

Guide d'onda

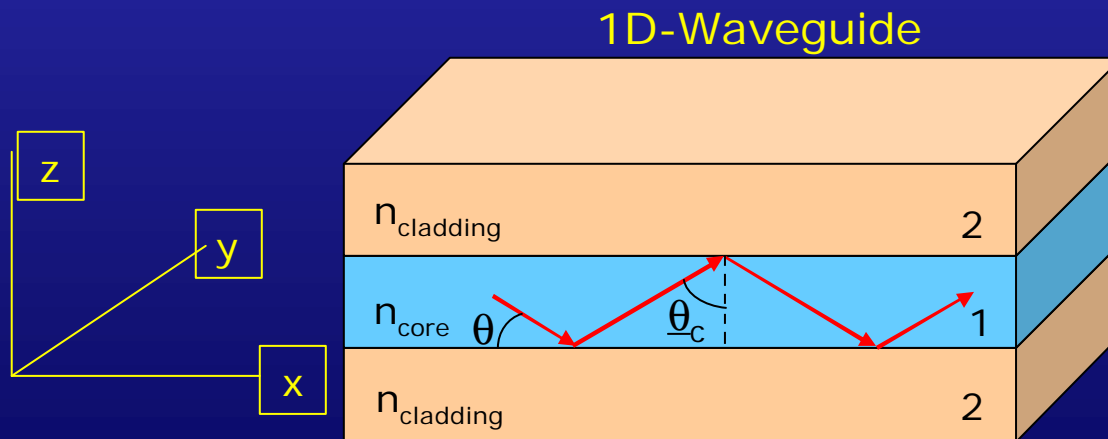
What is a dielectric waveguide?

- A waveguide acts as a “light trap”
- Total internal reflection conditions:

$n_{\text{core}} > n_{\text{cladding}}$, core: active dielectric mat., cladding: surrounding mat.

$\theta < \theta_c = \cos^{-1}(n_{\text{clad.}}/n_{\text{core}})$; $\{\theta > \theta_c \text{ power loss @ interfaces} \Rightarrow \text{extinction}\}$

- Optical wg provide the connections in integrated optics



Several geometries:

Slab - 1D wg

Rib - 2D wg

Cylinder - fiber

Waveguide analysis

Studying the propagation of an e.m. plane wave:

- Maxwell's equations;
- Self-consistency conditions;
- Boundary conditions:

$$E_t^{(1)} = E_t^{(2)}$$

$$H_t^{(1)} = H_t^{(2)}$$

$$E_\infty = 0$$

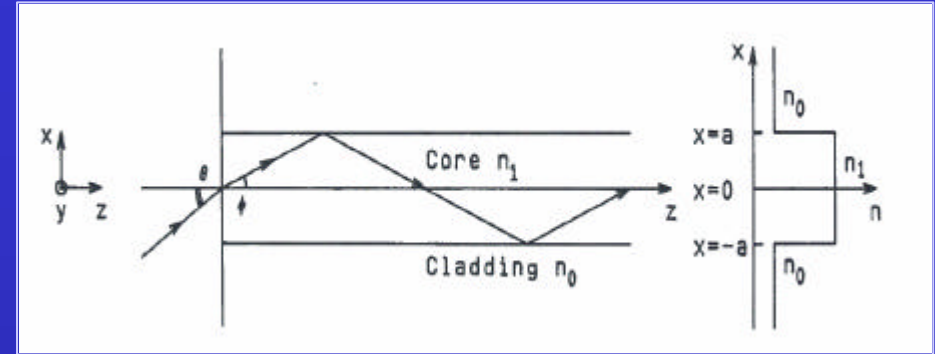
$$H_\infty = 0$$

Solving the problem \Rightarrow bounce angles:

- propagation constant;
- field distribution;
- group velocities.

What we would like to know?

- Waveguide modes
- Their refractive index



Definition: Mode is the optical field that maintain the same transverse distribution and polarisation along the waveguide axis (satisfies the phase-matching condition).

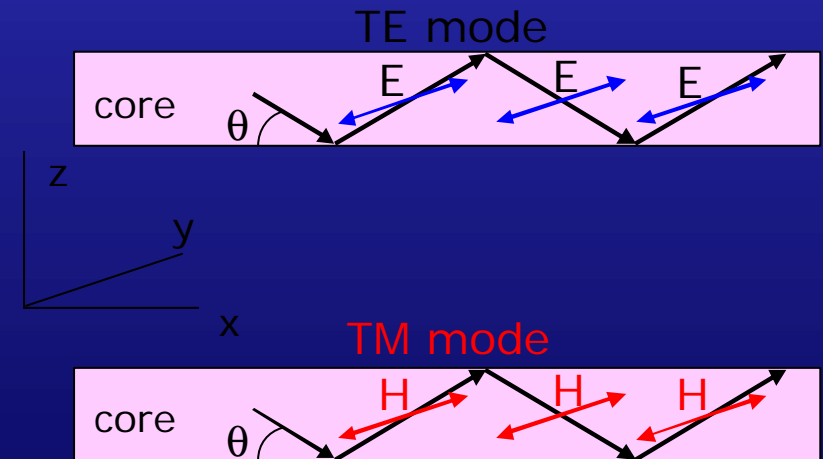
TE modes: E lies along y-axis

TM modes: H lies along y-axis

1D case: $M \approx 2(d/\lambda_0)NA$

2D case: $M \approx (\pi/4)(2d/\lambda_0)^2 NA^2$

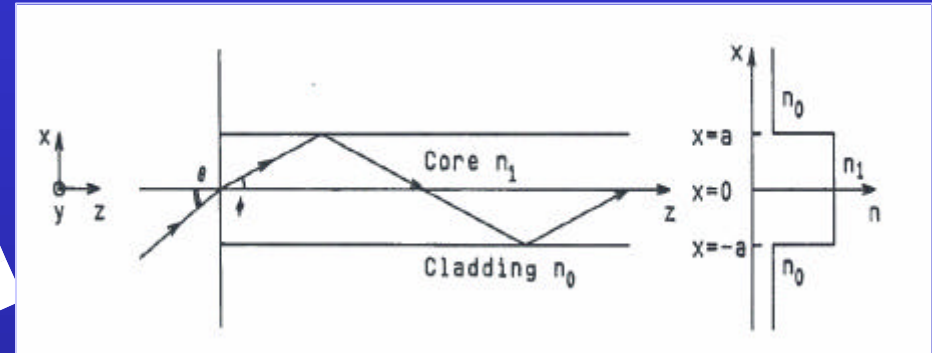
d = layer thickness, $NA = (n_{\text{core}}^2 - n_{\text{clad.}}^2)^{1/2}$



Riflessione totale:

$$n_{\text{core}} > n_{\text{cladding}}$$

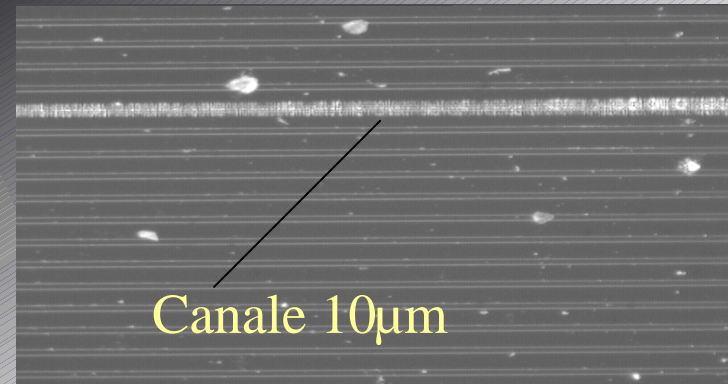
$$\theta < \theta_c = \cos^{-1} \left(\frac{n_{\text{cladding}}}{n_{\text{core}}} \right)$$



Parametri chiave:

- Indici di rifrazione (materiali)
- Dimensioni del core (tecnologie)
- Geometria (design)

Immagine microscopio



Canale $10\mu\text{m}$

Produzione tecnologia CMOS Compatibile

Processo

- Deposizione LPCVD

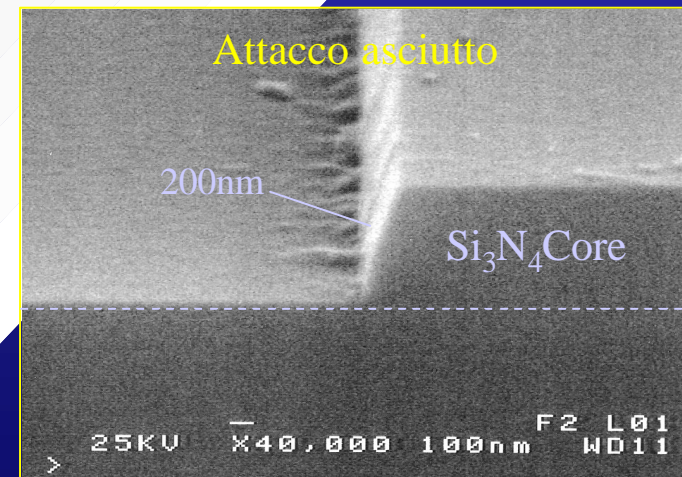
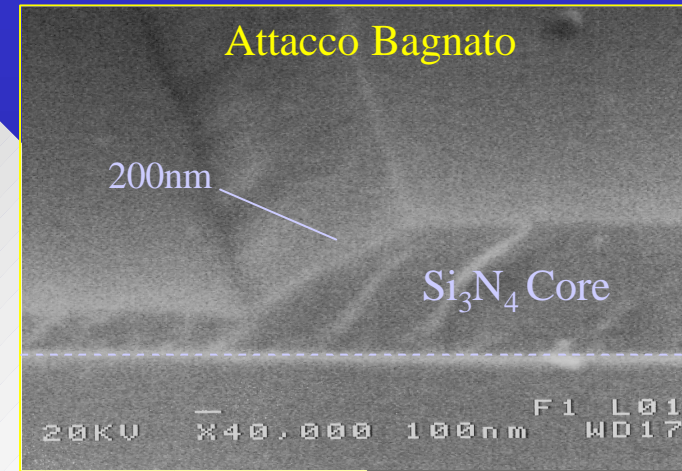
- SiO_2 $n= 1.46$ Cladding
- Si_3N_4 $n= 2.0$ Core (vis)
- Si $n= 3.5$ Core (IR)

- Trattamento termico

- Annealing Si 18h. 600°C Poly-Si

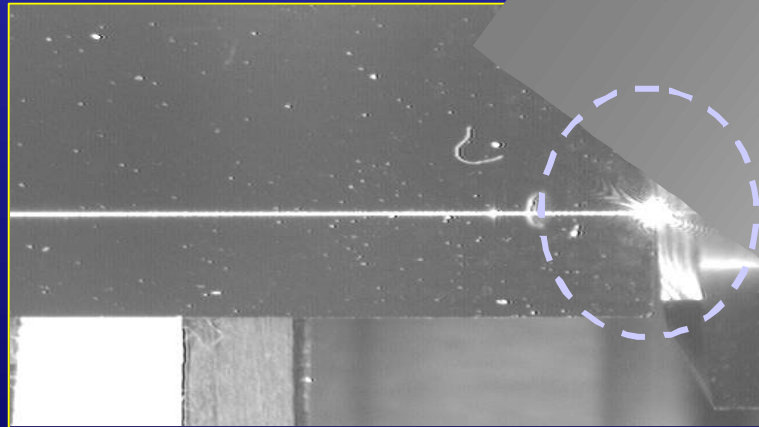
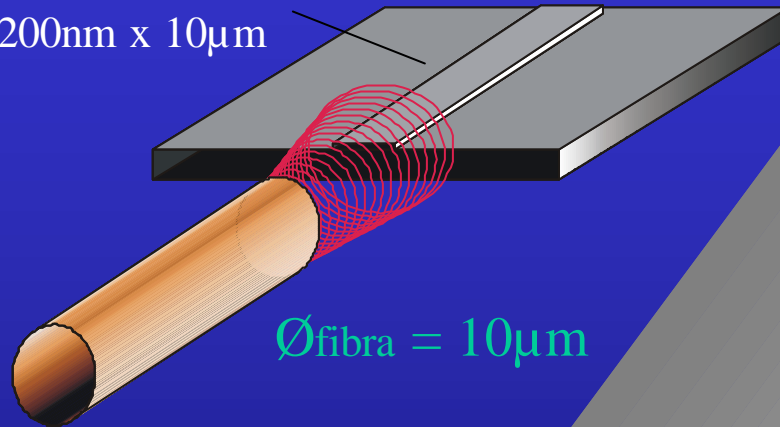
- Attacco chimico

- Bagnato (wet)
- Asciutto (dry)



Accoppiare la luce alla

Canale Guida
200nm x 10 μ m



Perdite...

- ✓ Dimensioni fibra - guida
- ✓ Apertura numerica
- ✓ Riflessione di Fresnel
- ✓ Disallineamento
- ✓ Difetti nelle facce
- ✓ Diffusione (*scattering*)
- ✓ Disaccoppiamento

"the edge problem"

lapped edge

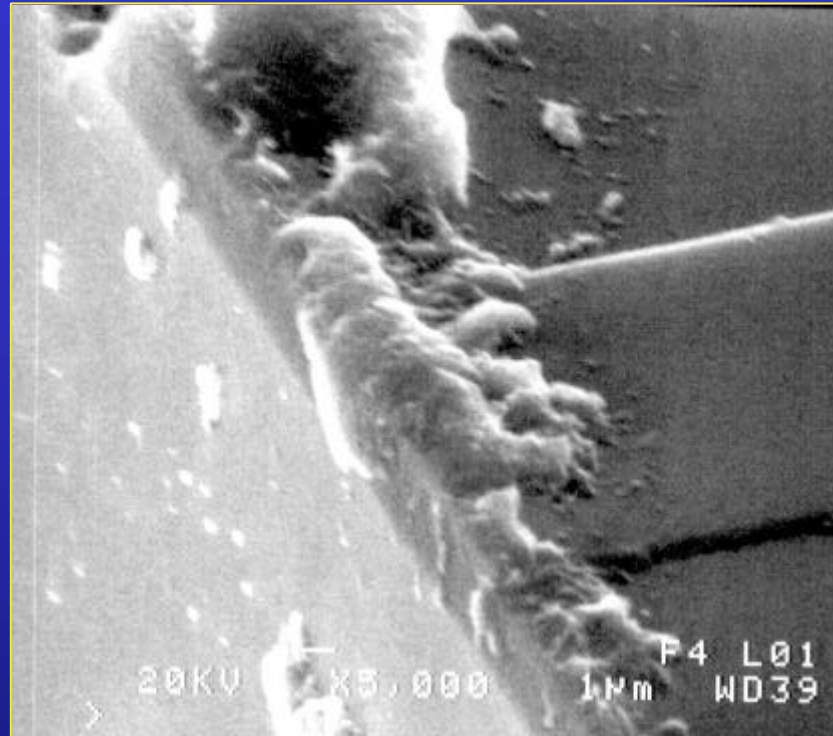


clived edge



**... bordo preparato nel processo (etching)...
on going**

"the cleaning "



- ethanol ? methanol ? Acetone ?
- effetti invecchiamento...

Waveguide coupling...

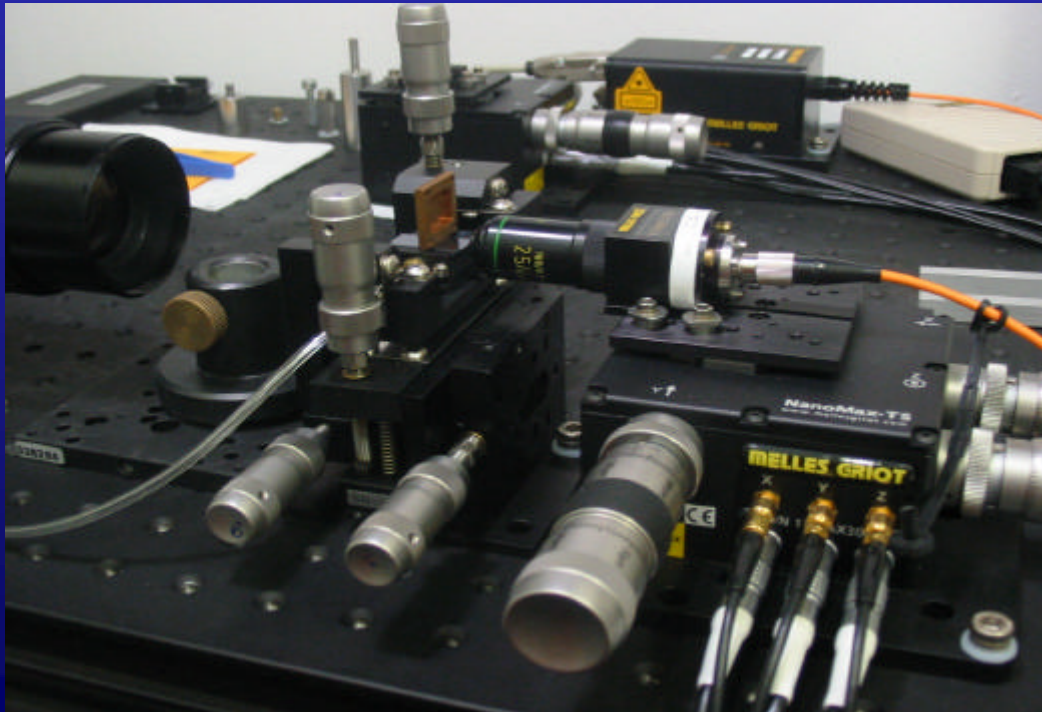
Intrinsic causes of coupling loss

- modal mismatch
- reflection loss

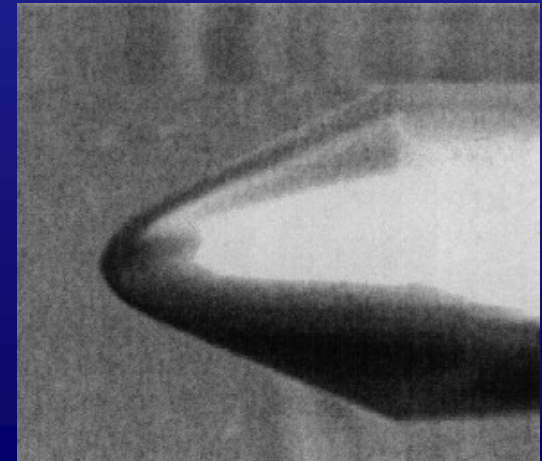
Extrinsic causes of coupling loss

- misalignment
- facet defects
- scattering and absorption

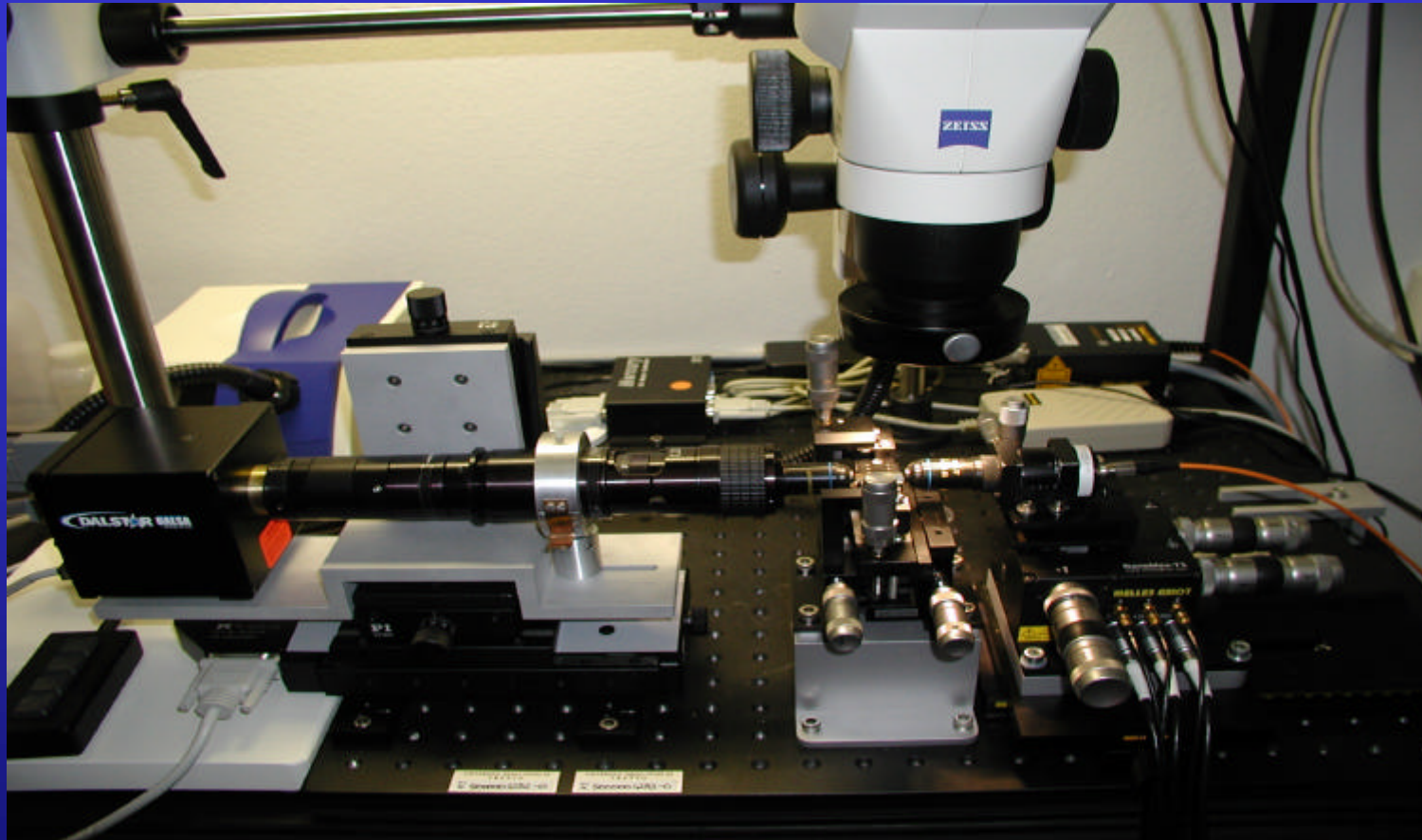
Objectives and nanopositioning



Tapered fibers

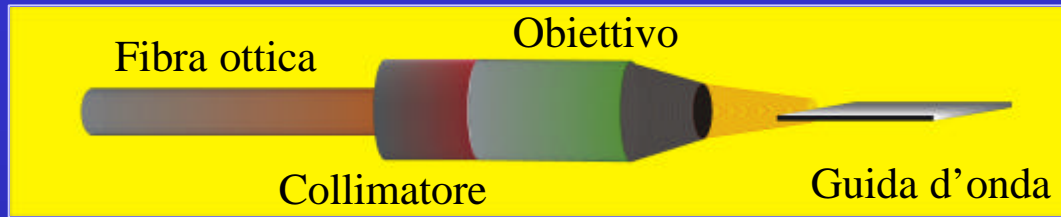


Waveguide setup



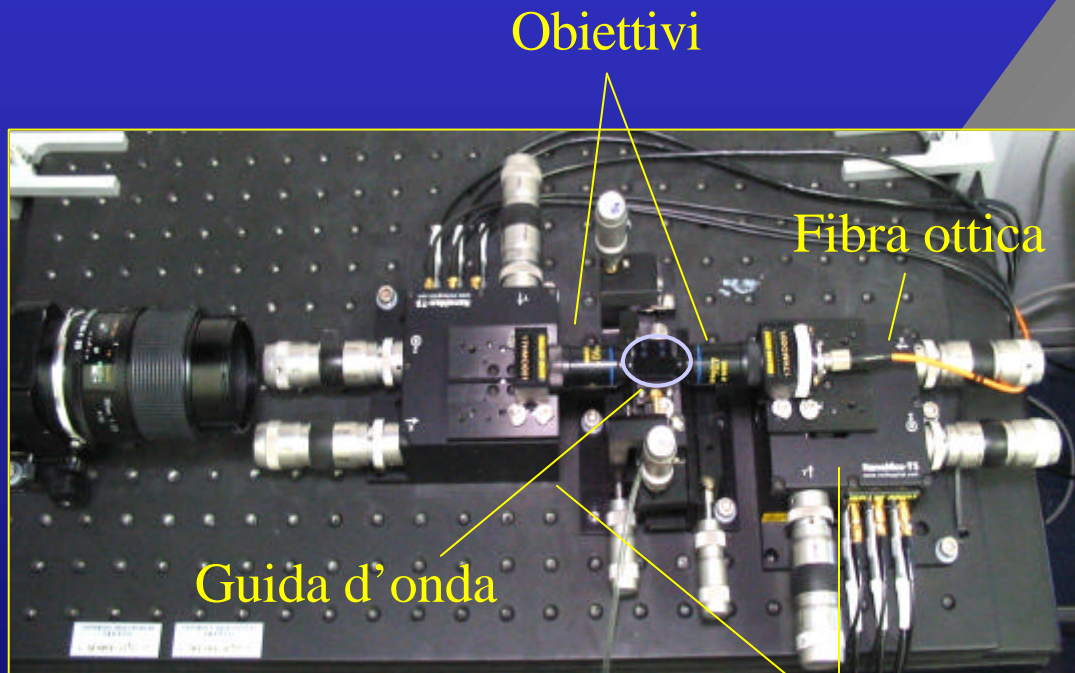
- xyz nano-positioning (IN & OUT), xyz stage (OUT)
- Sources: 780, 1300 & 1550nm (tunable) laser
- objectives (from 10 to 80x) and tapered fiber (VIS & IR)
- Detectors: Si CCD (VIS) and InGaAs array (IR)

Accoppiamento in Laboratorio



Procedure di allestimento setup

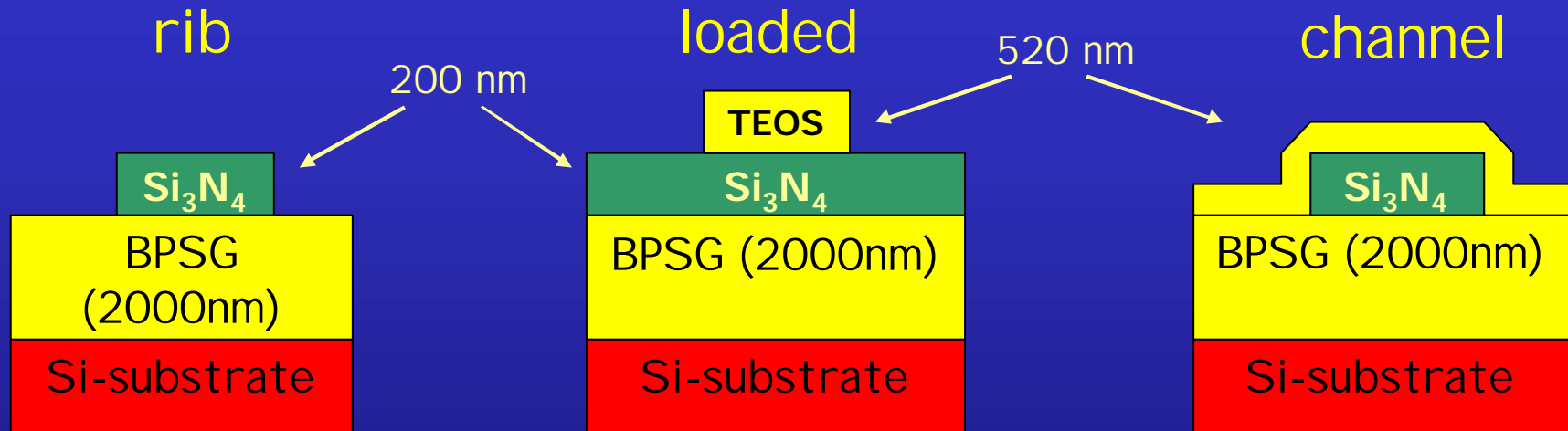
- Montaggio e studio componentistica
- Misure dimensioni fascio laser
- Analisi NA e distanze di lavoro obiettivi



Nanoposizionamenti piezoelettrici

Loss measurements: cut-back

Si_3N_4 @ 780nm



Aim

Production of rectangular waveguides

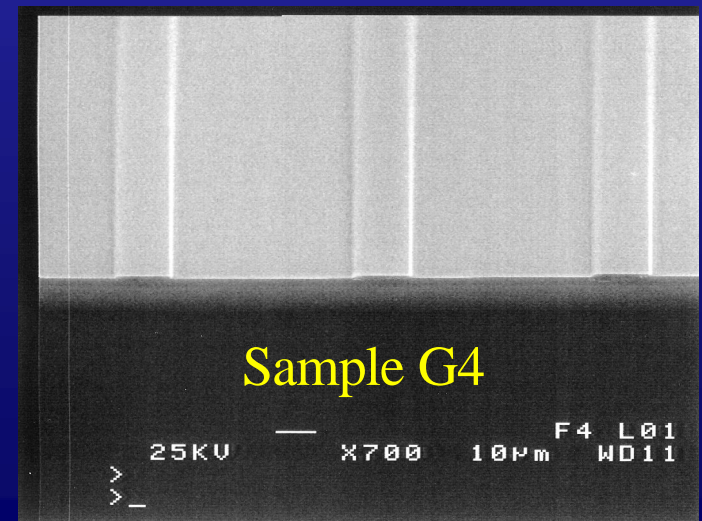
Role of interface roughness

Testing of different etching techniques:

Si_3N_4 : Tegal, Cobrain

TEOS: wet or dry, wet and dry

Loss measurements



Perdite di propagazione



CAUSE:

-Assorbimento

Perché misurarle:

Ottimizzazione dei materiali e dei processi di preparazione

$$I = I_0 e^{-aL}$$

Perdite di propagazione

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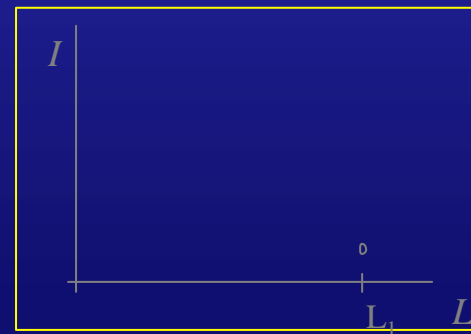
-Assorbimento

Perché misurarle:

Ottimizzazione dei materiali e dei processi di preparazione

Misura con tecnica *cut-back*

Supponiamo accoppiamento omogeneo



Perdite di propagazione $I = I_0 e^{-\alpha L}$



CAUSE:

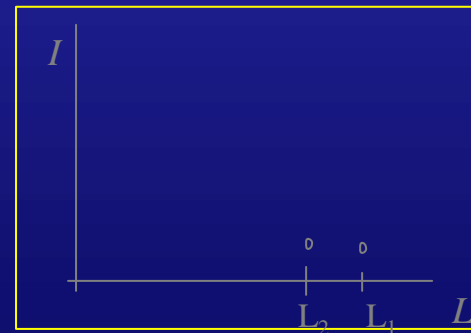
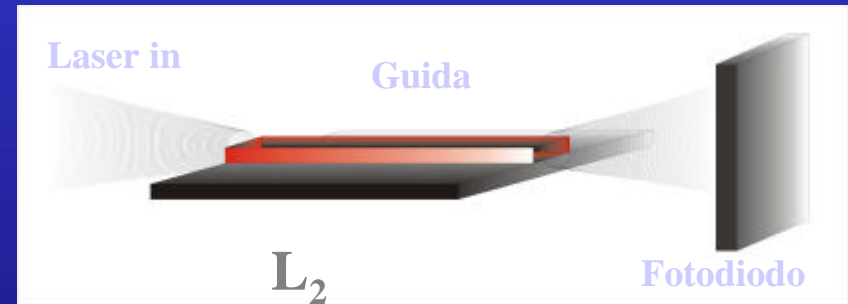
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Perdite di propagazione $I = I_0 e^{-\alpha L}$



CAUSE:

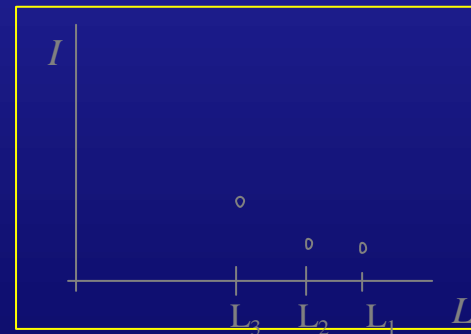
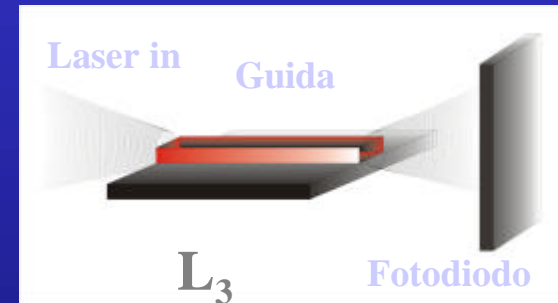
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Perdite di propagazione

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CAUSE:

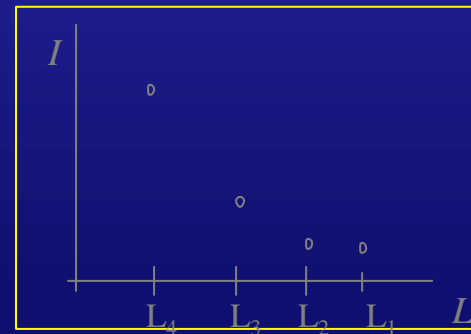
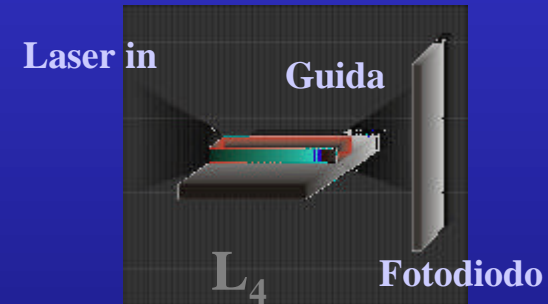
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Misura con tecnica *cut-back*

Supponiamo accoppiamento omogeneo



Perdite di propagazione

$$I = I_0 e^{-aL}$$



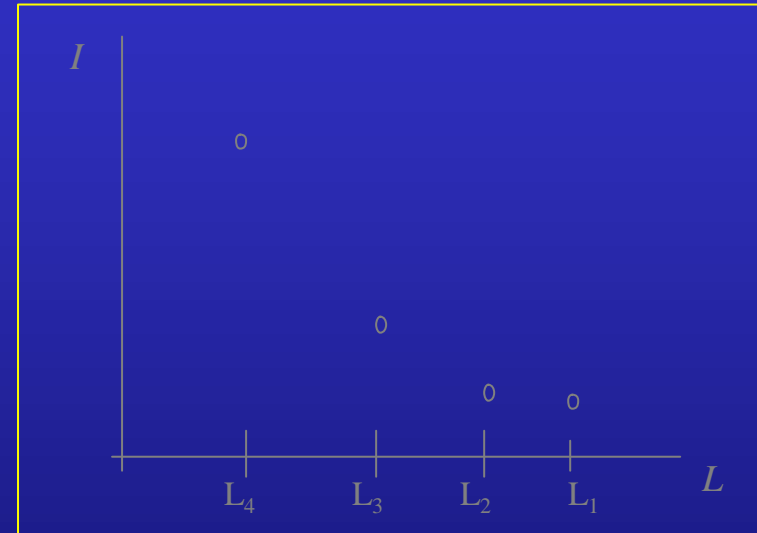
CAUSE:

-Assorbimento
-Riflessioni

Perché misurarle:

Ottimizzazione dei materiali e dei processi di preparazione

Misura con tecnica *cut-back*



$$\ln(I) = \ln(I_0) - aL$$

Perdite di propagazione

$$I = I_0 e^{-aL}$$



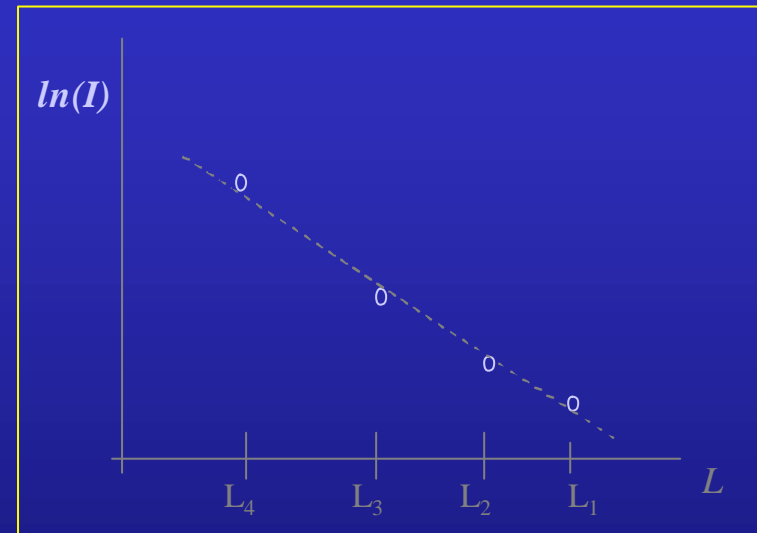
CAUSE:

-Assorbimento

Perché misurarle:

Ottimizzazione dei materiali e dei processi di preparazione

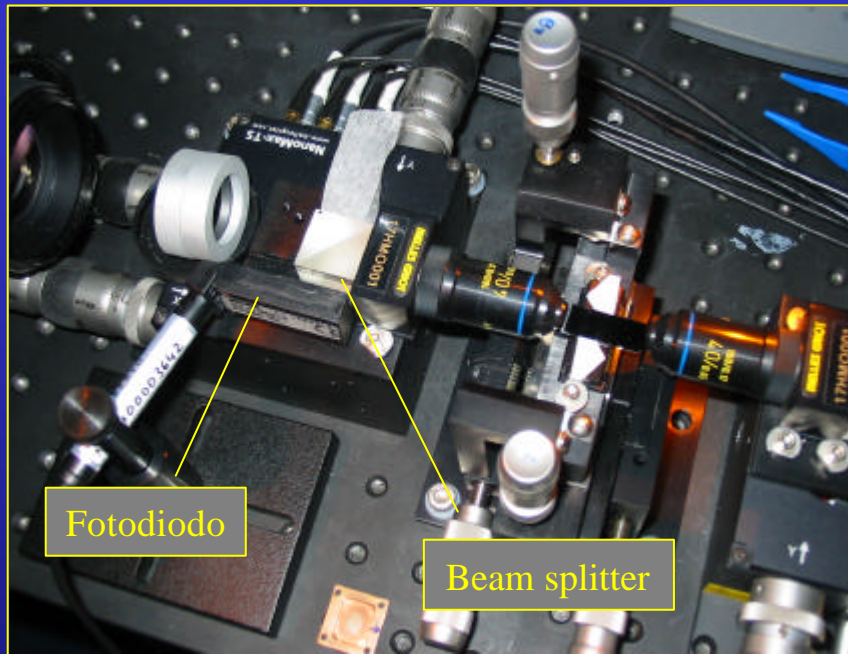
Misura con tecnica *cut-back*



$$\ln(I) = \ln(I_0) - aL$$

Fit lineare $\rightarrow a$

Setup e metodo



?=780nm

Accoppiamenti omogenei

Precisione

Pulizia

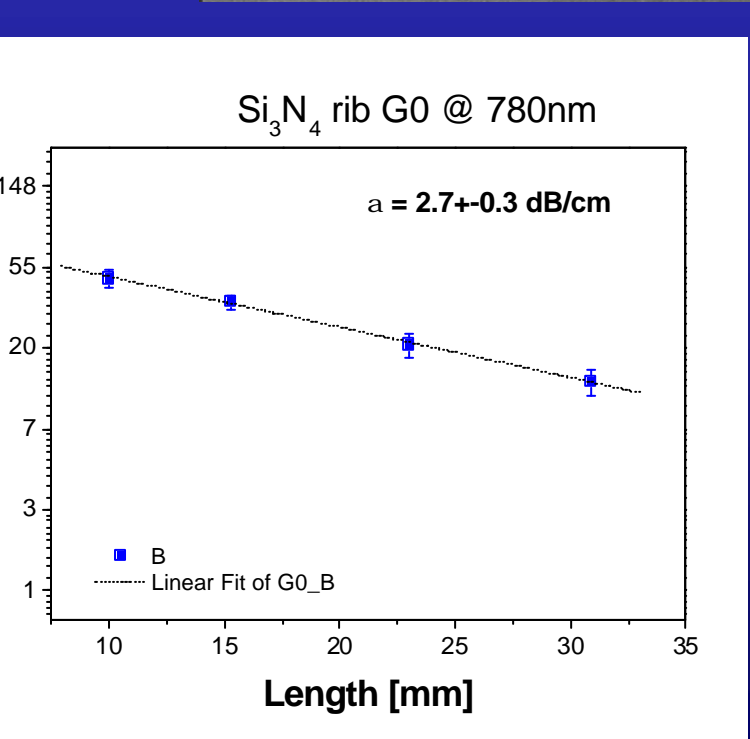
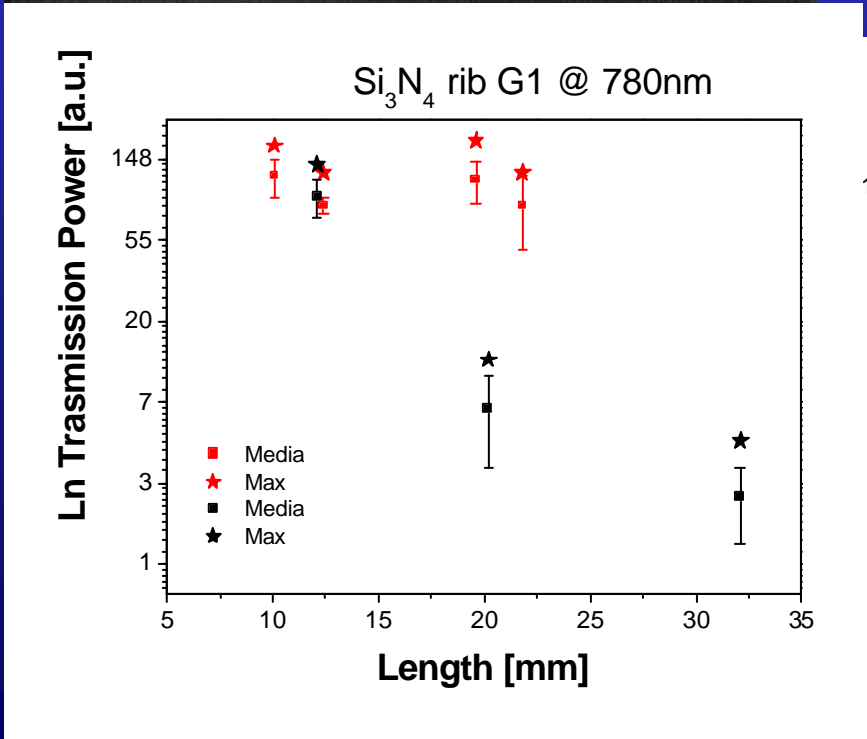
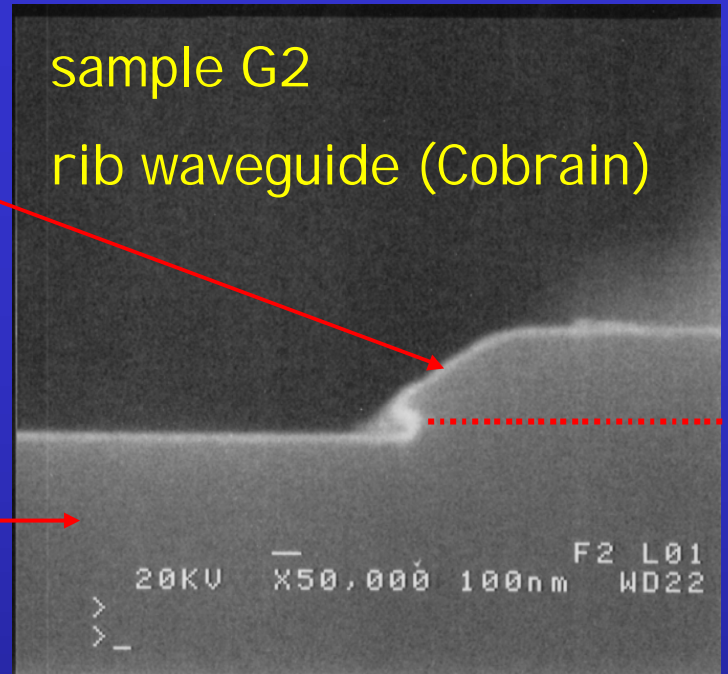
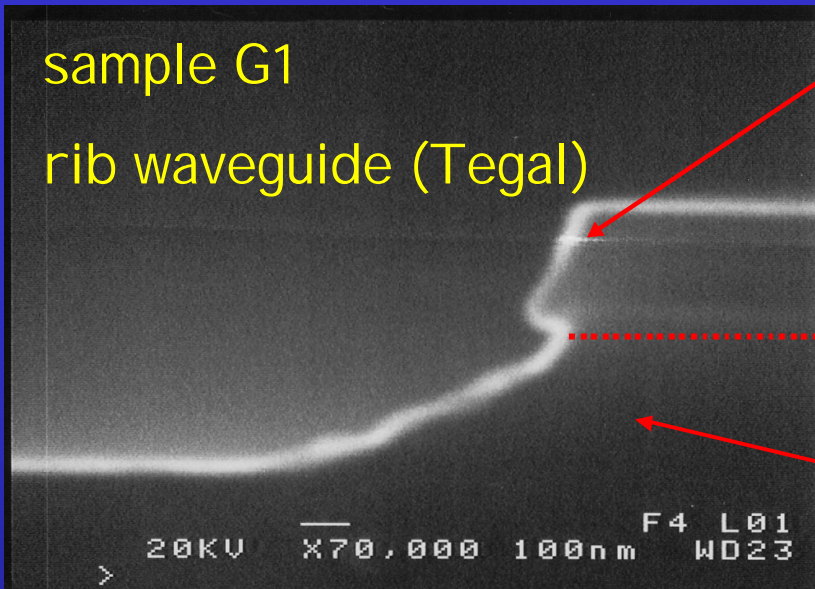
Riproducibilità

Ottimizzazione

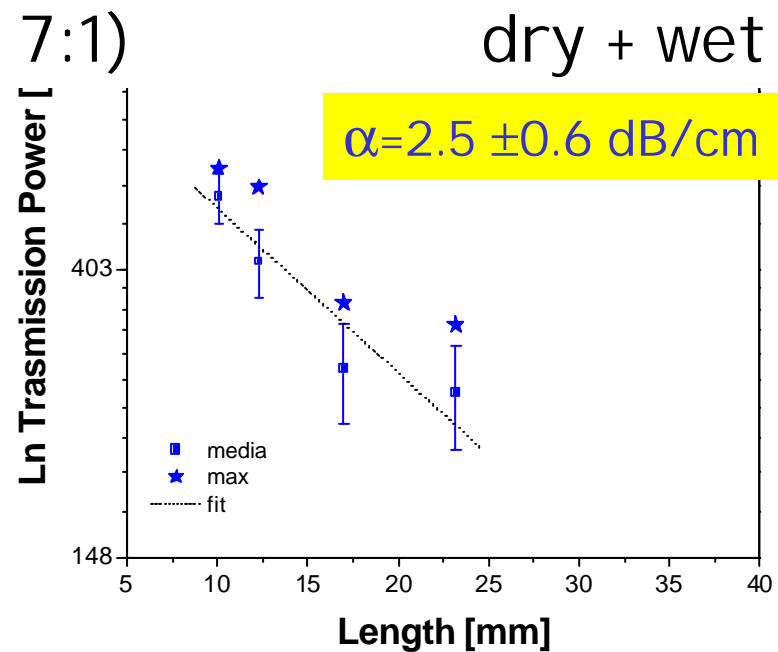
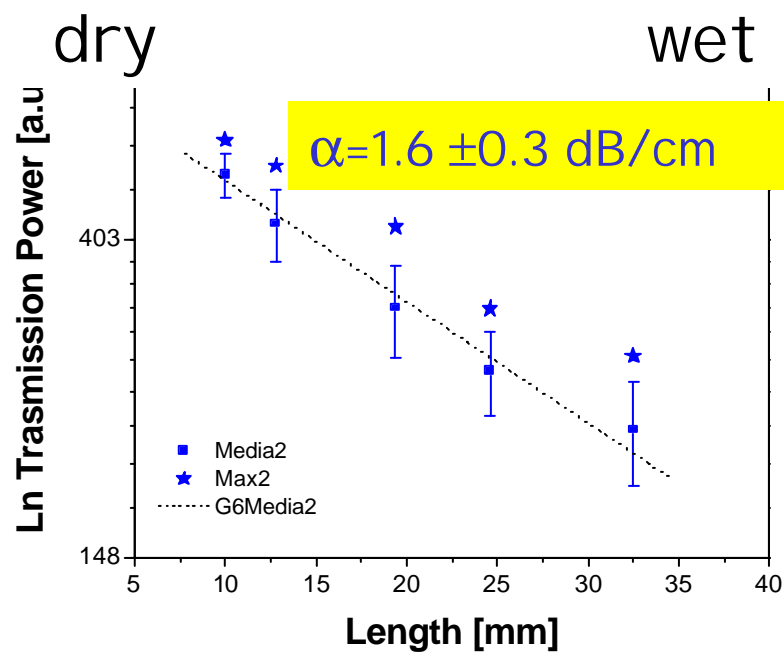
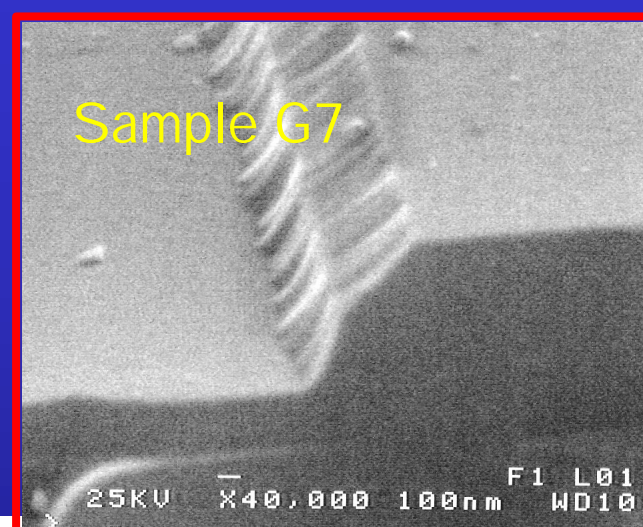
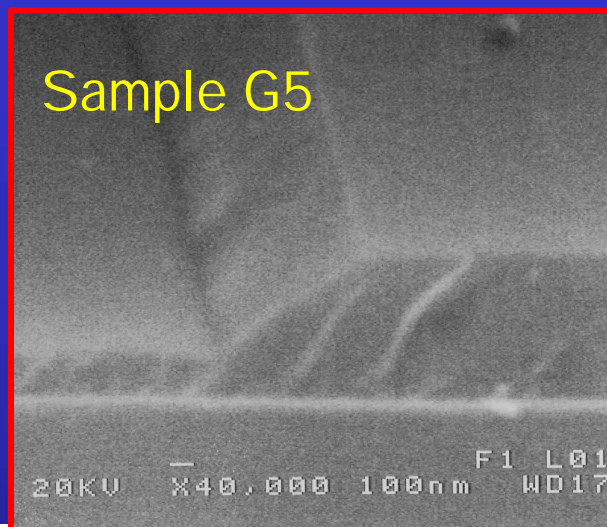
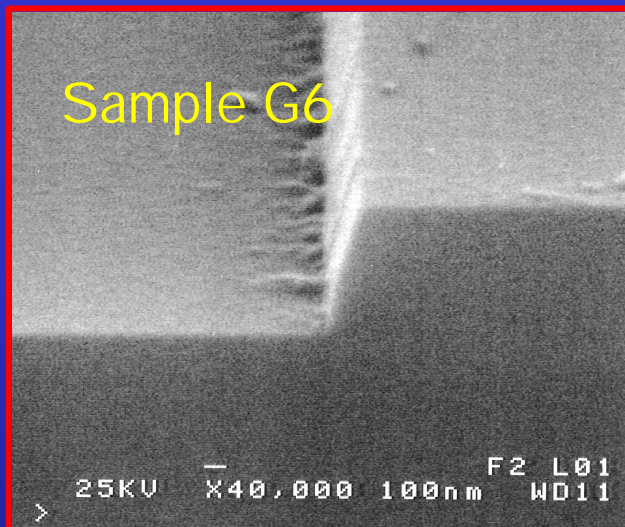
accoppiamento mediante

movimenti piezo:

- immagine frontale
- immagine dall'alto
- massimizzazione I_{out}



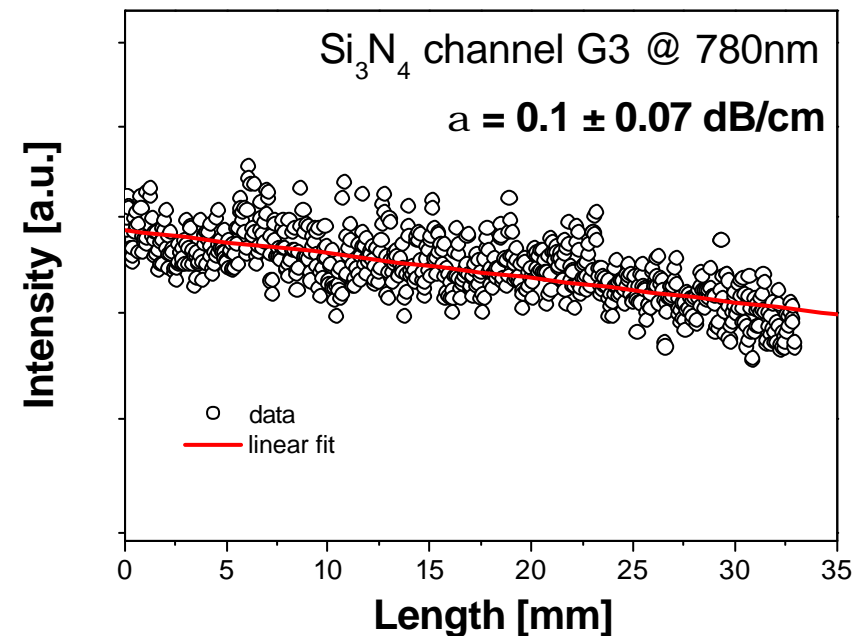
Loss measurements: cut-back @780 nm



Top view: loss measurements

Light coupling in 200nm thick channel waveguide of Si_3N_4 @ 780 nm

Coupling light into a 0.2 μm thick waveguide

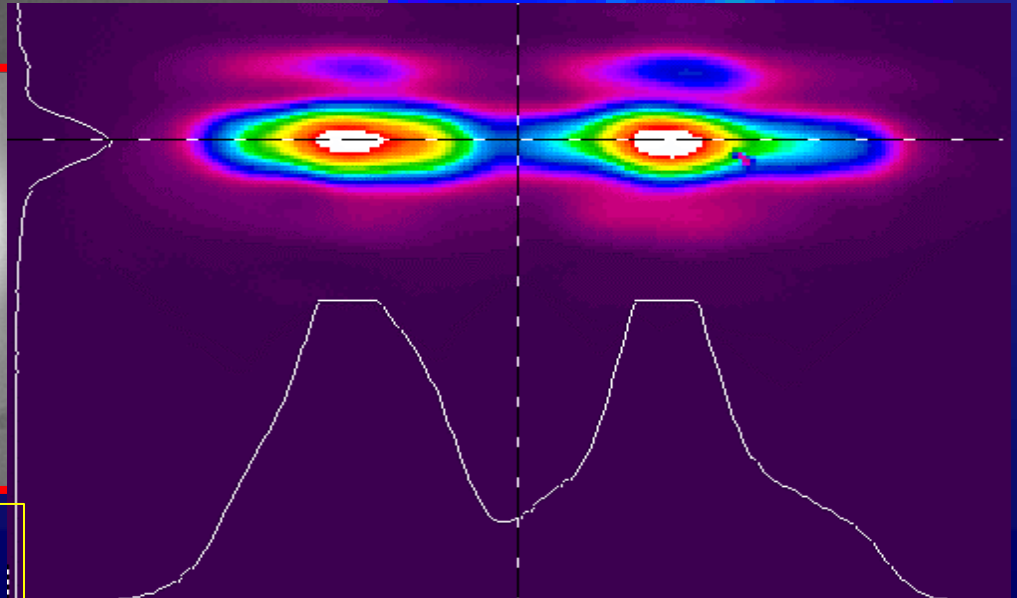
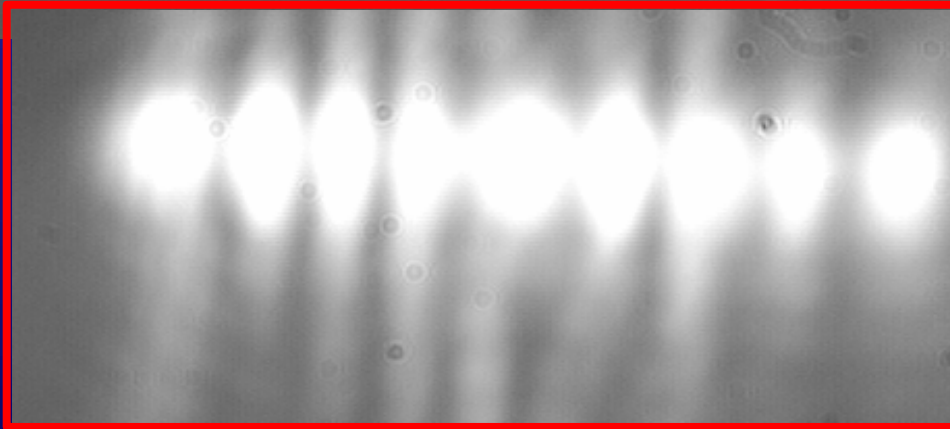
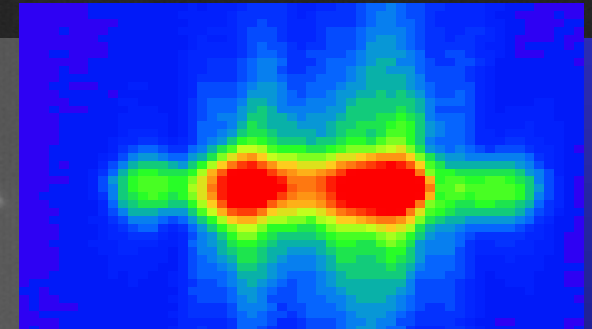
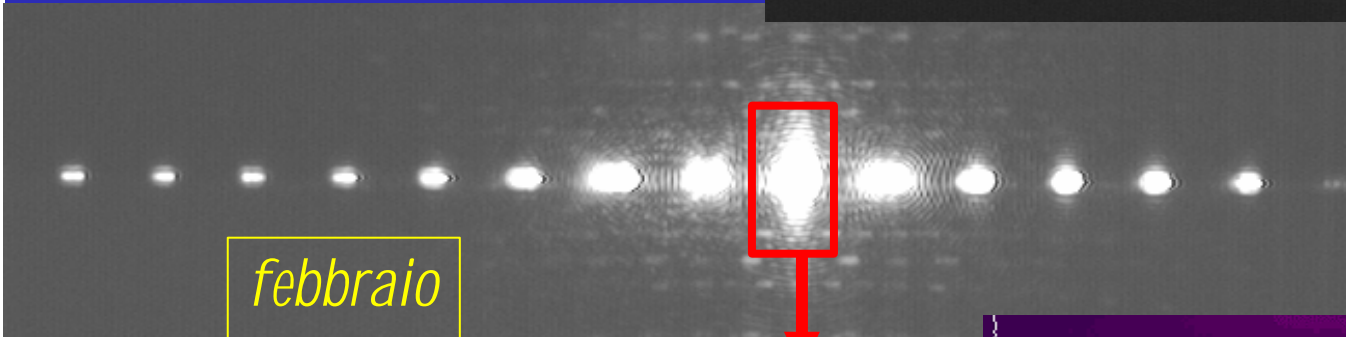
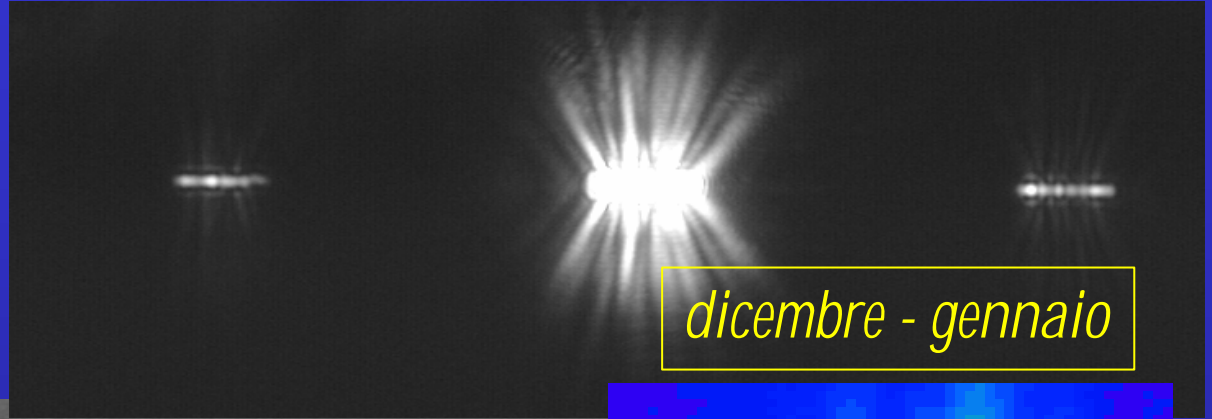


Propagation losses

Samples	Waveguide	Propagation loss coefficient [dB/cm]	
		Cut-back	Top-view
G1	Rib (oxide plasma etcher)	2 ± 1	1.8 ± 0.2
G3	Channel (nitride plasma etcher)	0.2 ± 0.2	0.1 ± 0.05
G4	Channel (oxide plasma etcher)	0.3 ± 0.2	0.2 ± 0.2
G5	Strip-loaded (BHF wet etching)	2.5 ± 0.6	-
G6	Strip-loaded (oxide plasma etcher)	1.5 ± 0.2	1.4 ± 0.4

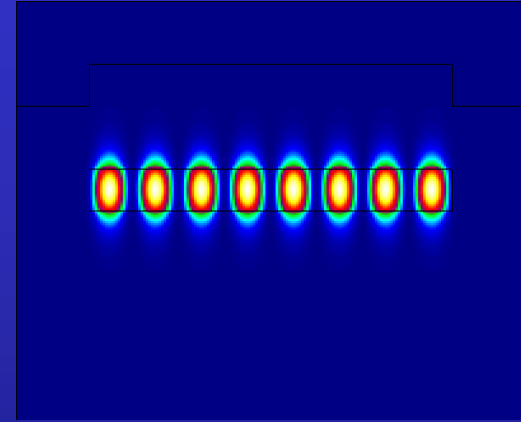
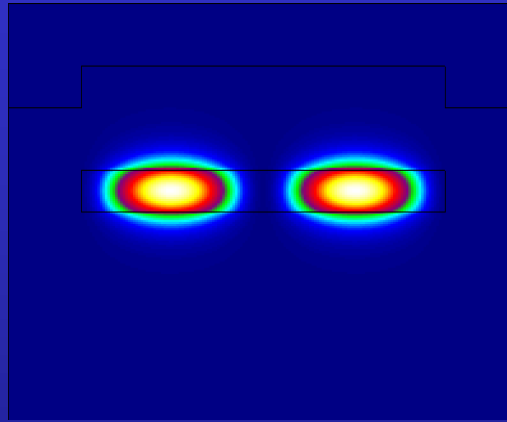
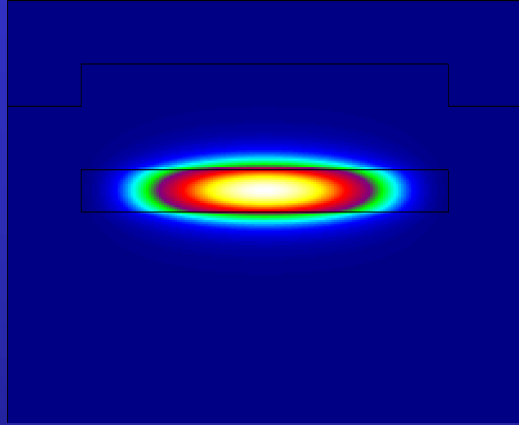
On the basis of a careful comparison between different waveguide geometries and etching processes, the best choice in terms of propagation losses is the channel waveguides, which have shown losses of about 0.1-0.2 dB/cm, and good reproducibility as a function of time and channels. The choice of dry etching rather than wet etching is to be considered for smaller channel width.

Mode Profiling

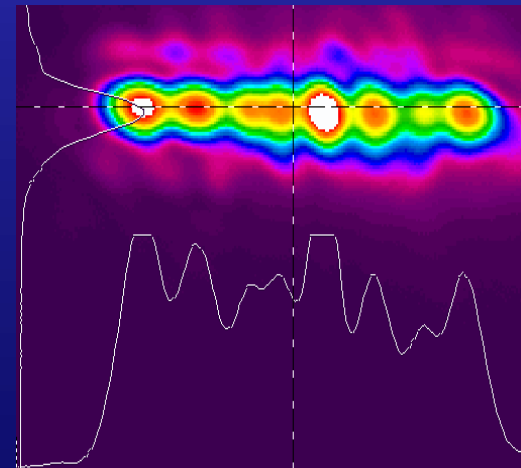
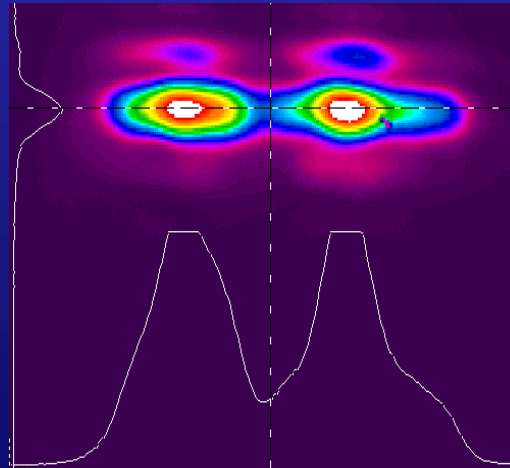
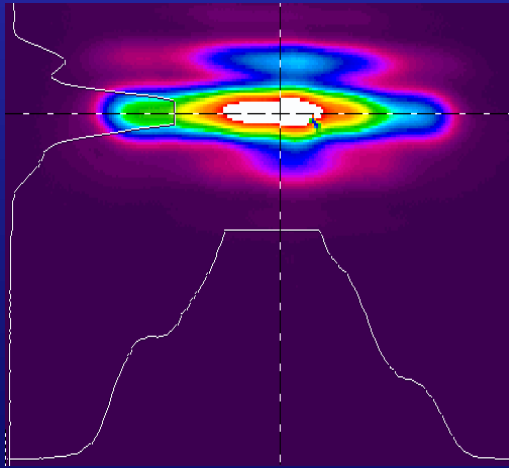


Mode profiling

Theory



Exper.



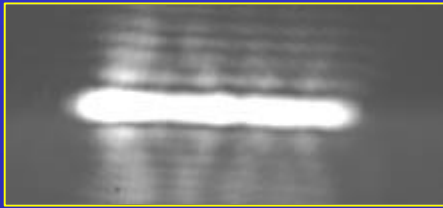
Profilo di Fascio *(Guida strip @780nm)*

Si₃N₄

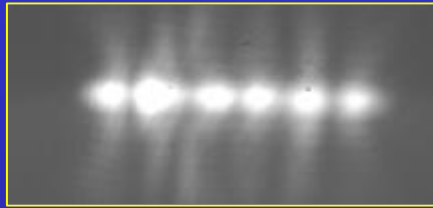
BPSG
(2000nm)

Si-substrate

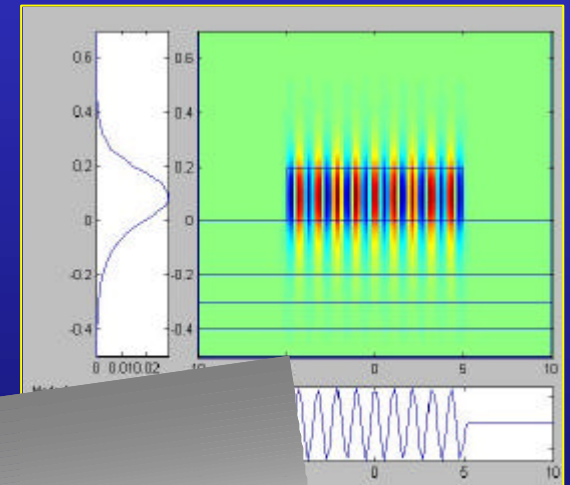
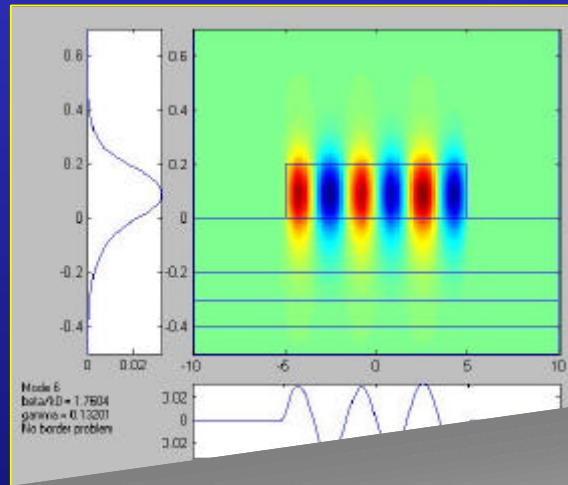
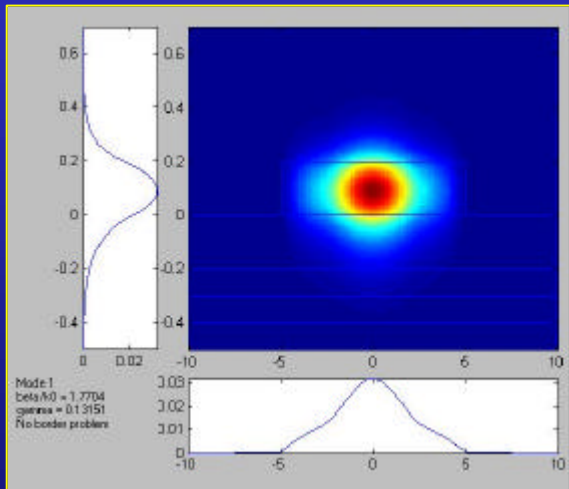
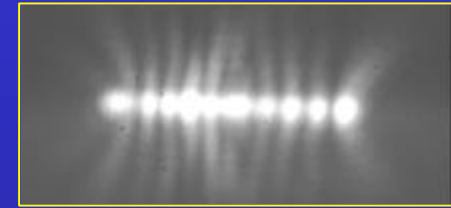
Modo 1 di 32



Modo 6 di 32



Modo 10 di 32



- Si distinguono i **modi di ordine superiore**
- **Dimensioni laterali** del canale molto elevate ($10\mu\text{m}$)