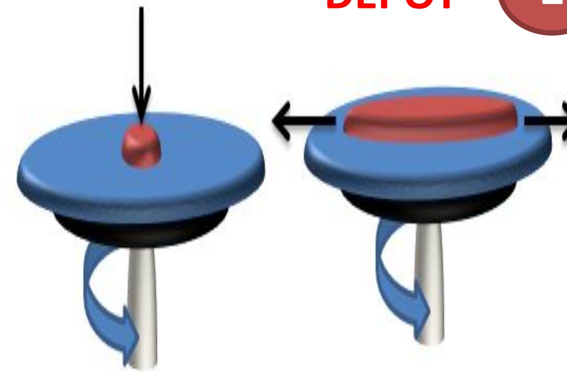


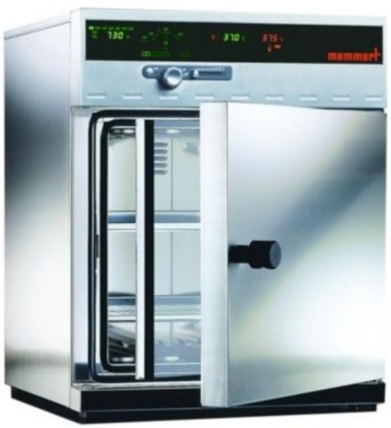
Fabrication de circuits en polymère



1 **SYNTHESE**

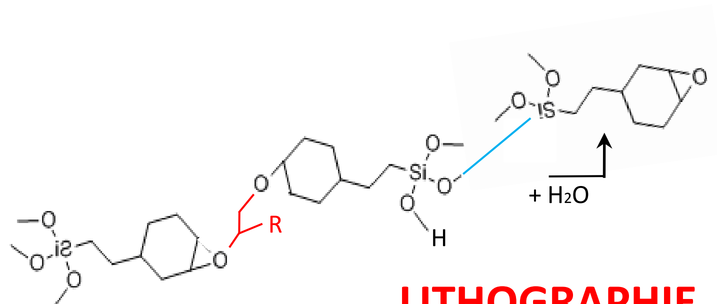
DEPOT 2





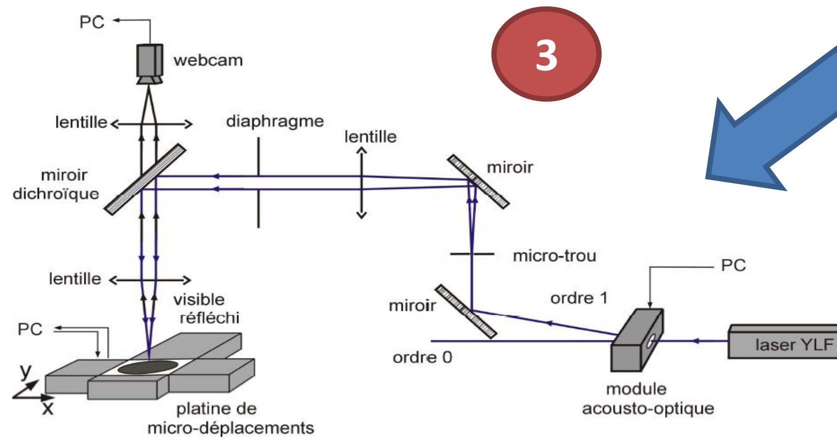
4

RECUIT
110°C

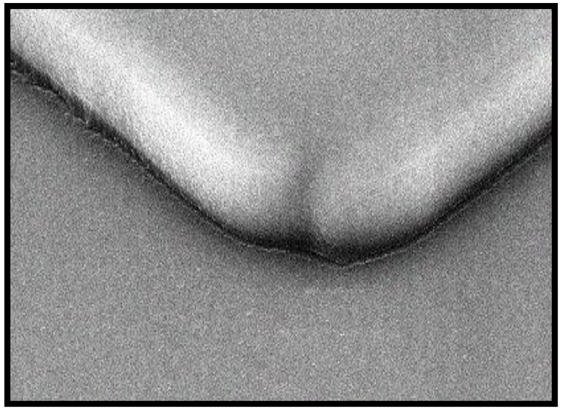


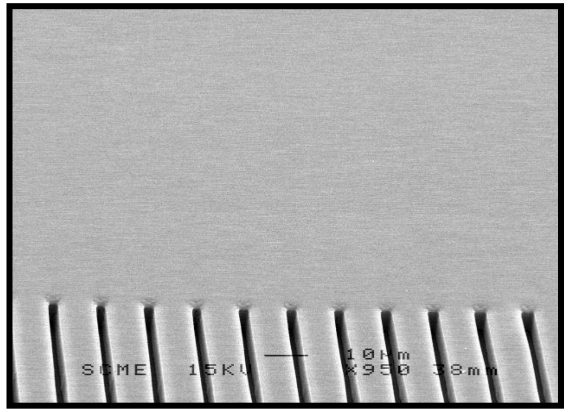
LITHOGRAPHIE

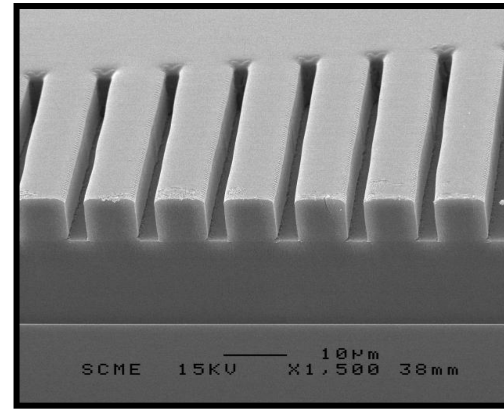
3

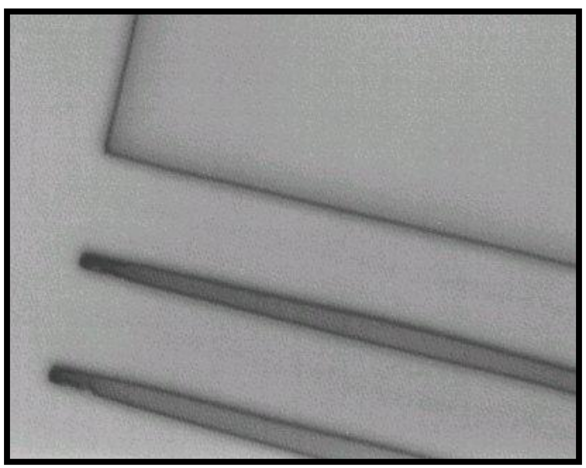


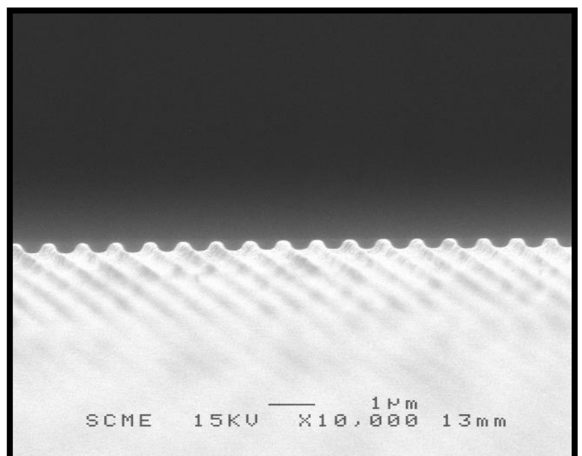
Résultats

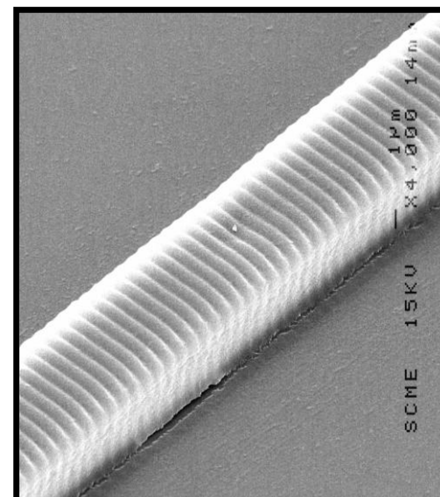



10µm
SCME 15KV X950 38mm

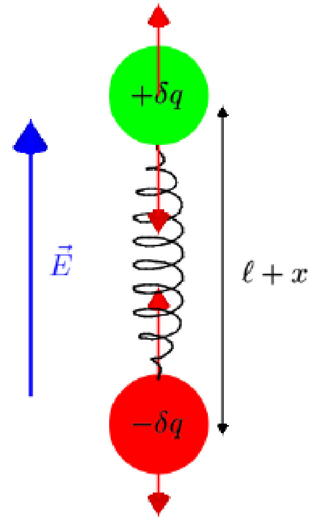

10µm
SCME 15KV X1,500 38mm

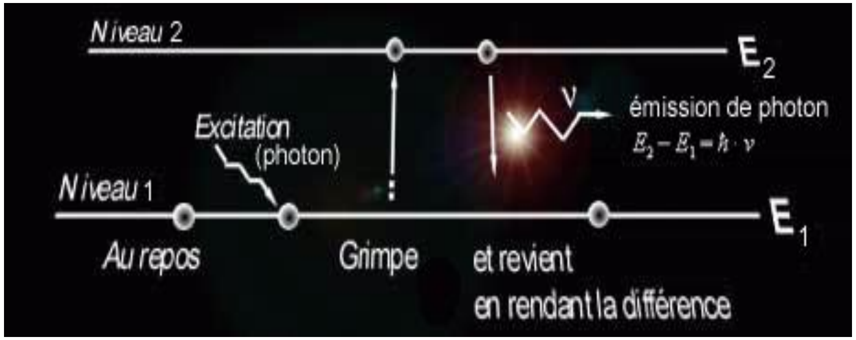


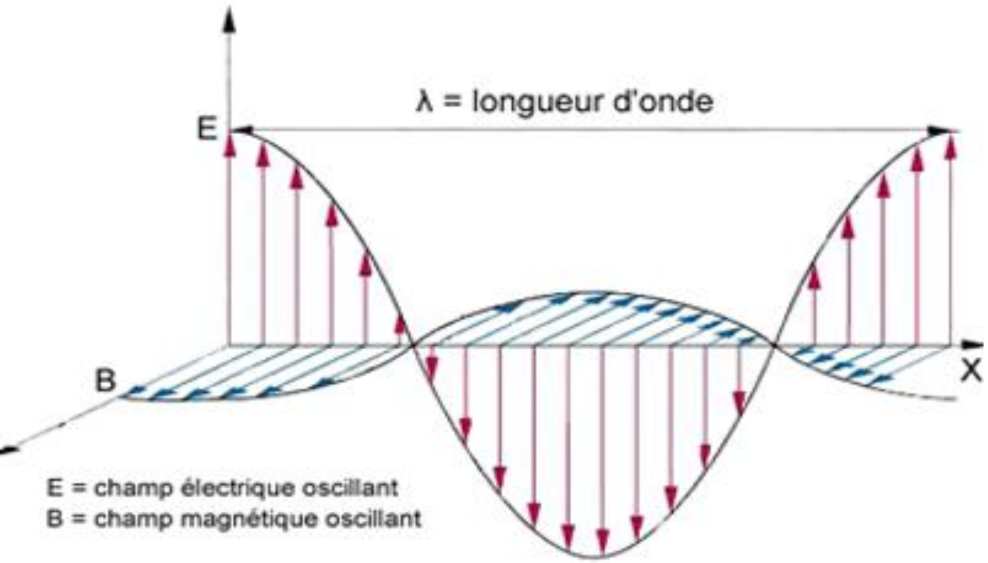

1µm
SCME 15KV X10,000 13mm

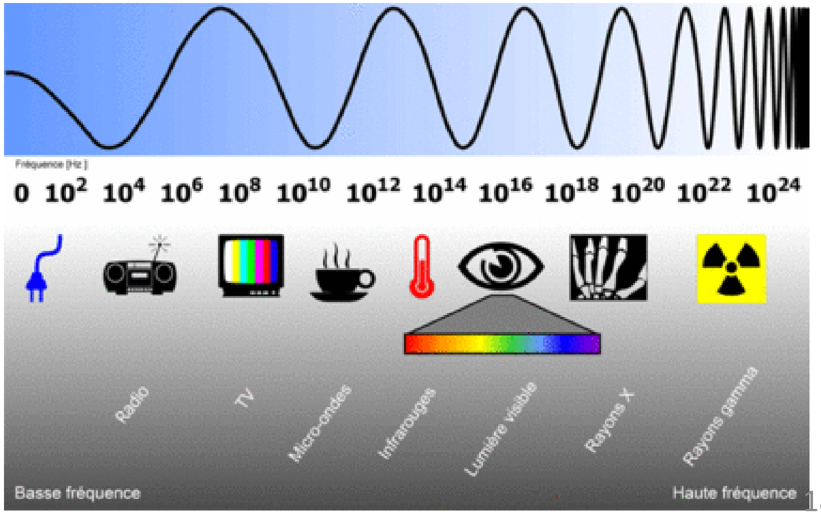

1µm
SCME 15KV X4,000

L'onde électromagnétique

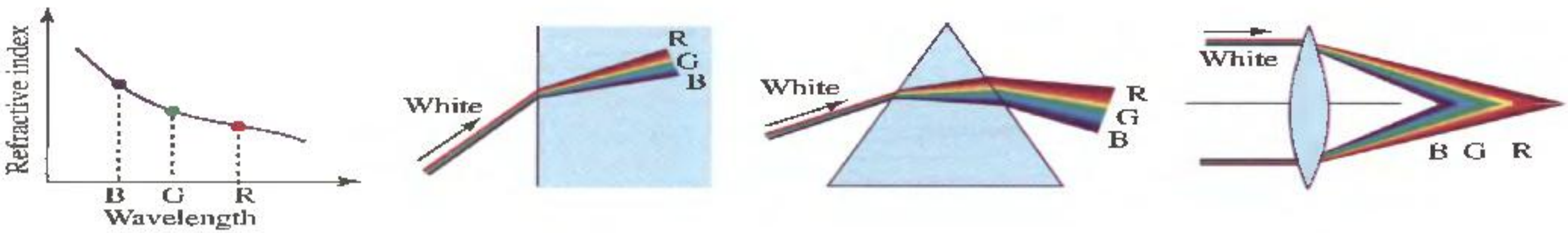






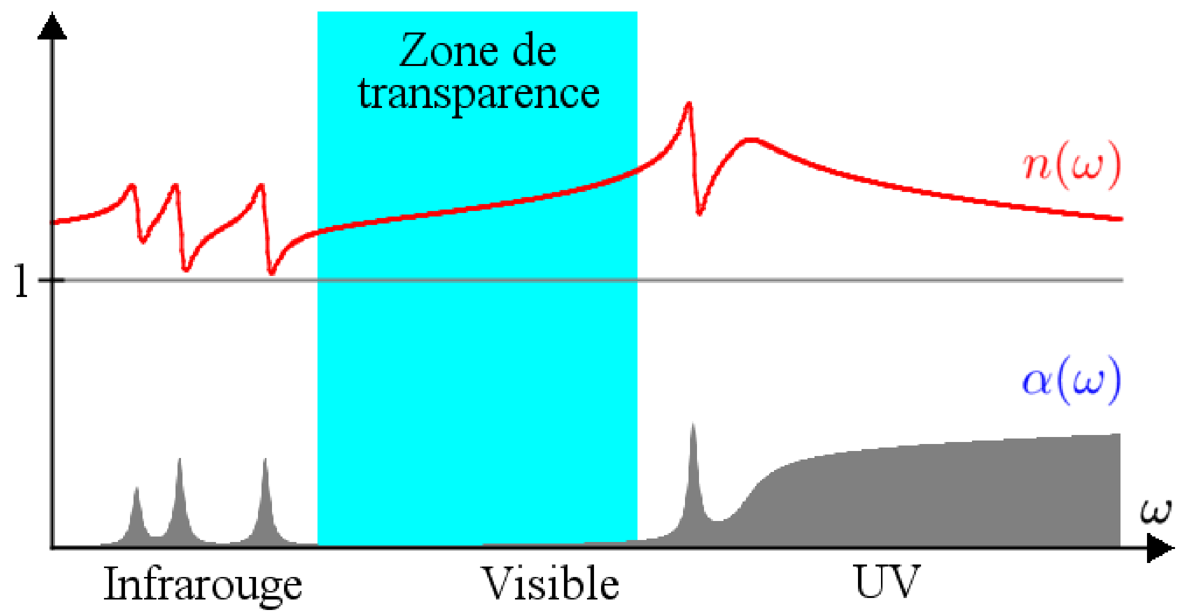


Indice de réfraction et transmission

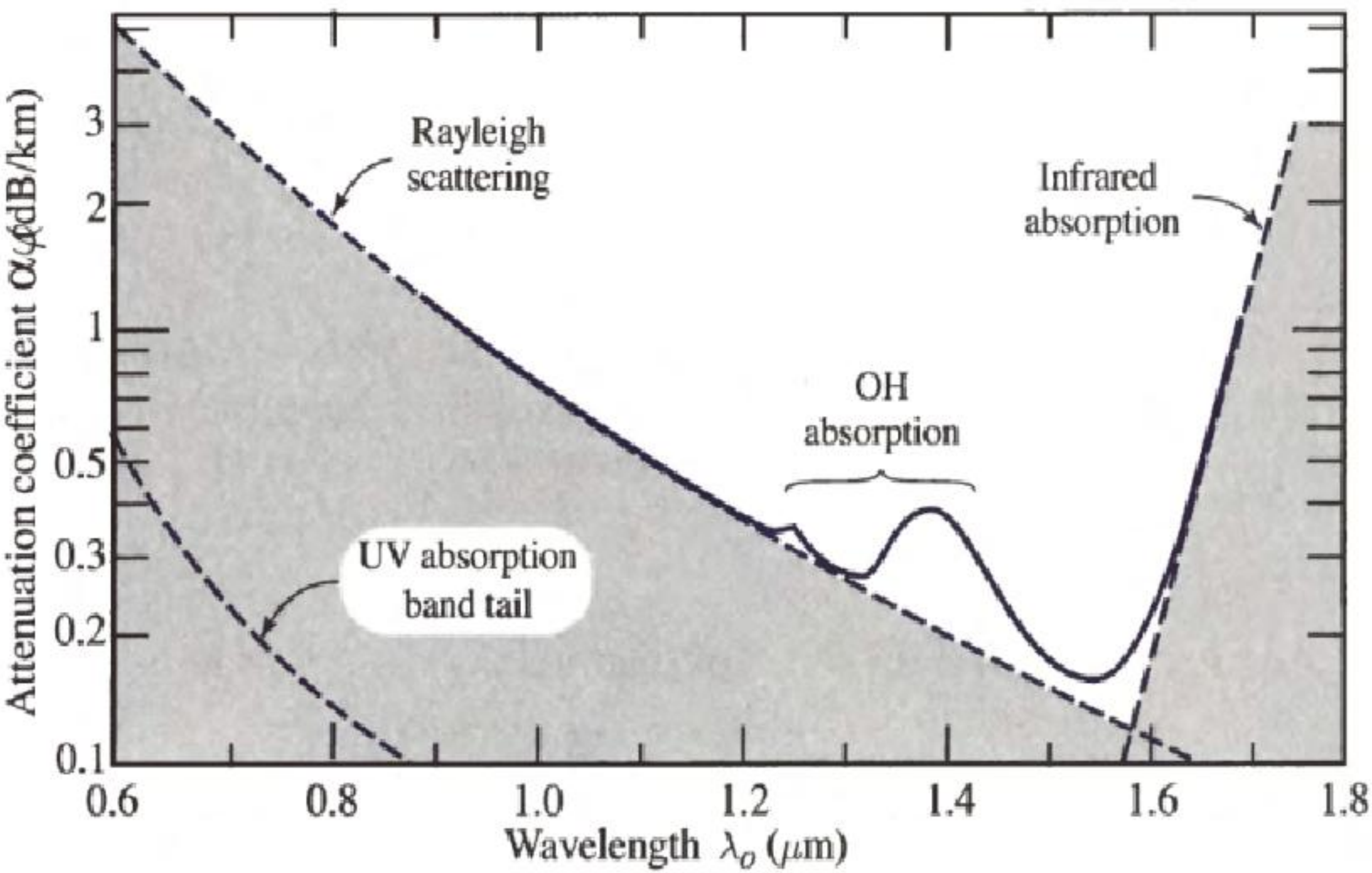


Vitesse de déplacement dans la matière: **v = c / n**

Indice du matériau: **n + j.k**



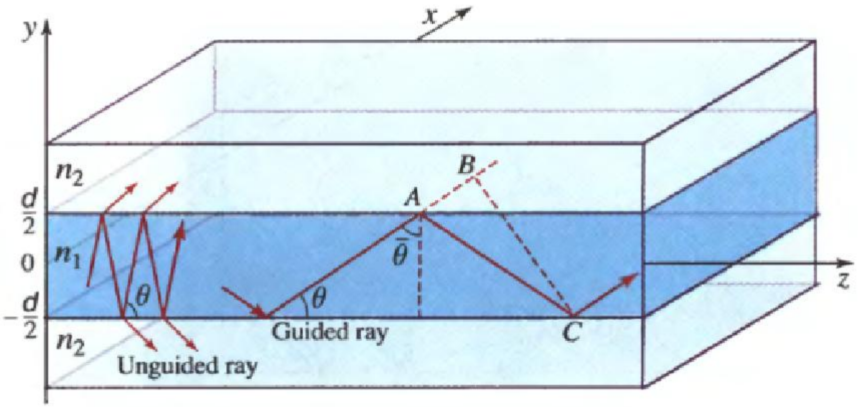
Atténuation dans le verre

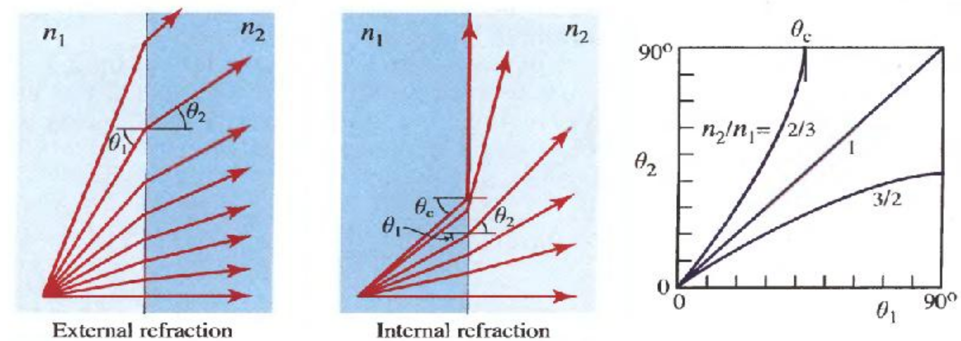


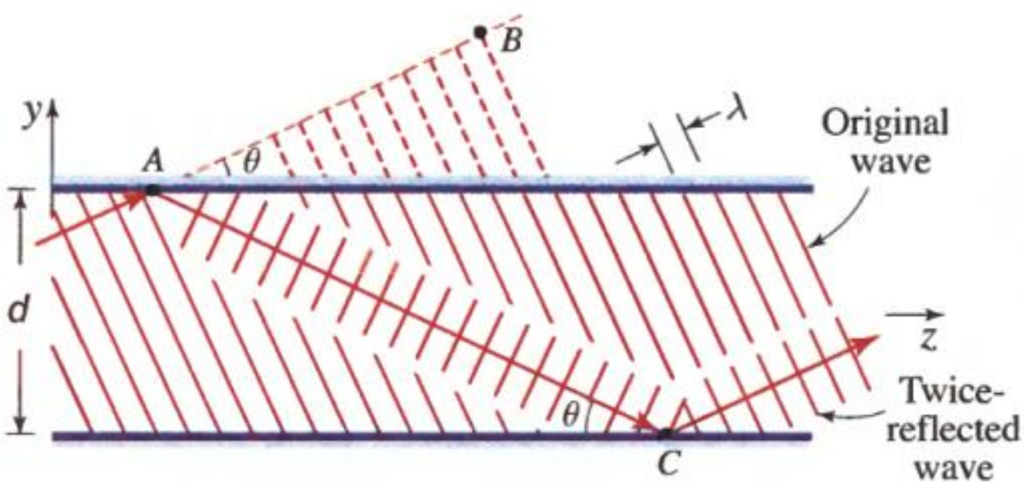
Confinement de la lumière

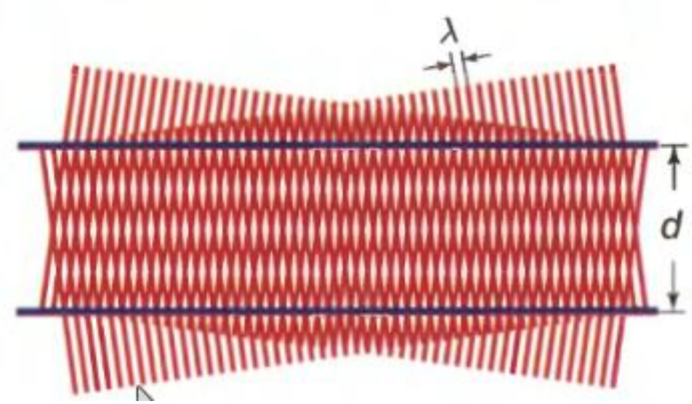
1/ Réflexion totale interne

$$n1.\sin(\theta_1)=n2.\sin(\theta_2)$$



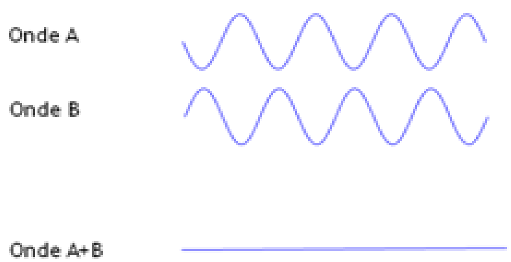


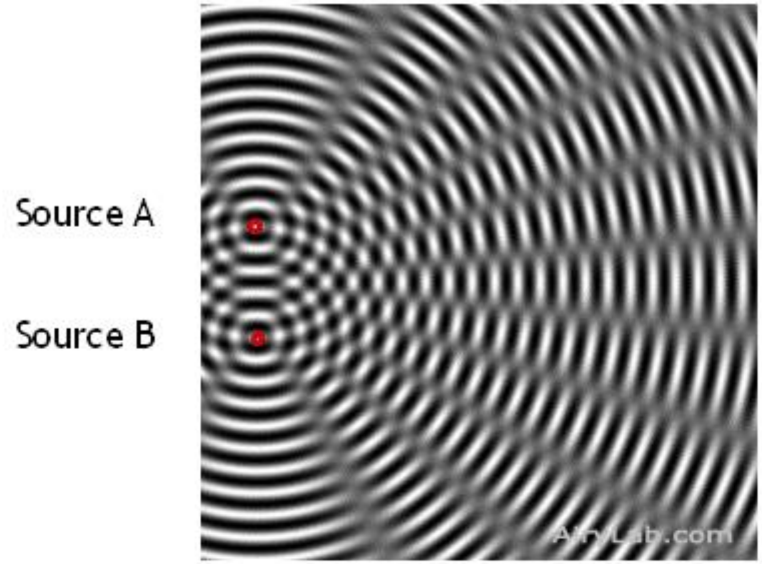




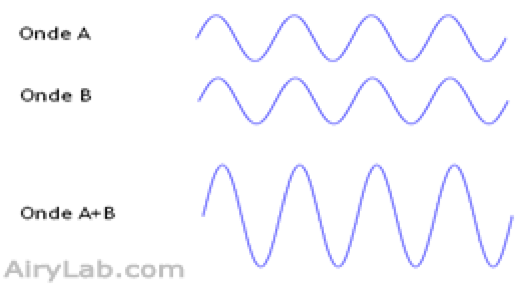
Interférences

Interférences destructives





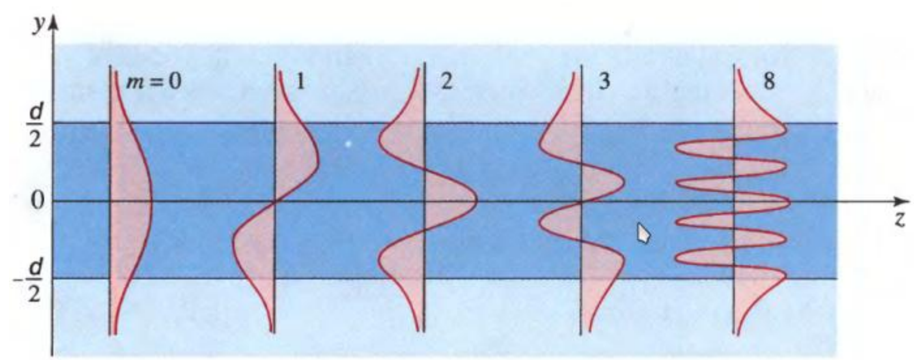
Interférences constructives



2/ Autocohérence

Modes guidés:

Chemins possibles de propagation



Propriétés des modes guidés

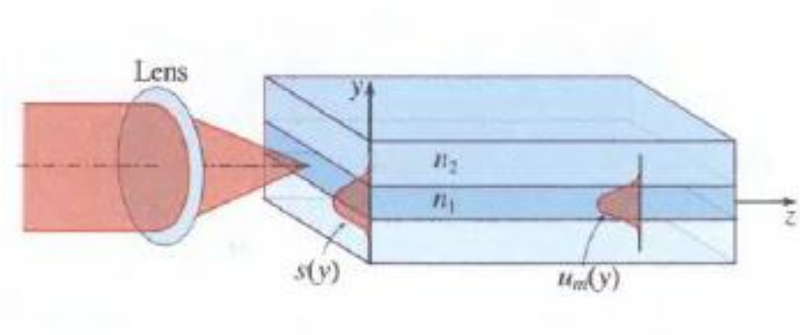
Le confinement et le nombre de modes augmente avec:

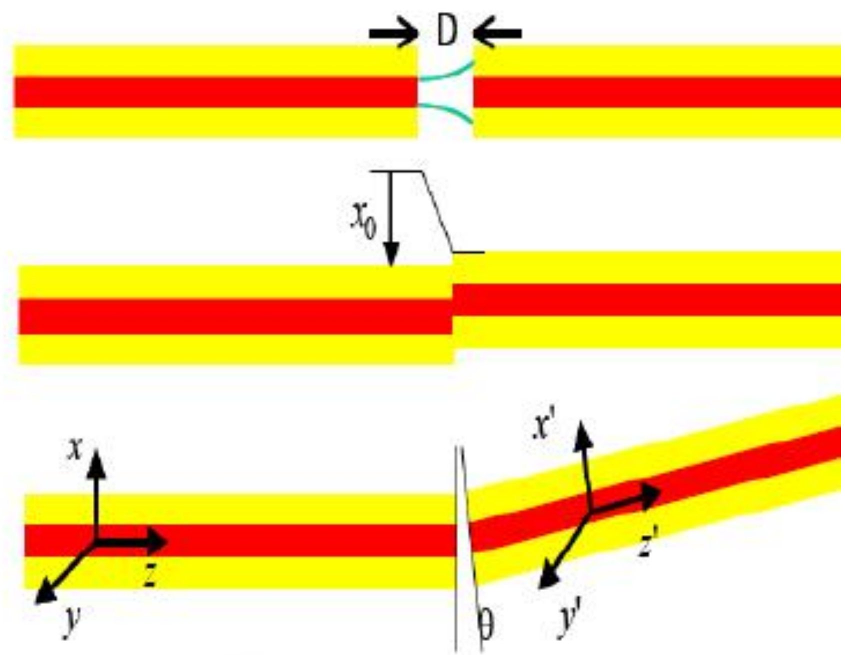
- Taille du guide.
- Fréquence de l'onde.
- Différence des indices.

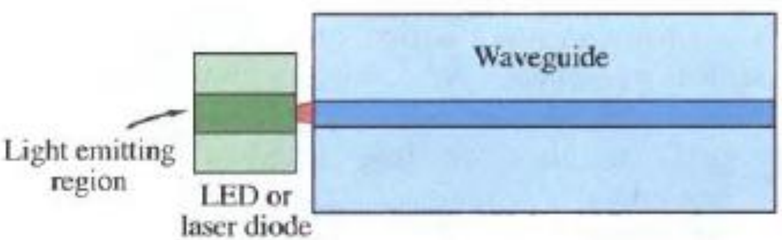
Chemin/mode 0 existe toujours, le plus rapide et le moins étalé dans la gaine.

La lumière se déplace indépendamment sur chaque mode/chemin
(pas d'échange d'énergie lumineuse entre les modes).

Couplage vers un mode





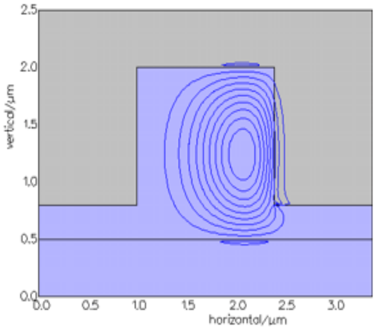


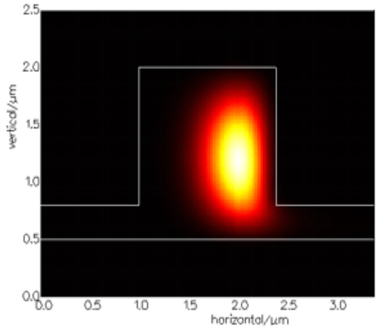
In the guide : $$E(y,z) = \sum_m a_m u_m(y) \exp(-j\beta_m z)$$

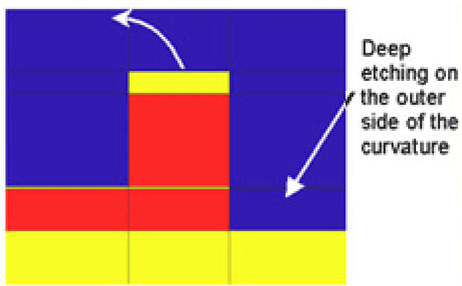
Source : $$s(y) = \sum a_m u_m(y)$$

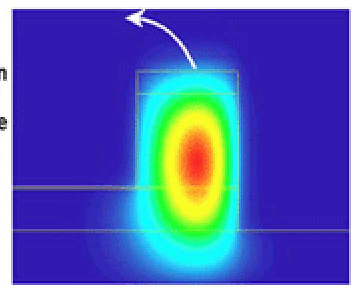
Excitation $$a_l = \int_{-\infty}^{\infty} s(y)\, u_l^*(y)\, dy$$

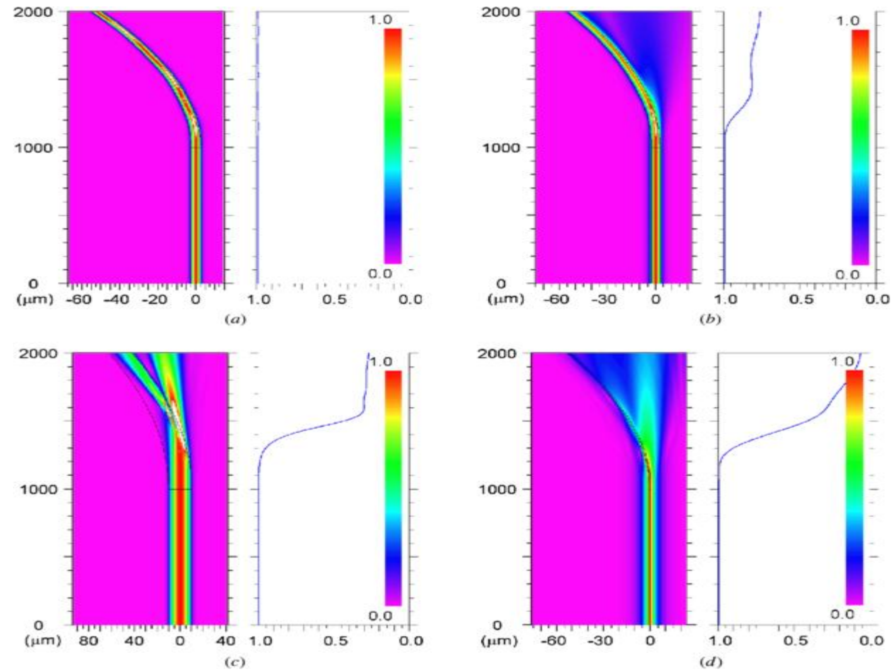
Guide courbes & pertes de courbure

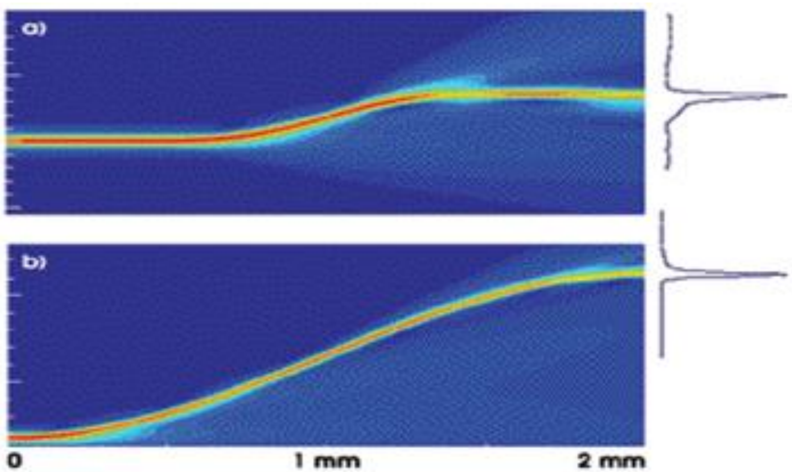


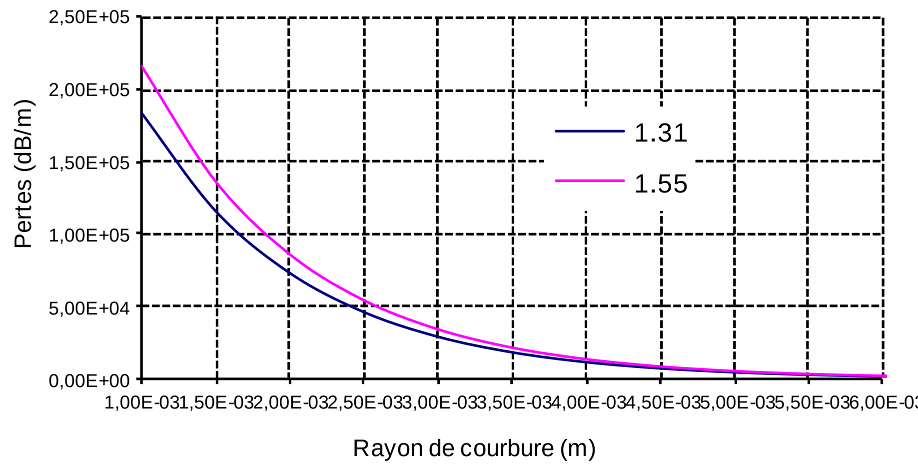




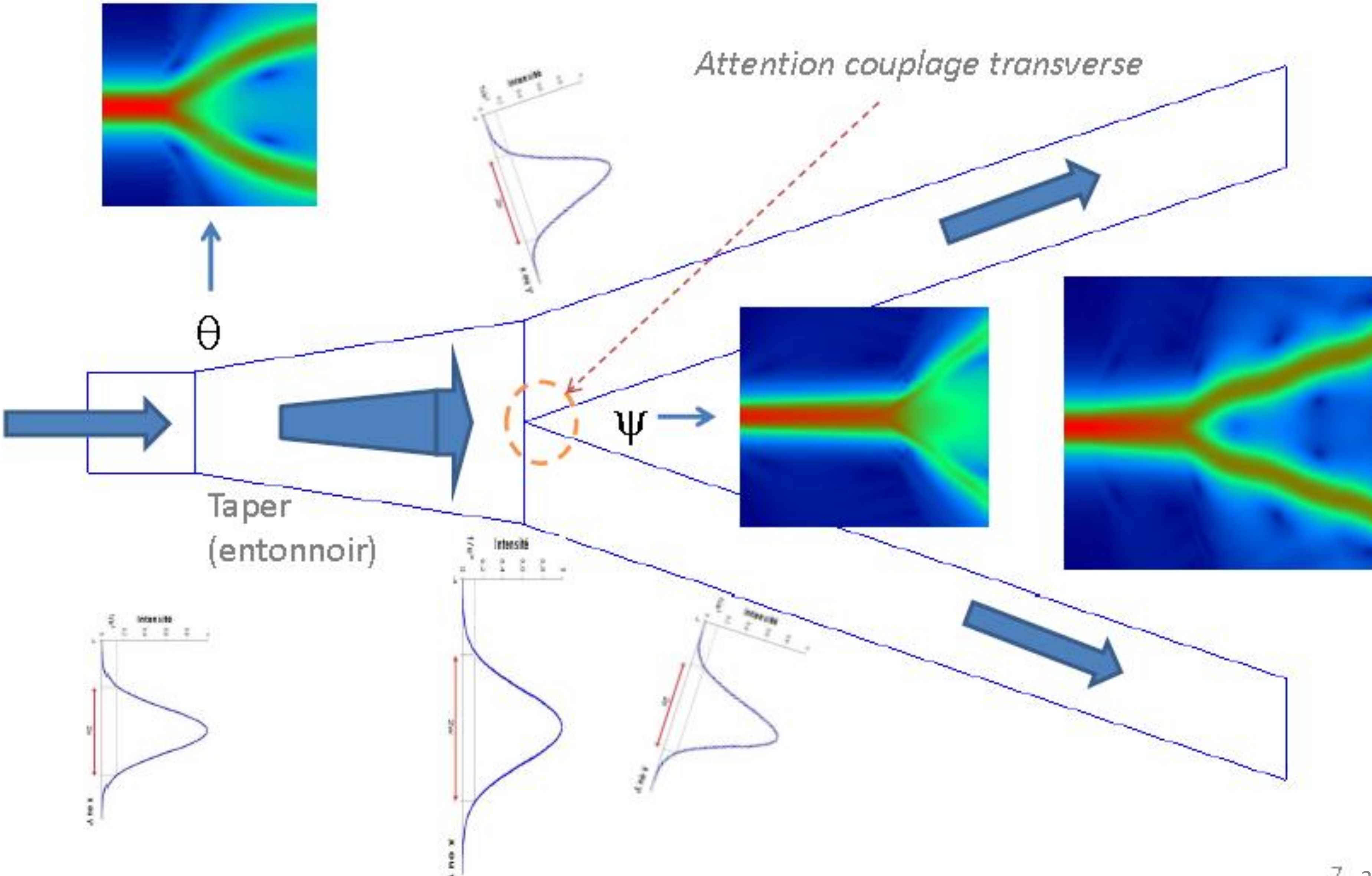




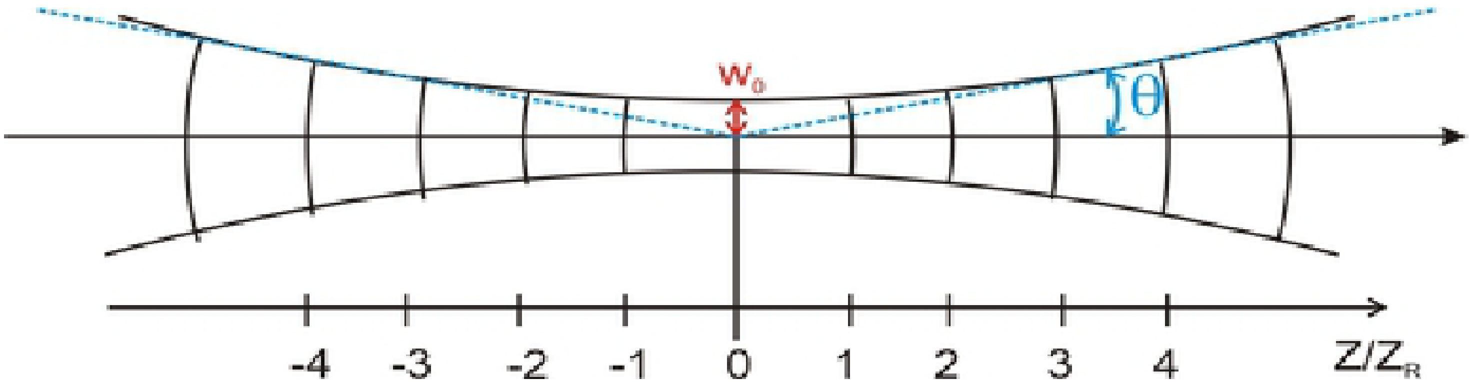




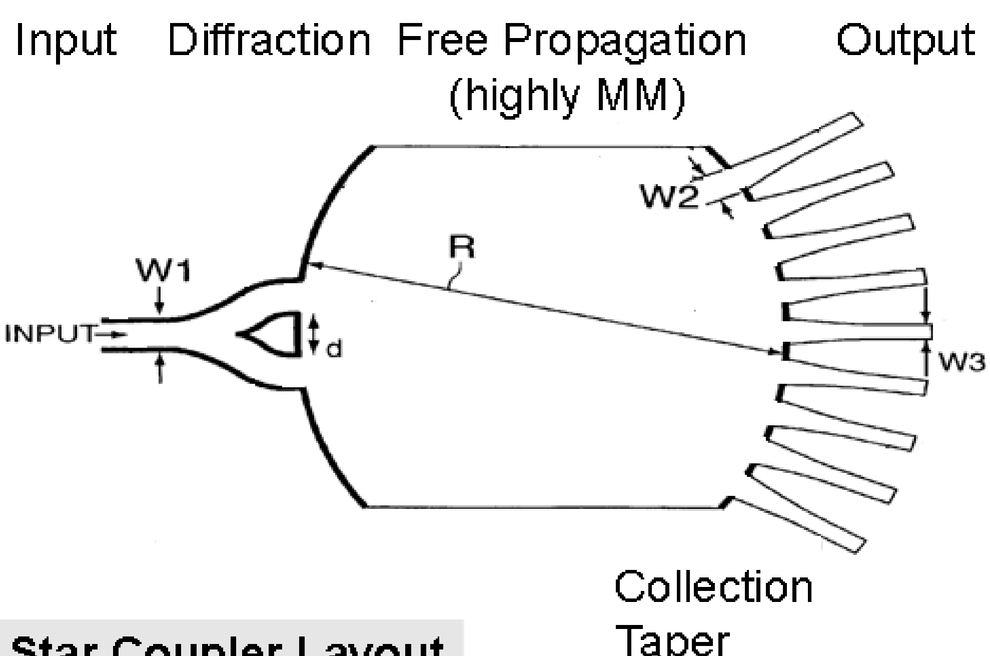
Jonction Y: division



Coupleur en étoile

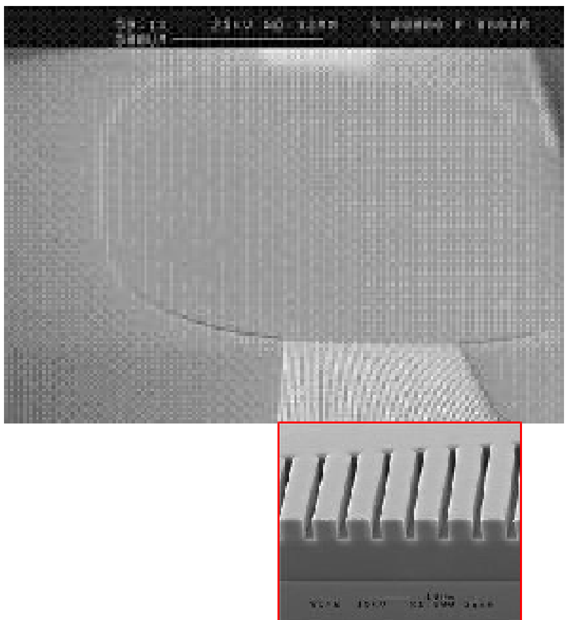


Free space gaussian beam propagation

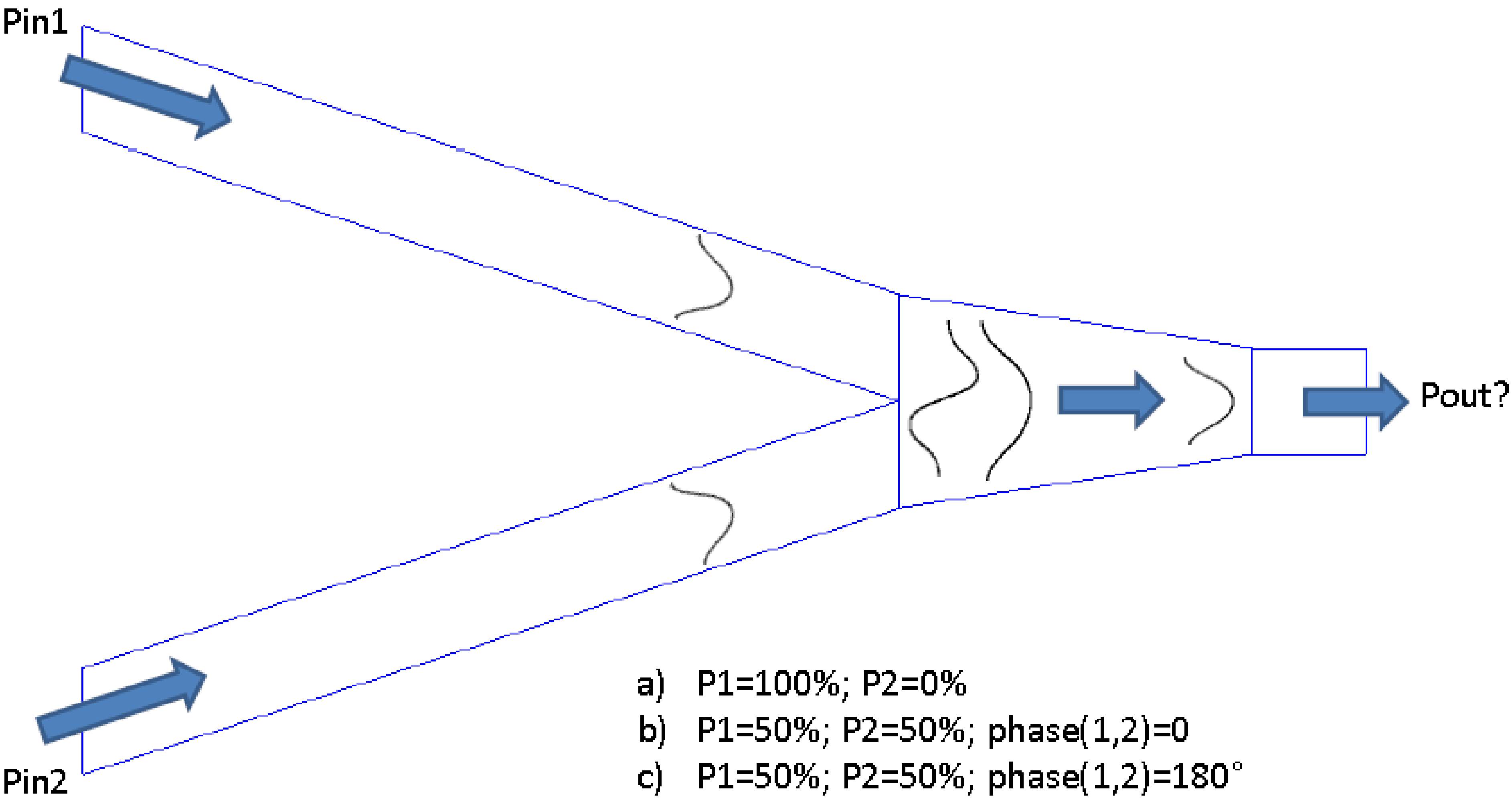


Star Coupler Layout

SEM image of polymer star coupler

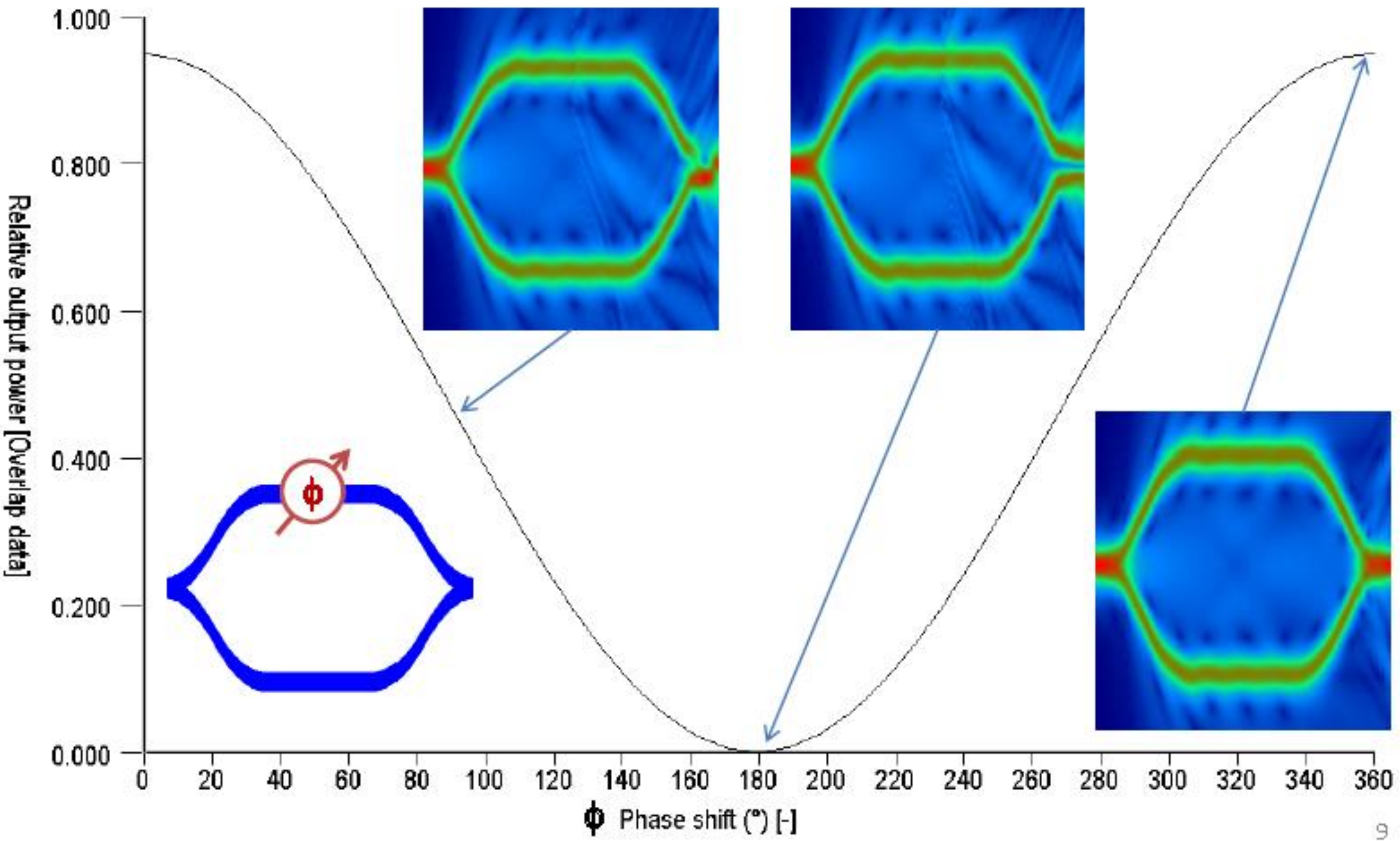


Jonction Y: combinaison

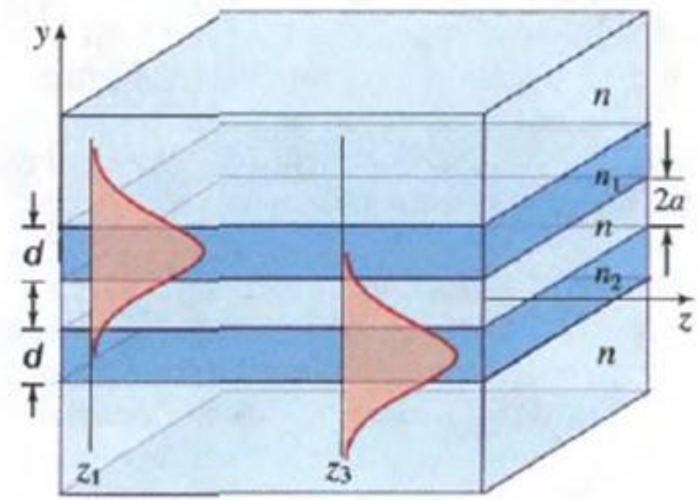


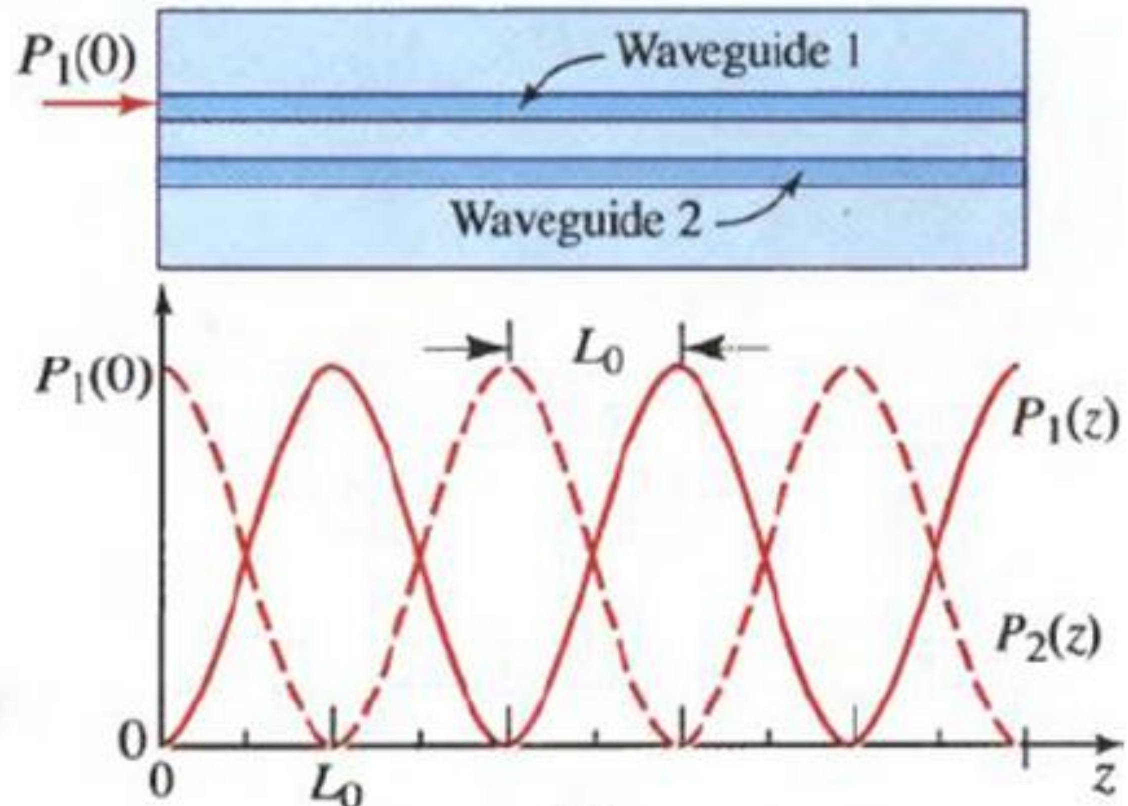
a) P1=100%; P2=0%
b) P1=50%; P2=50%; phase(1,2)=0
c) P1=50%; P2=50%; phase(1,2)=180°

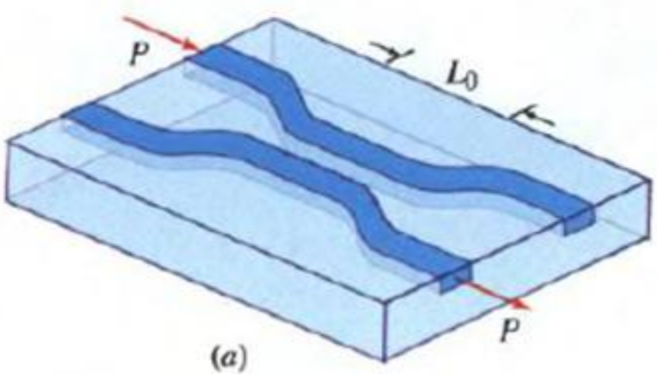
Interféromètre Mach-Zehnder

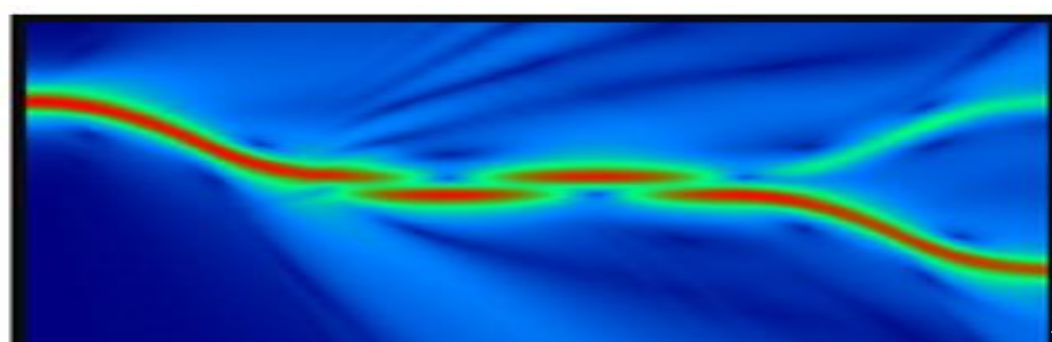


Couplage par champ évanescent

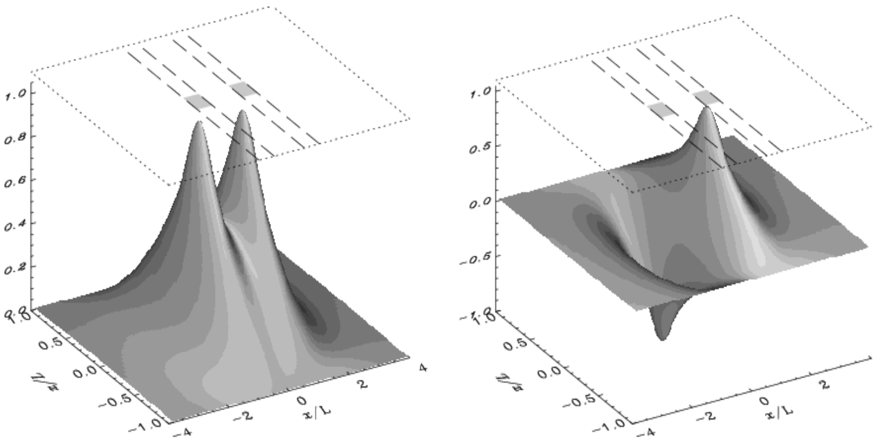




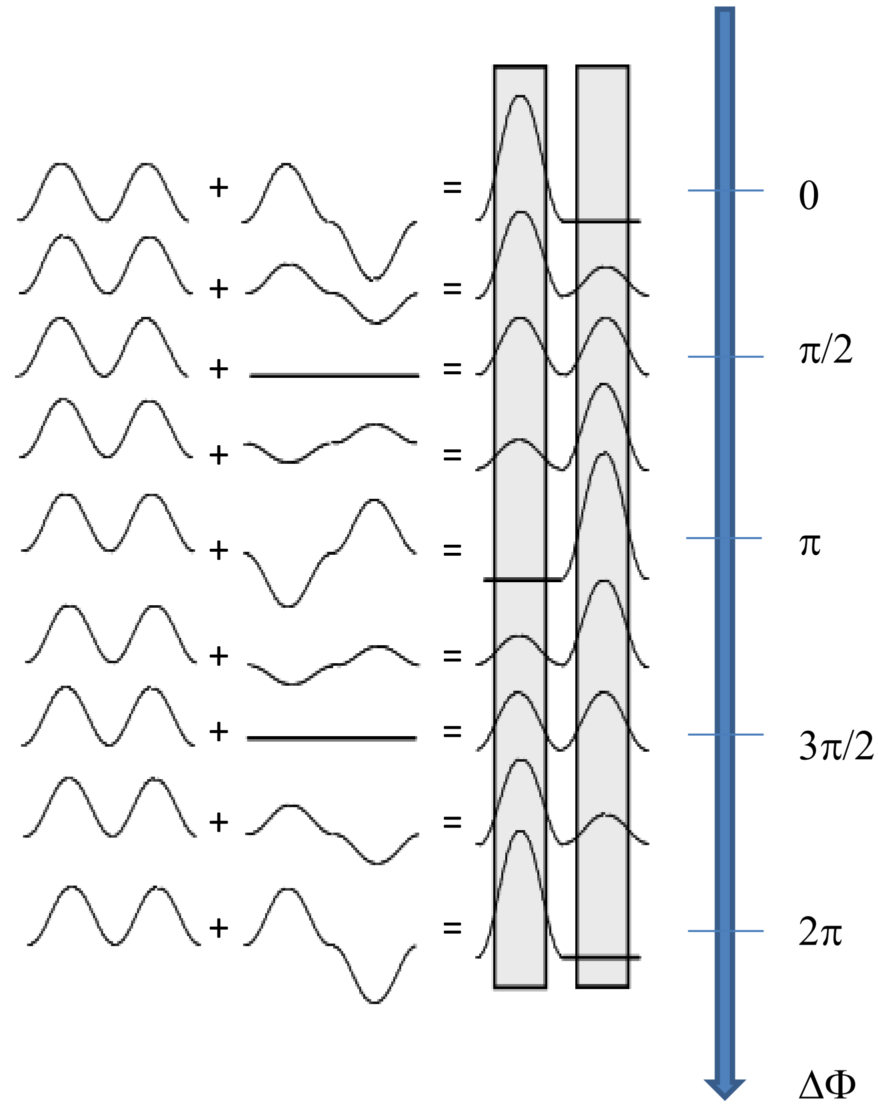




Interférences modales



(a) (b)



Les deux guides sont considérés comme un seul guide mais à double cœur.

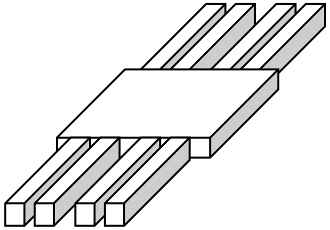
Ce guide est caractérisé par 2 modes: un symétrique et un antisymétrique.

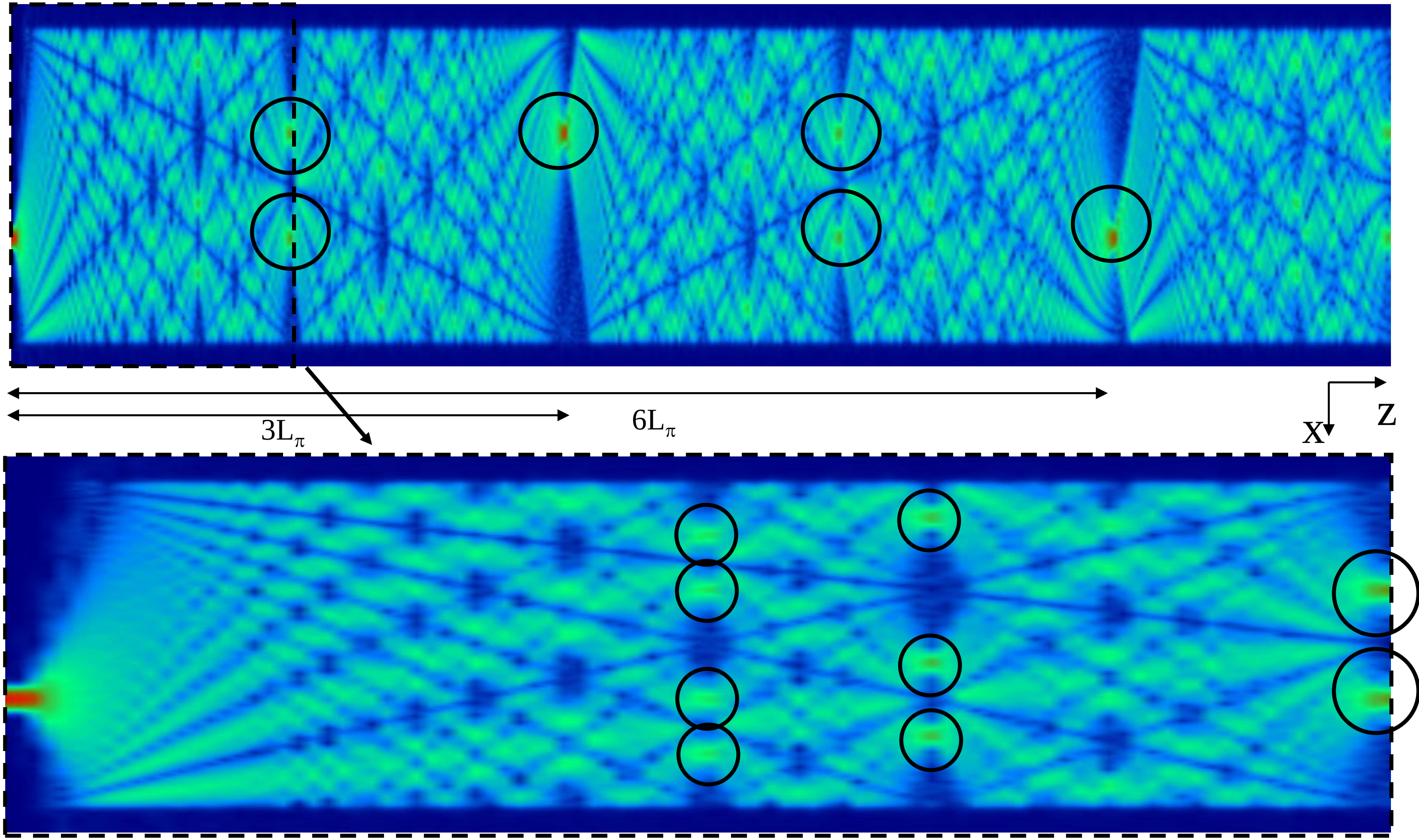
Le mode symétrique est toujours le mieux confiné.

La différence entre les indices effectifs des modes est l à la longueur d'échange d'énergie.

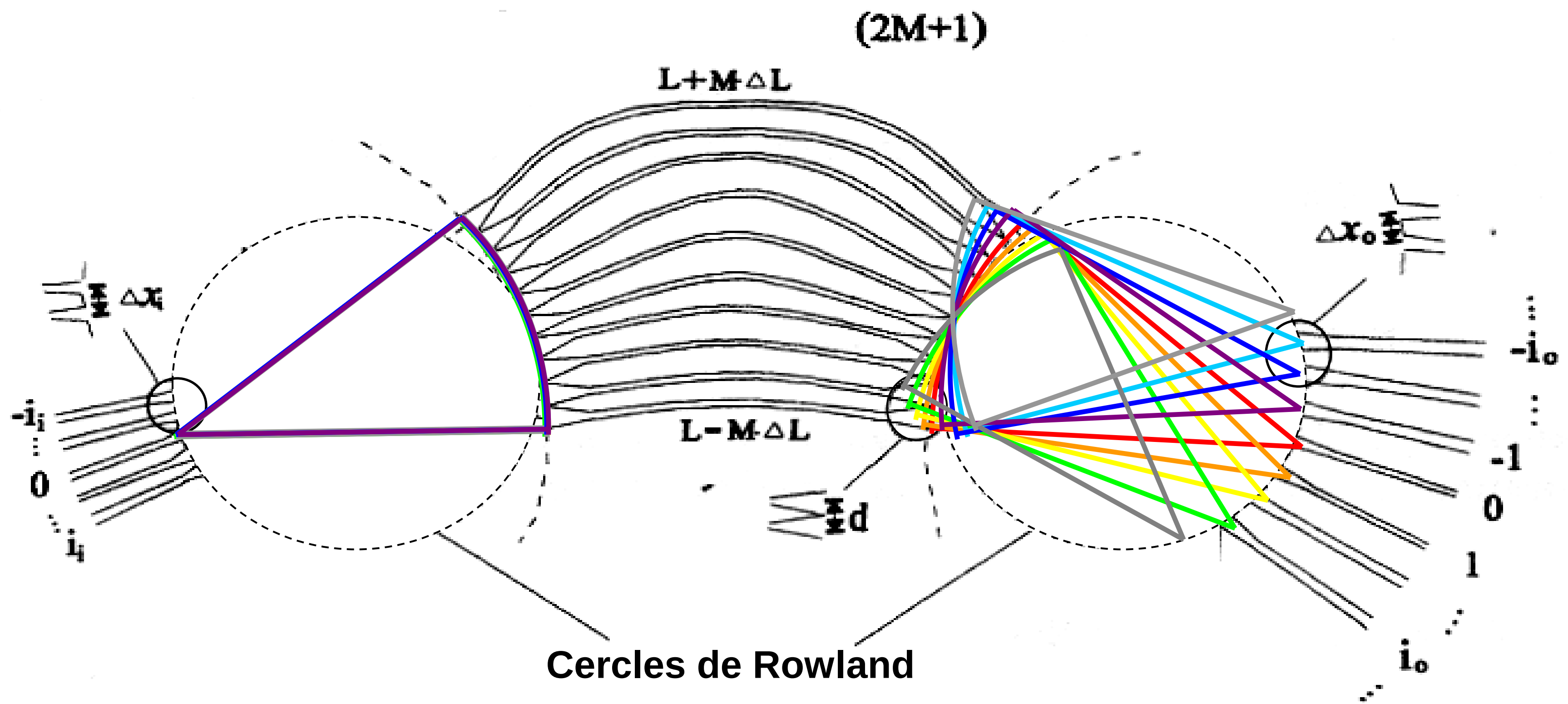
Cet échange d'énergie est périodique.

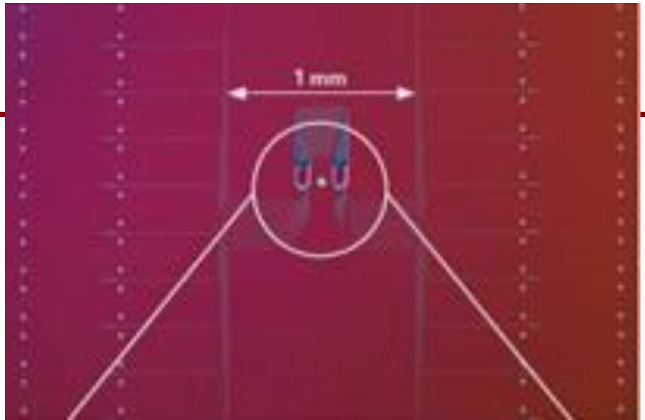
Interféromètre multimode:

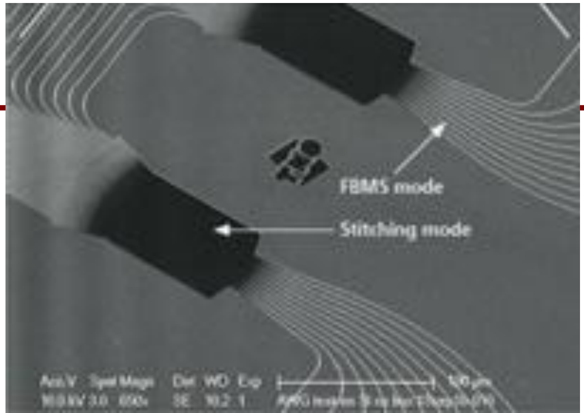




Séparateur/combineur de couleurs

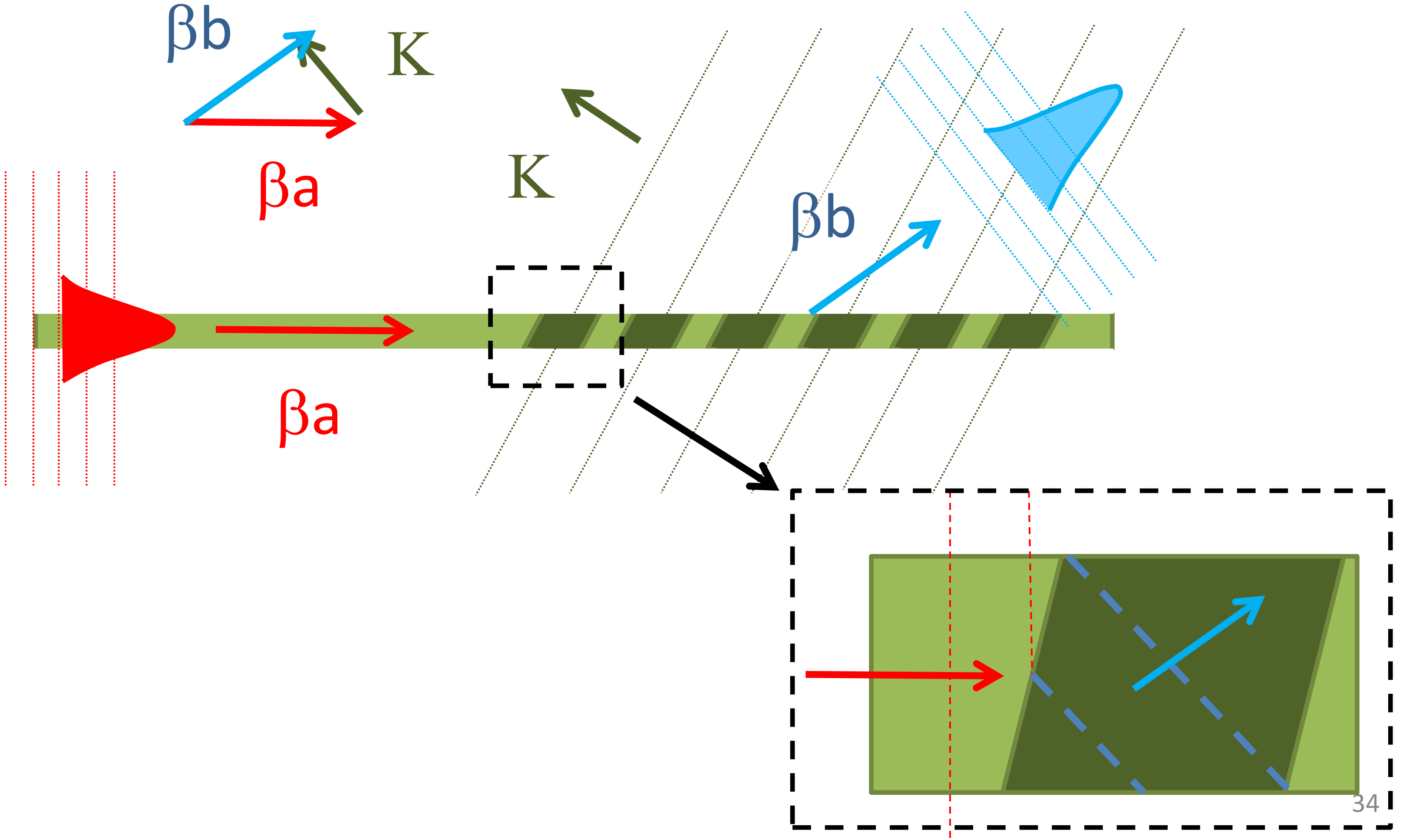




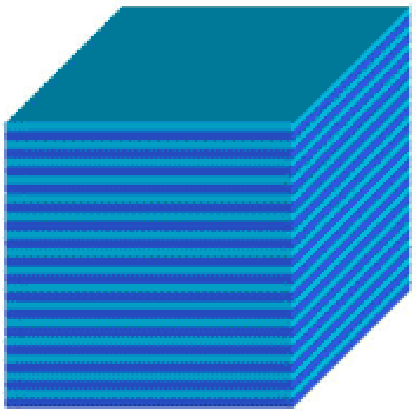


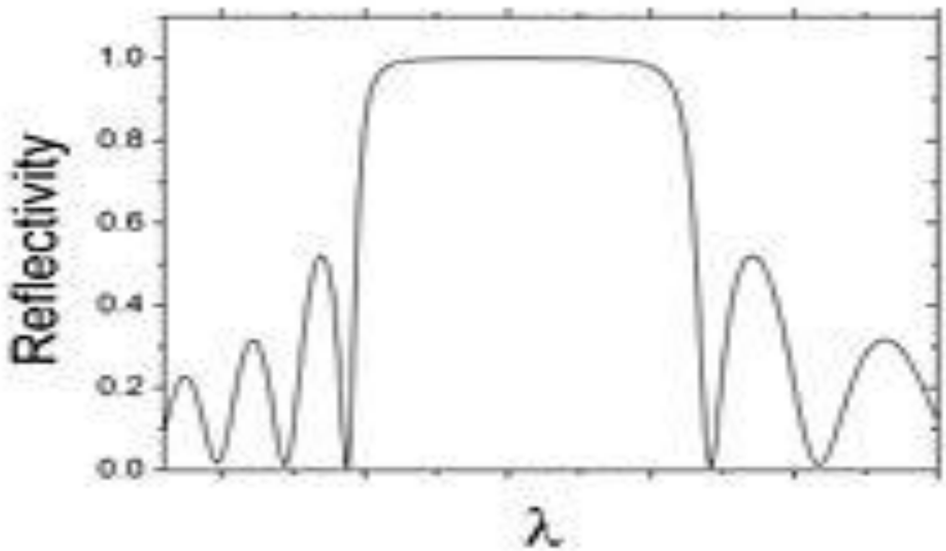
Réseau de diffraction

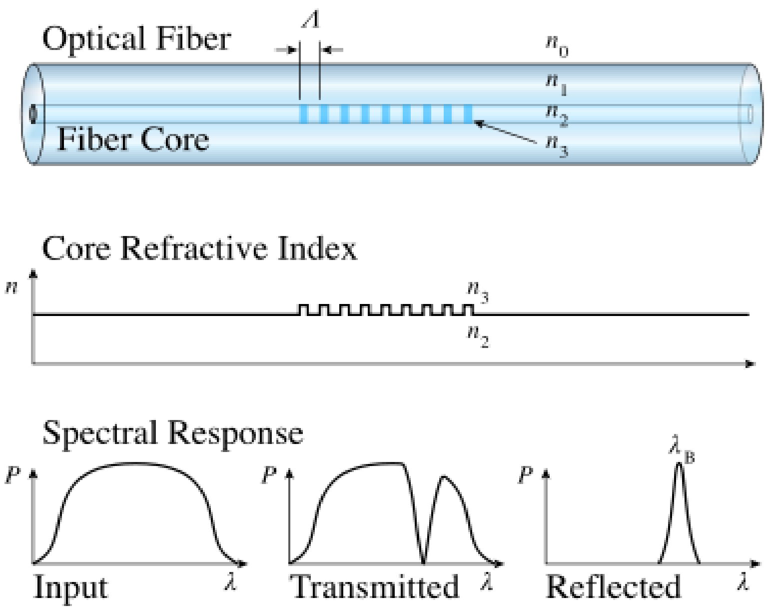
$$\overrightarrow{\beta}_b = \overrightarrow{\beta}_a + q.\overrightarrow{K}, q = 0, \pm 1, \pm 2, \ldots$$

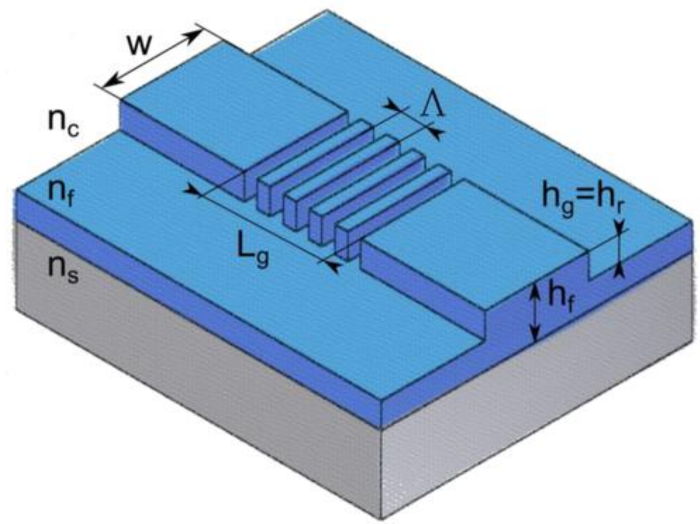


Réflecteur à réseau

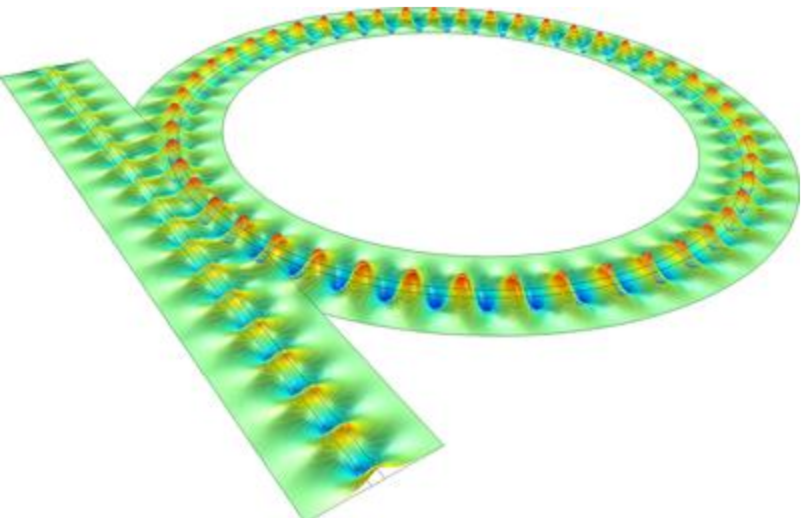


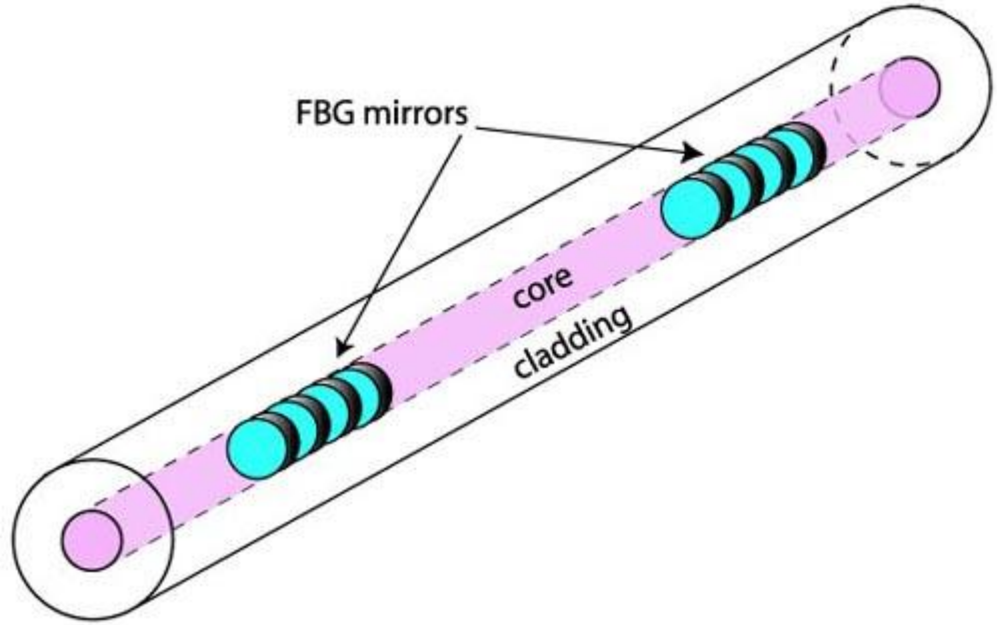


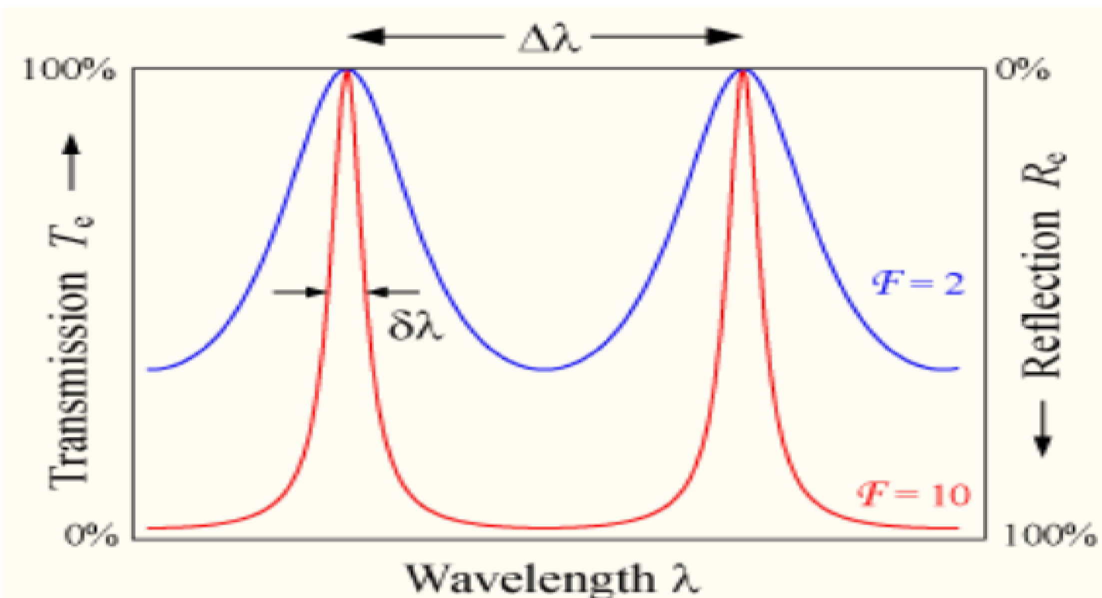




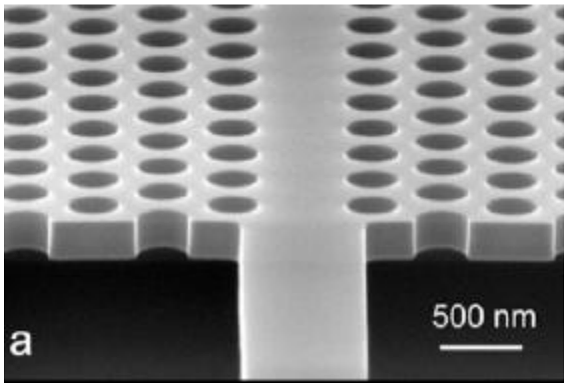
Résonateurs

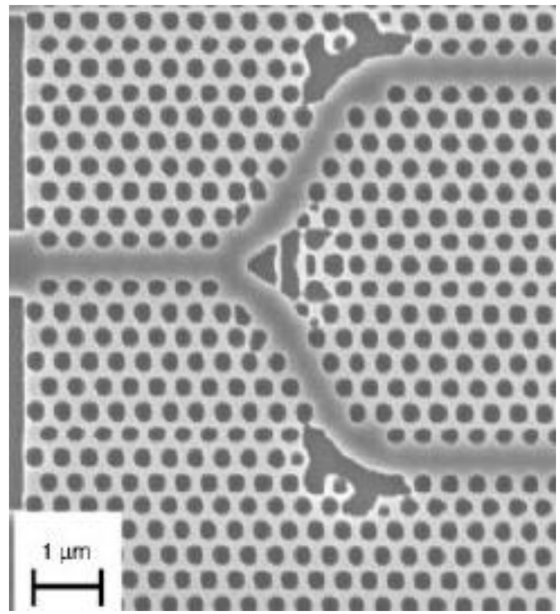


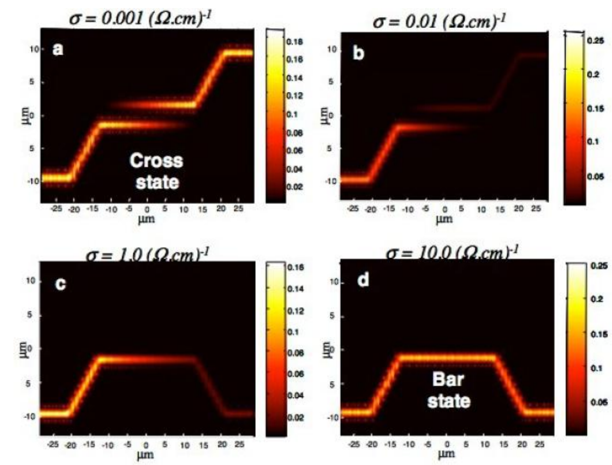


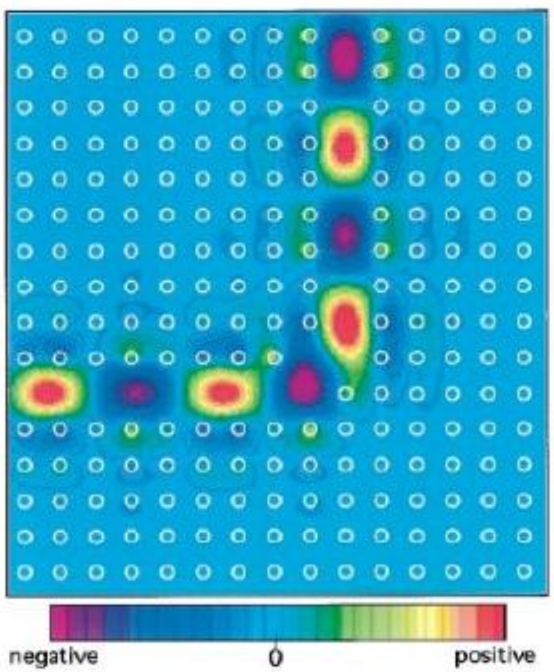


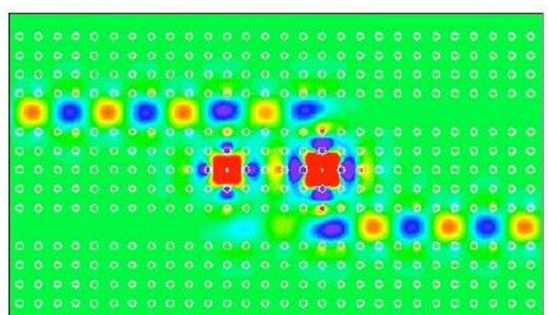
Cristaux photoniques

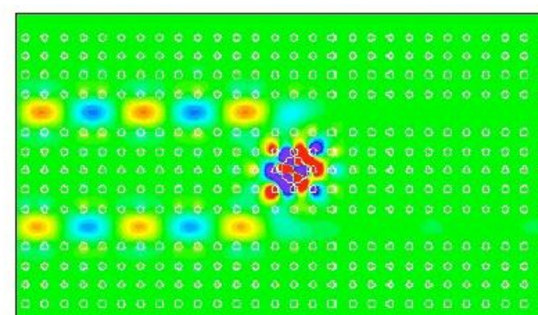






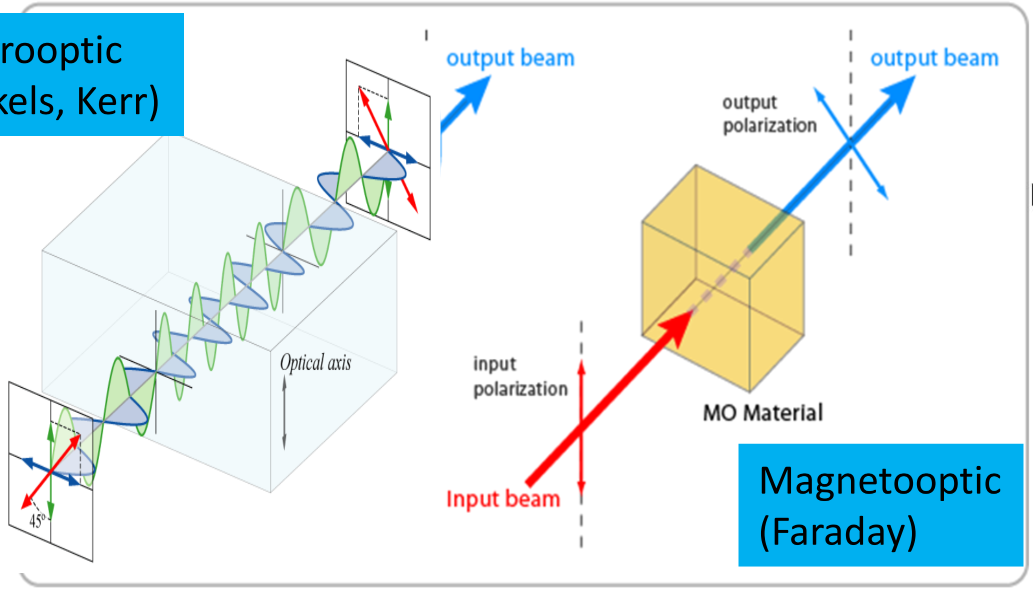






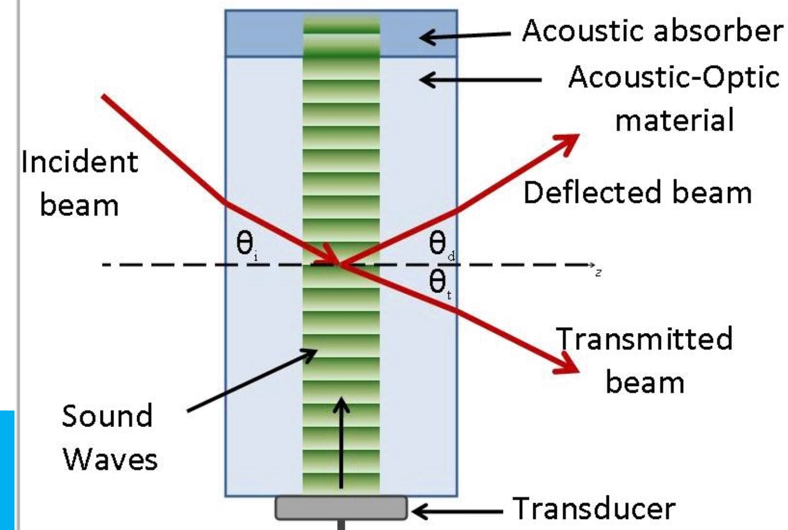
Active circuits …

Electrooptic
(Pockels, Kerr)

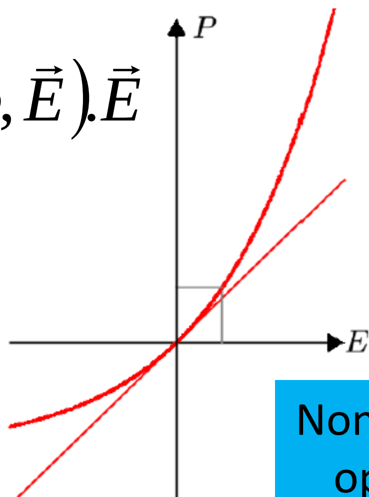


Magnetooptic
(Faraday)

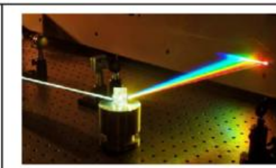
Elastooptic
Acoustooptic



$$\vec{P} = \varepsilon_0 \chi\left(\omega, \vec{E}\right) \vec{E}$$



Nonlinear
optics

$\chi^{(1)}$	Optique linéaire	Dispersion Absorption	
$\chi^{(2)}$	Optique non-linéaire quadratique	Doublage de fréquence	
$\chi^{(3)}$	Optique non-linéaire du troisième ordre	Effet Kerr optique