Self-trapped beams for fabrication of optofluidic chips

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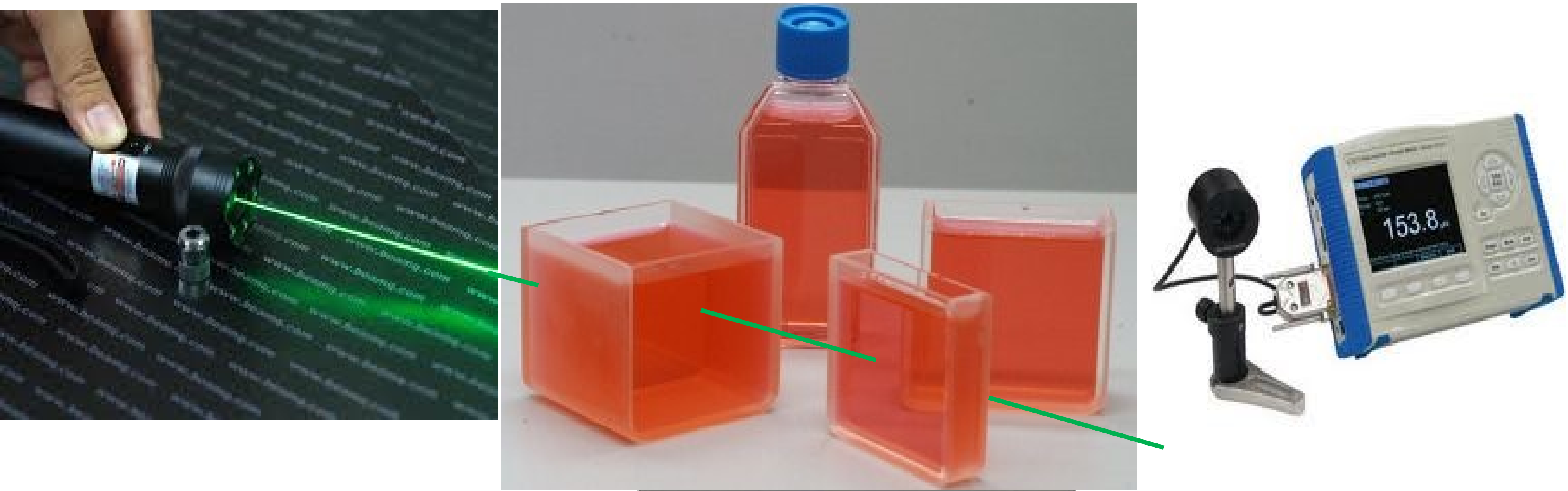
Outline of the talk

- Context
- Self-trapped beam technique

- Experimental demonstration
- Fabrication and test of index sensor
- Potential for integrated optics
- Conclusions.

Context

Analysis of liquid or gas properties using light

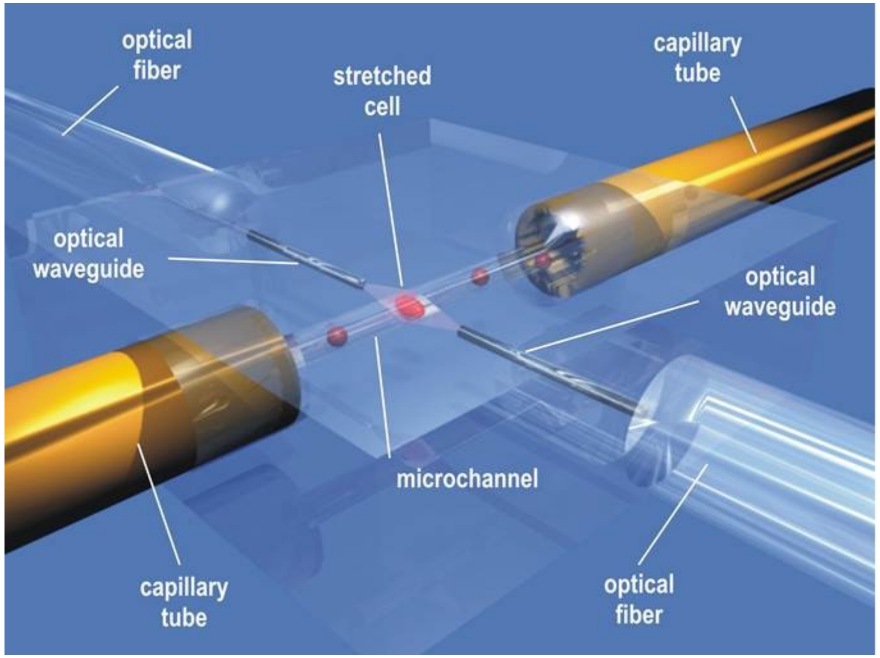


Available devices are often bulky

Great interest for fabrication of integrated devices

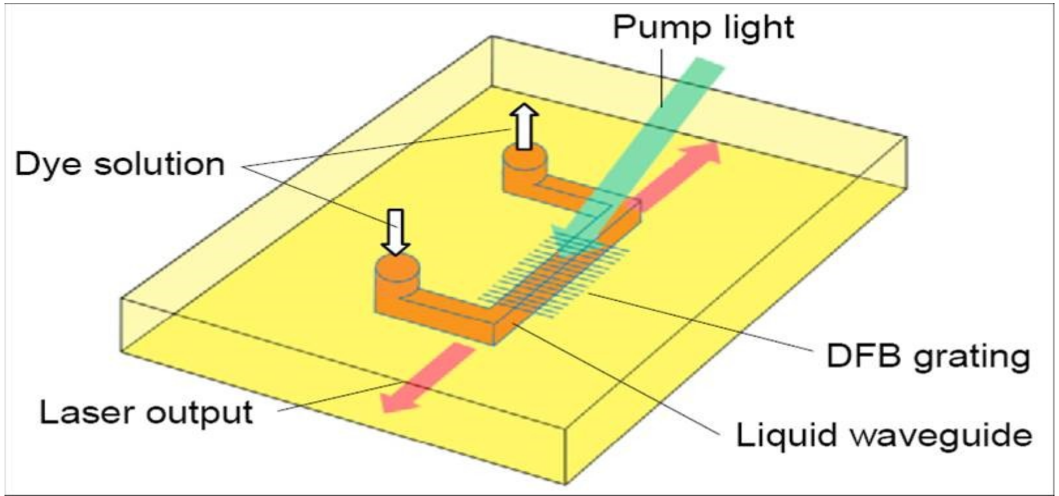
Context

Integrated optofluidic devices



Optofluidic chip for cell manipulation. From : R. Osselame, Politecnico Di Milano.

Domain of Interest : biology, chemistry, biomedical, integrated optics…



Optofluidic dye laser. From : Li, Z. Y., Zhang, Z. Y., Emery, T., Scherer, A. & Psaltis, D., *Opt. Express 14, 696–701 (2006).*

Interests :

- **Portable devices**
- **Fast response**
- **Very small quantity of analyte.**

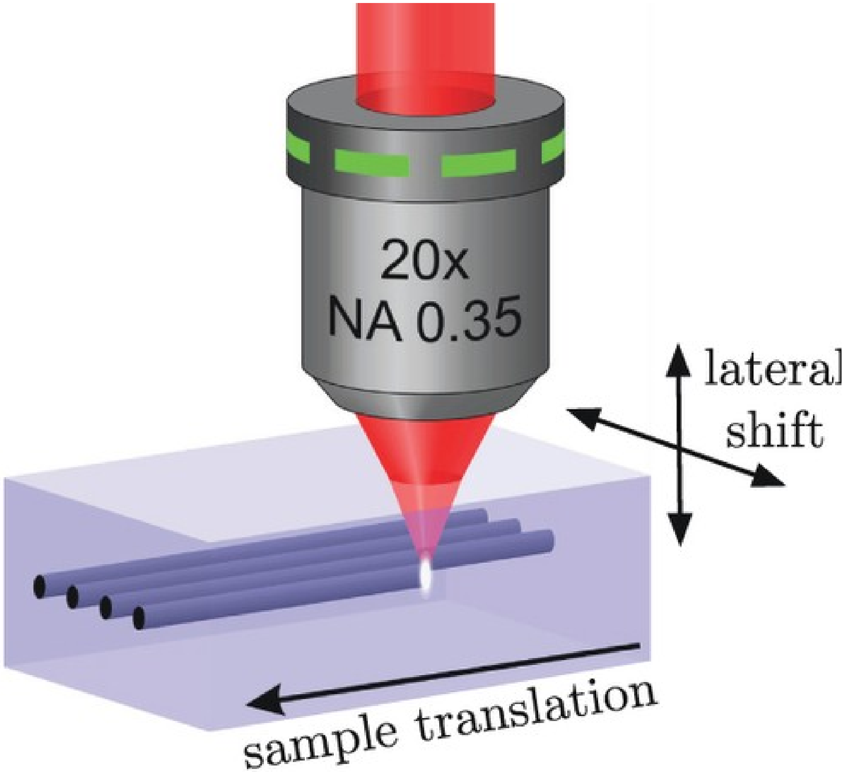
Context

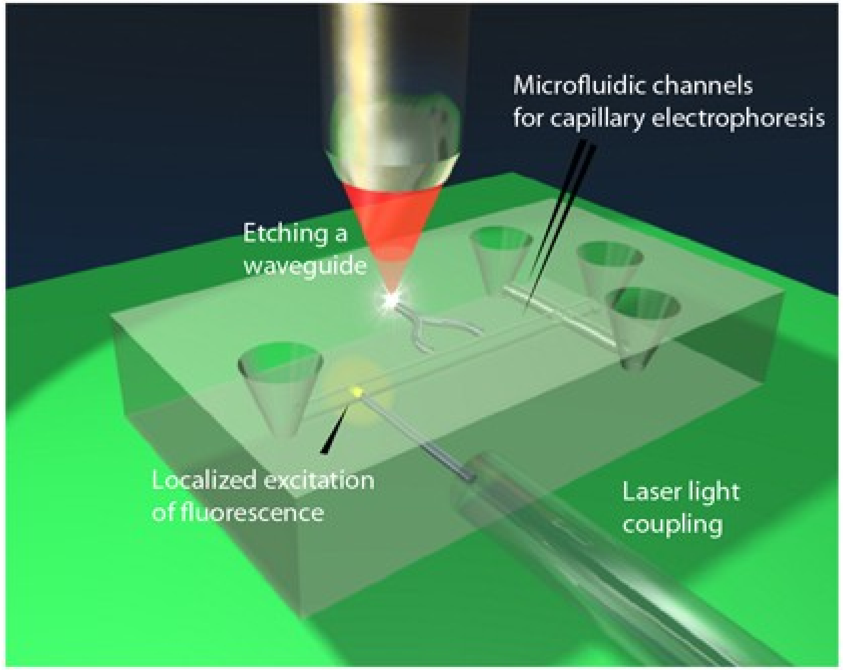
- Challenges : combination of micro-channels & optical waveguides :

  - Fluidic channels with smooth walls
  - Buried waveguides
  - Optimization of waveguides/channels alignment

Fabrication technique

Scanning beam technique

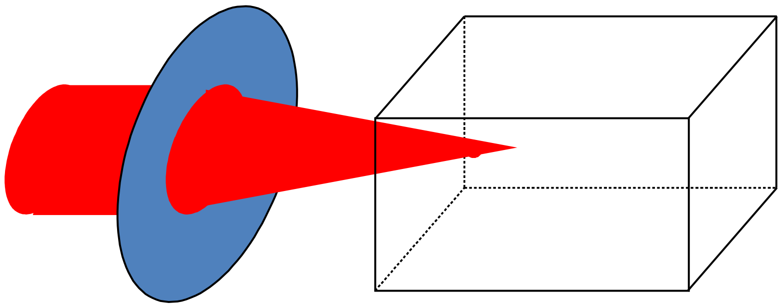




Integrating optical sensing into lab-on-a-chip systems, R. Osellame et. al. SPIE Newsroom, DOI: 10.1117/2.1200905.1597(1997)

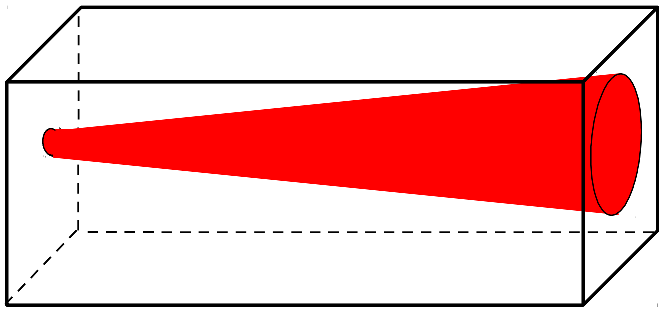
Fabrication technique

Self-trapped beams



Self-trapped beam writing technique

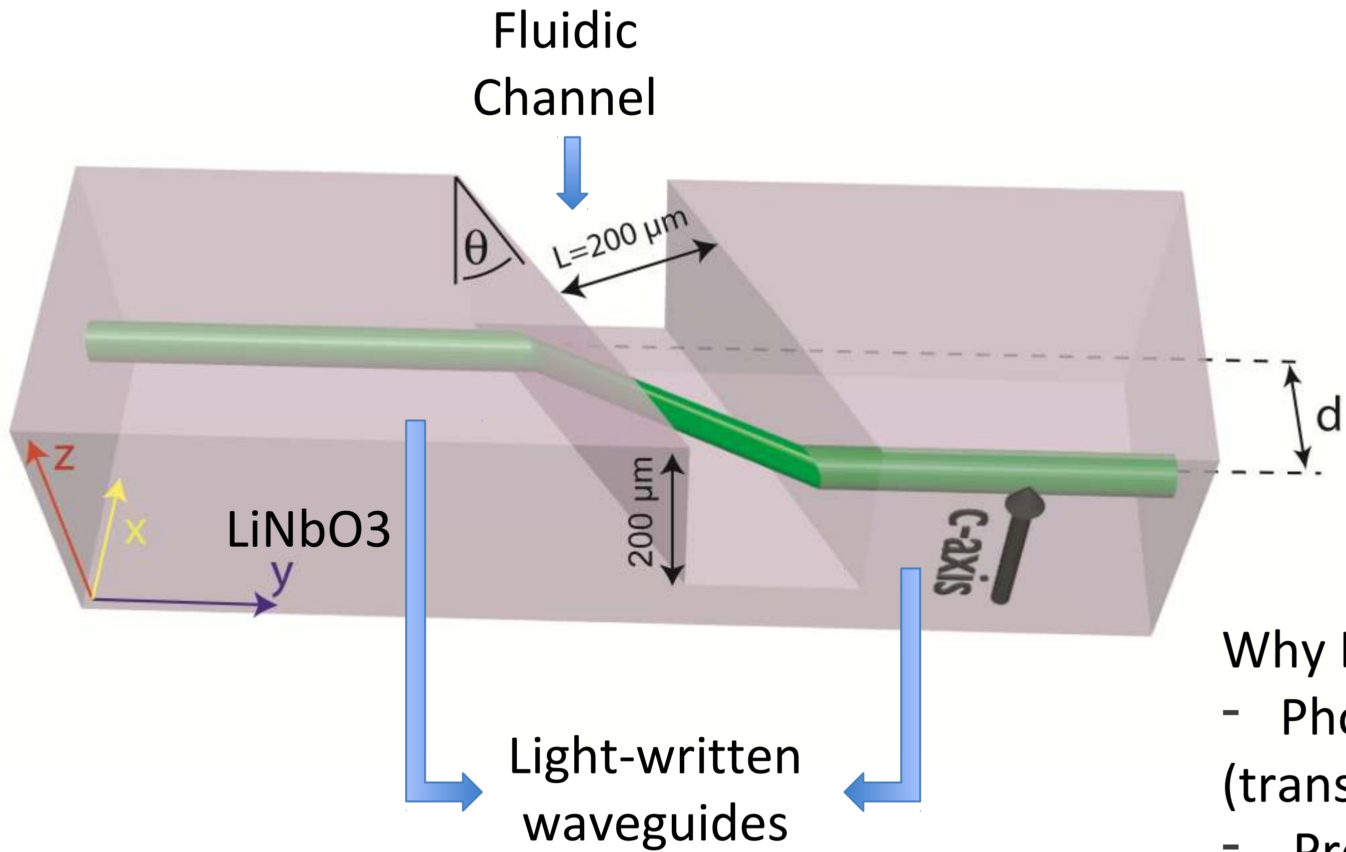
- Single step process
- Self-induced singlemode waveguides
- Low loss circular waveguides
- Self-aligned trajectory



Requirements and characteristics

- Nonlinear focusing medium (Kerr, thermal, photopolymer, photorefractive..)
- Stable self-confinement of 2-D beams with saturable nonlinearity
- Ultimately spatial soliton can be formed

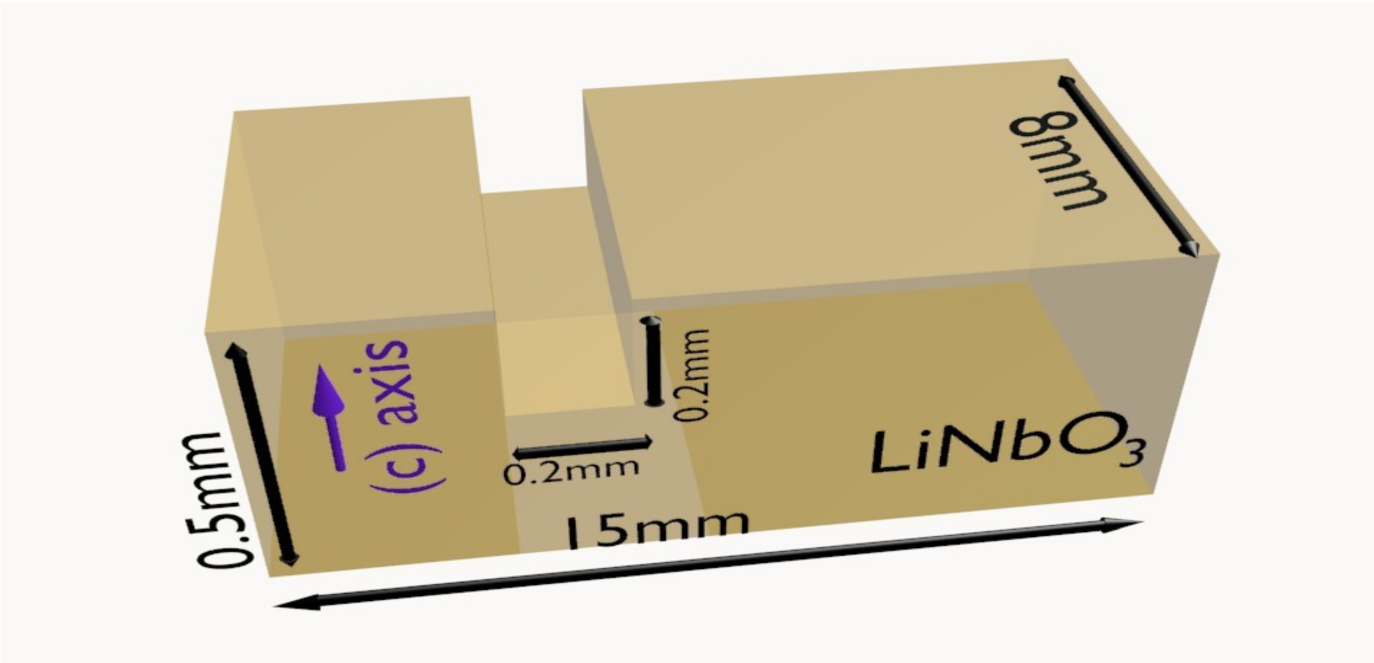
Studied configuration



Why LiNbO3 ?

- Photonic material
(transparent Vis-NIR, electro-optic, ..)
- Properties
(photorefractive, pyroelectric, ..)

Samples fabrication

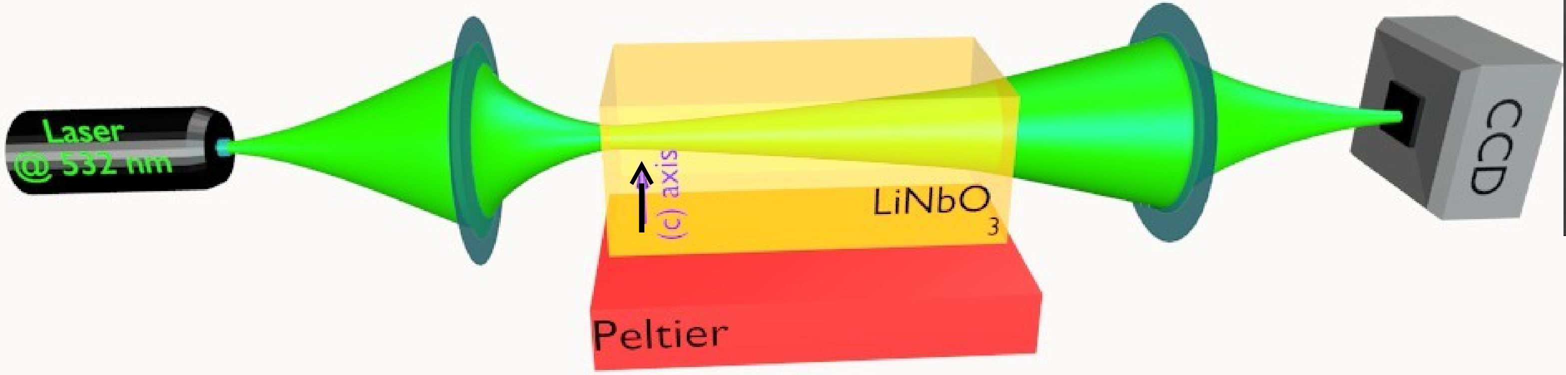


Precision saw Disco DAD 321

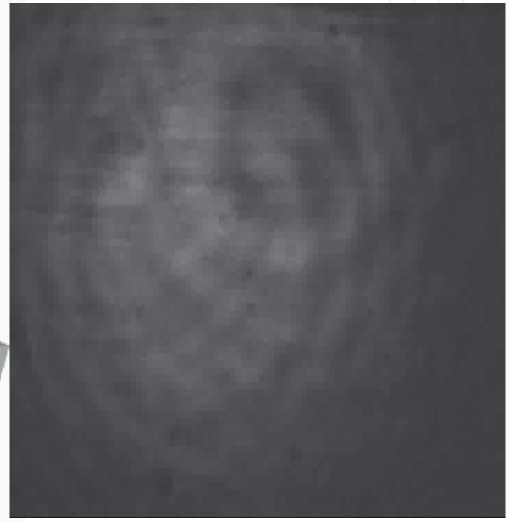
Precision dicing/polishing is used to cut the sample and to inscribe the fluidic channel.

Waveguides induction : principle

Optical set- up



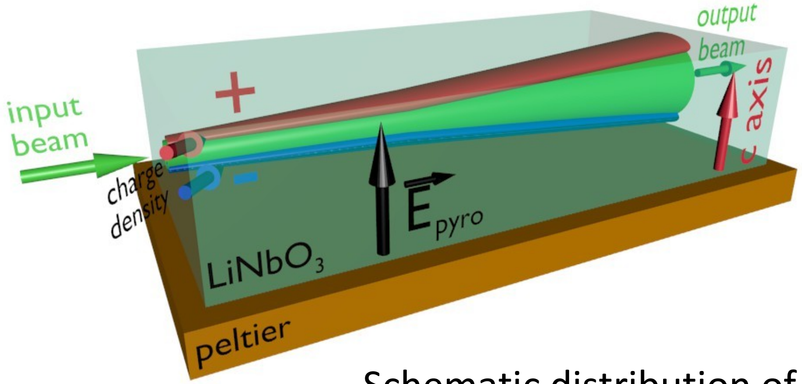
At room temperature



Experimental observation
(15mm long crystal, ΔT= 20°C, P=200µW)

The optical waveguide is induced by photorefractive beam self-trapping controlled by the pyroelectric effect.

Underlying physics



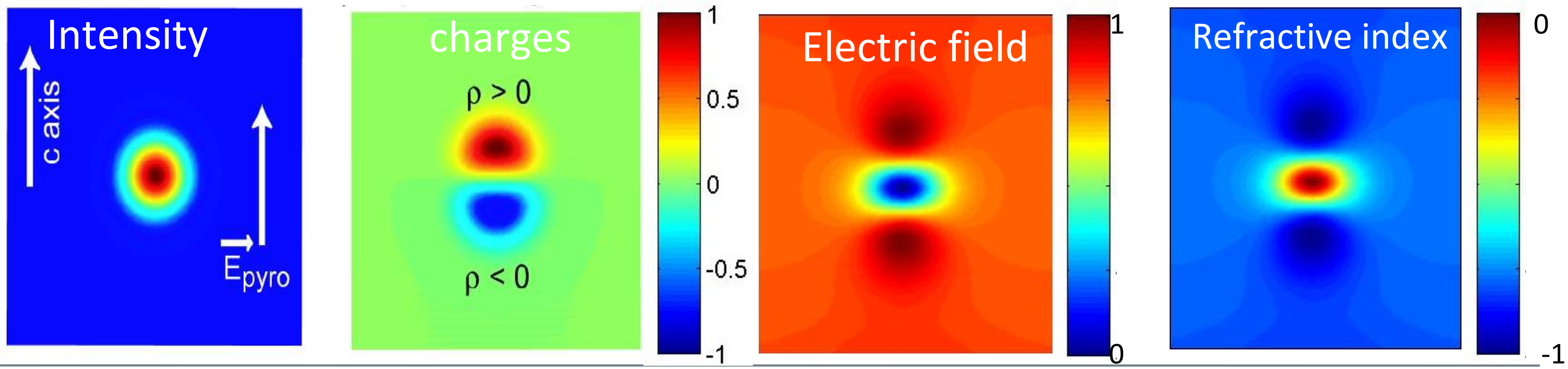
Schematic distribution of charge

Pyroelectric field

$$E_{pyro} = \frac{-1}{\varepsilon_0 \varepsilon_r} p \Delta T$$

$$\Delta T = 20°C \Rightarrow E_{py} \approx 42\, kV / cm$$

Normalized distributions



Safioui et. al., "Pyroliton: pyroelectric spatial soliton",Opt.Express **17**,2209 (2009).

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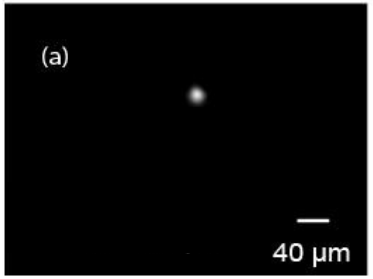
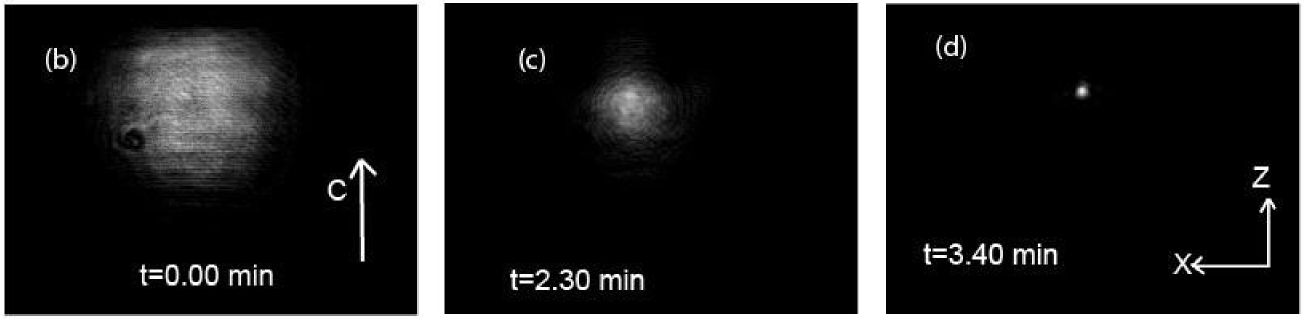
Waveguide crossing channel (θ=0)

Input Beam (FWHM≈10µm)

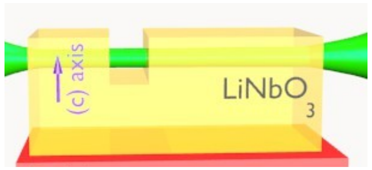


Parameters :
λ = 532nm, extraordinary polarization, P= 70µW

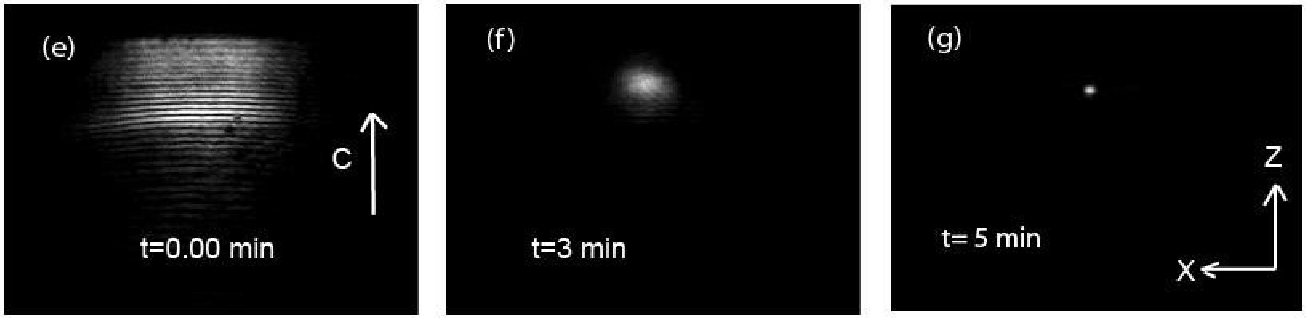
Without channel



ΔT=20°C



With channel (θ=0)



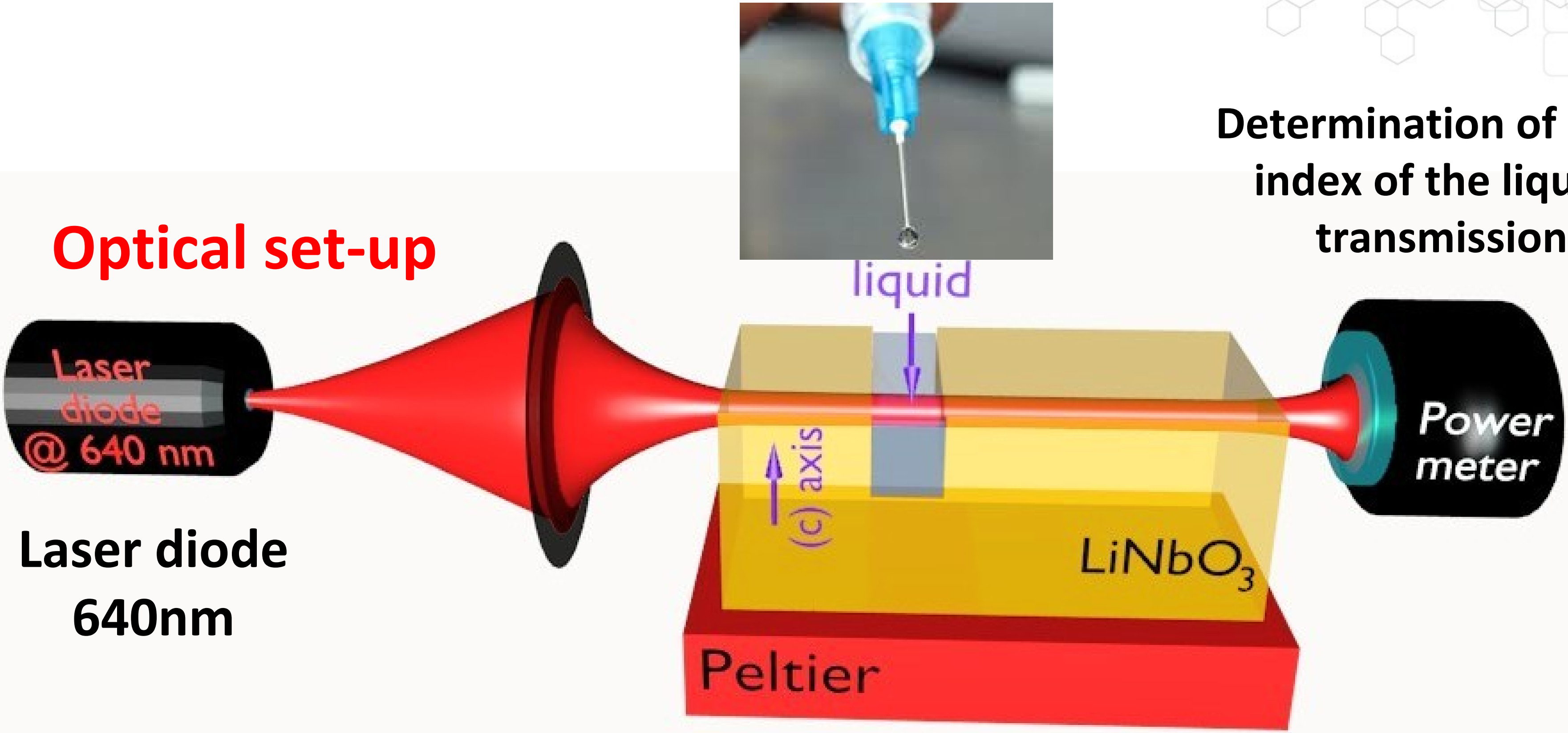
Properties of induced waveguide :

- **Singlemode**
- **Low losses (0.9dB)**
- **Quasi-permanent (lifetime > several months)**

Realization of an index sensor

Determination of the refractive index of the liquid (*nliq*) by transmission analysis

Optical set-up



Laser diode 640nm

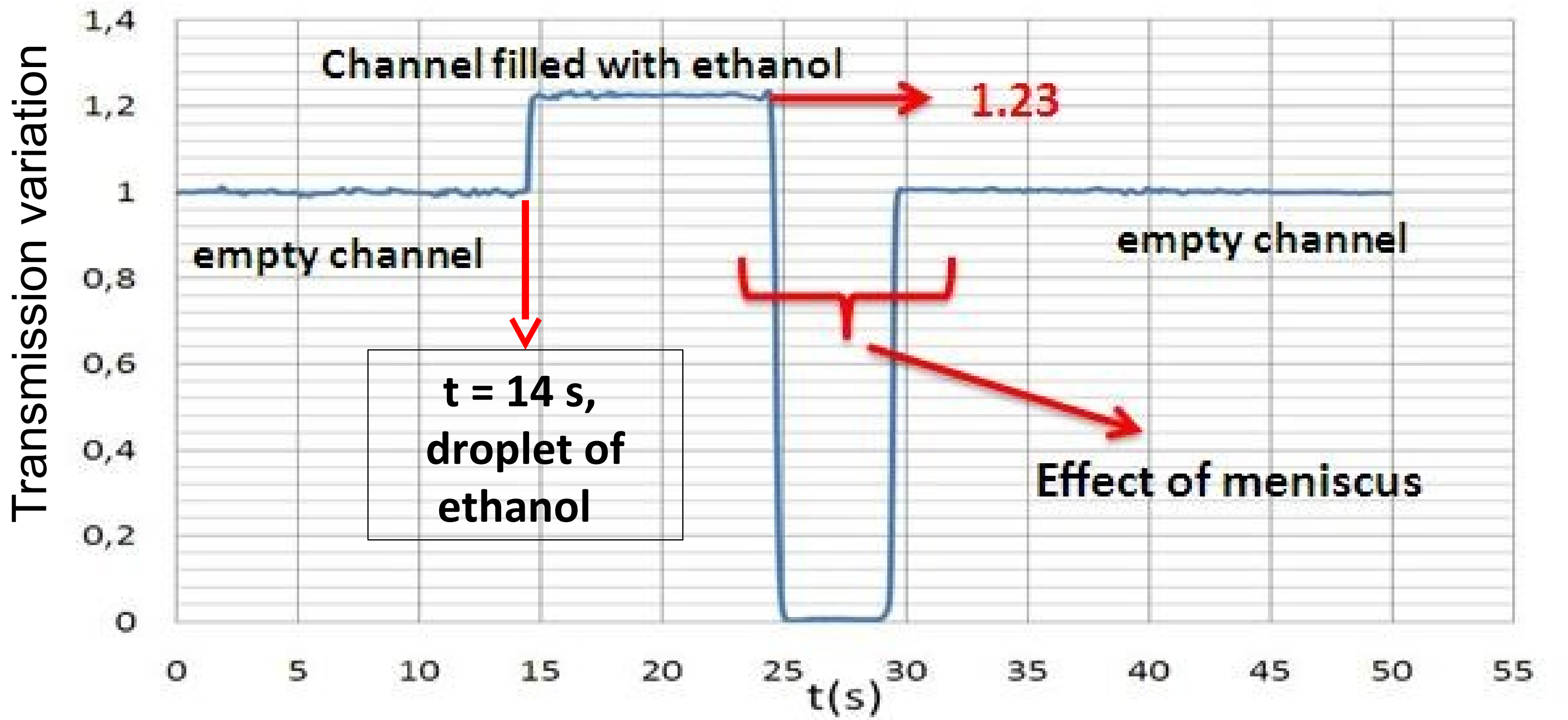
Step 1 : waveguide induction
- No liquid
- Laser diode at high power
- Sample temperature = 40°C

Step 2 : index measurement
- Liquid present
- Laser diode current below threshold
- Sample at ambient temperature

Chauvet et. al., "Integrated optofluidic index sensor based on self-trapped beams in LiNbO3",Appl. Phys. Lett, **101**, 181104 (2012).

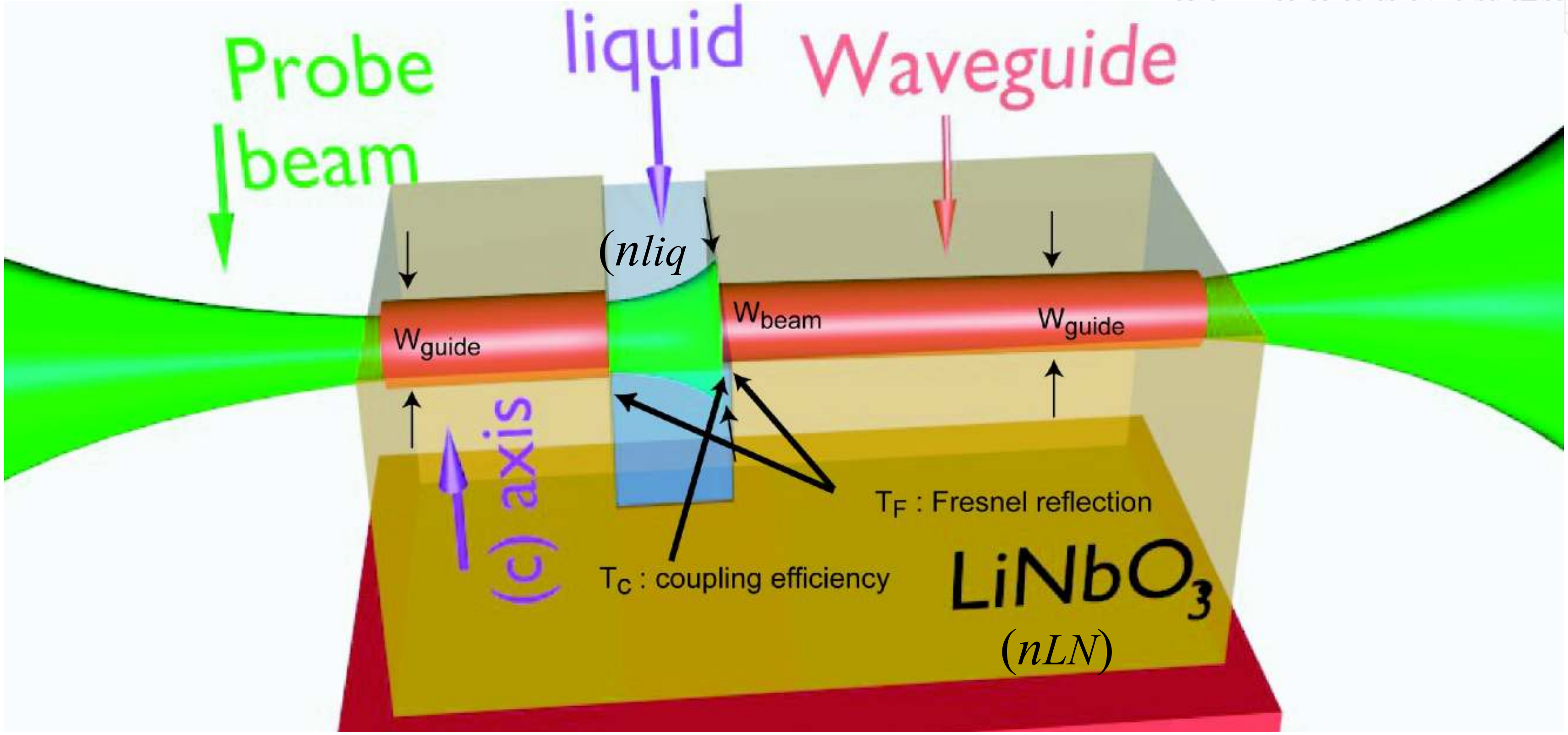
Test of index sensor

Sensor response with ethanol



Evolution of the normalized sensor transmission versus time.

Modeling of index sensor



Fresnel reflections :

$$T_F = \frac{2 n_{LN} n_{liq}}{n_{LN}^2 + n_{liq}^2}$$

Beam diffraction :

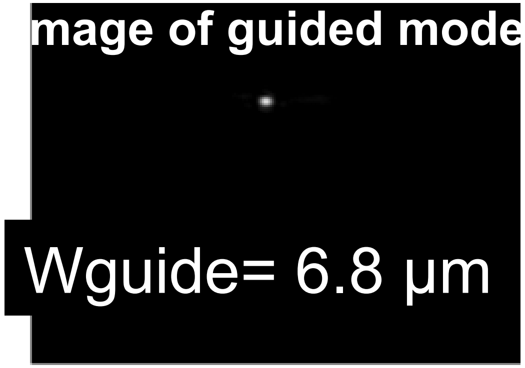
$$T_c = \frac{2 W_{guide} W_{beam}}{W_{guide}^2 + W_{beam}^2}$$

$$W_{beam} = W_{guide} \sqrt{1 + \left(\frac{\lambda_0 L}{\pi n_{liq} W_{guide}^2} \right)^2}$$

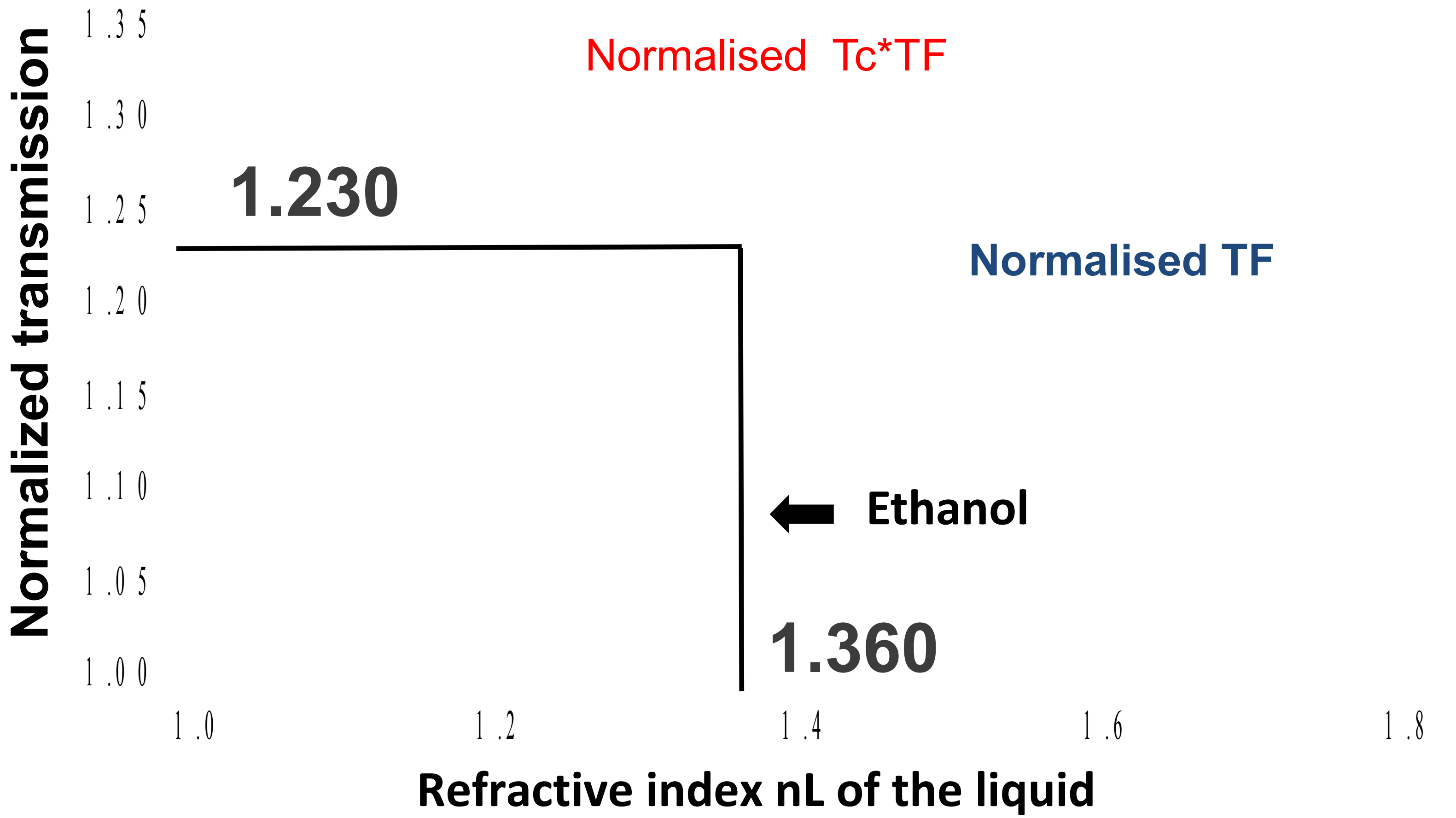
Total gap transmission :

$$T = T_c \times T_F$$

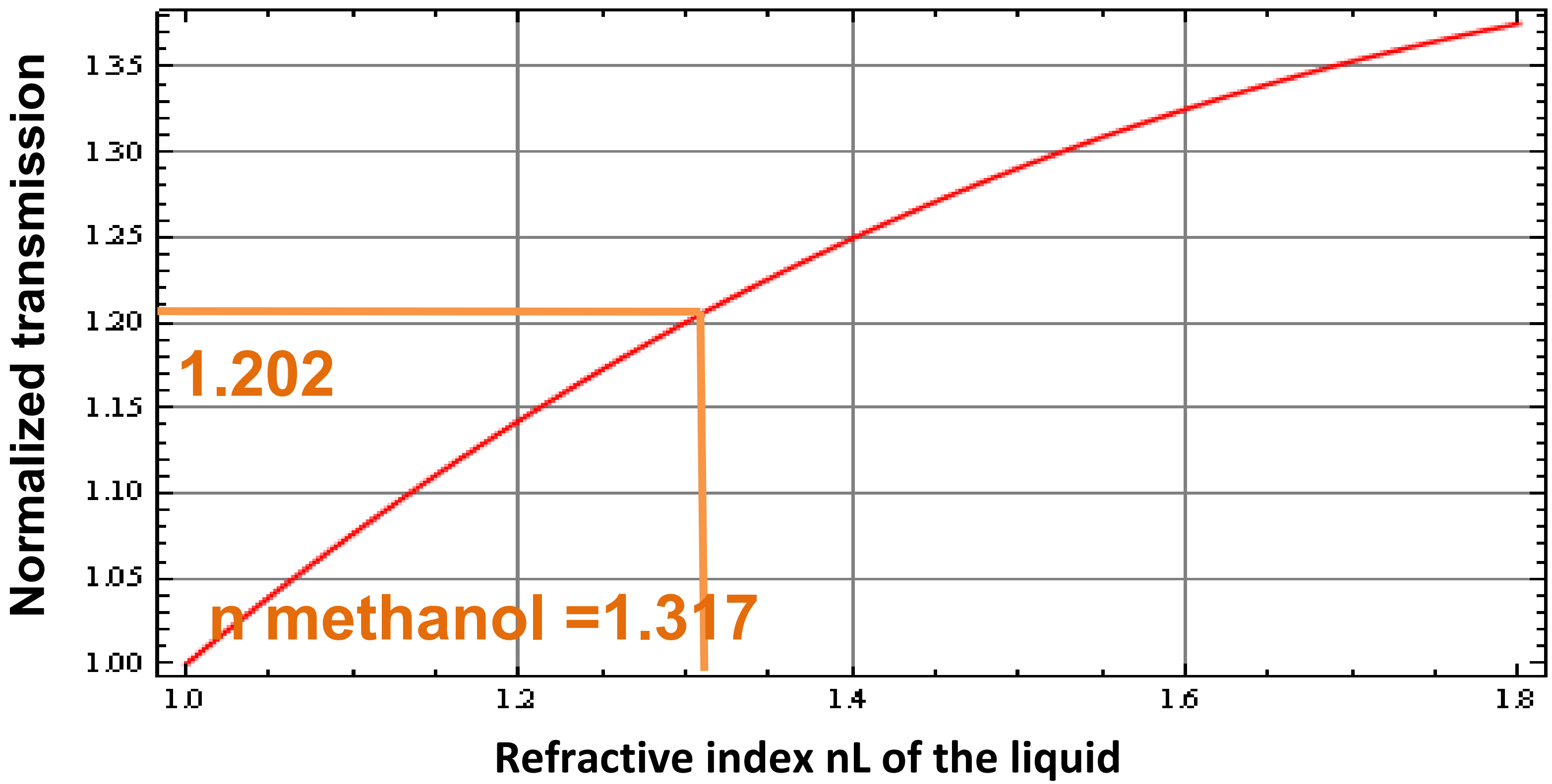
Theoretical response of sensor



Parameters :
L = 200µm,
λ0 = 640nm,
nLN : Sellmeier equation.



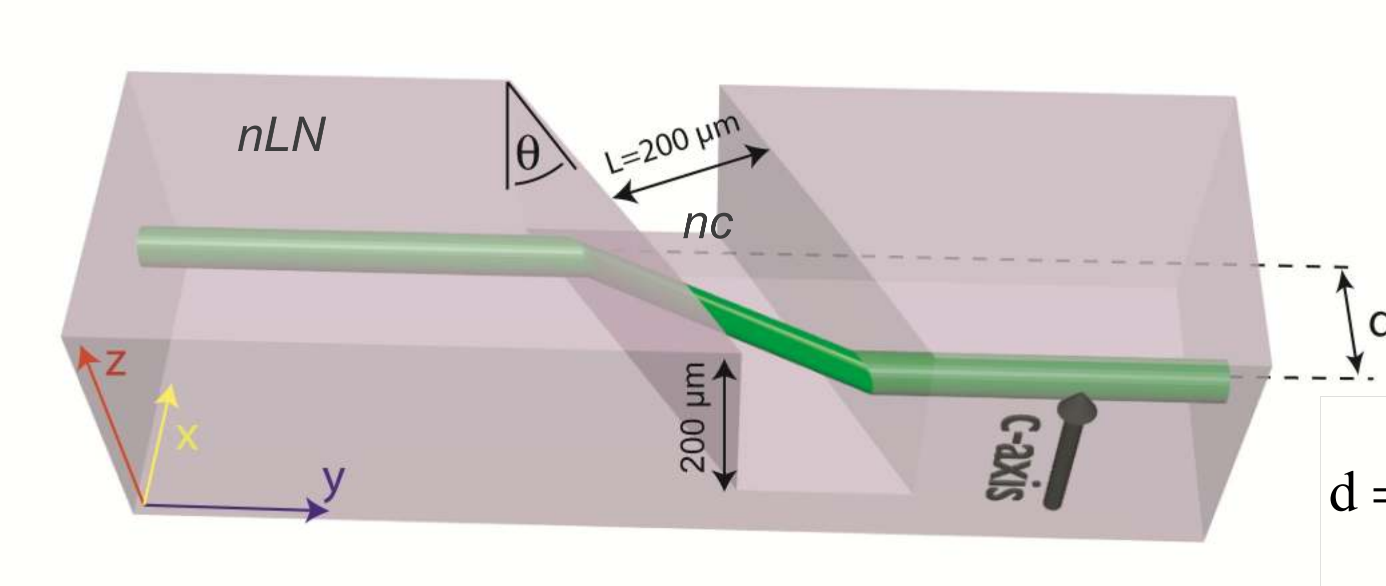
Measurement with methanol



$$n_{meth}^{\exp} = 1.317 \pm 0.005 \longleftrightarrow n^{theo} = 1.320$$

Tilted channels (θ≠0)

Interest : high sensitivity sensors, innovative integrated optics ..

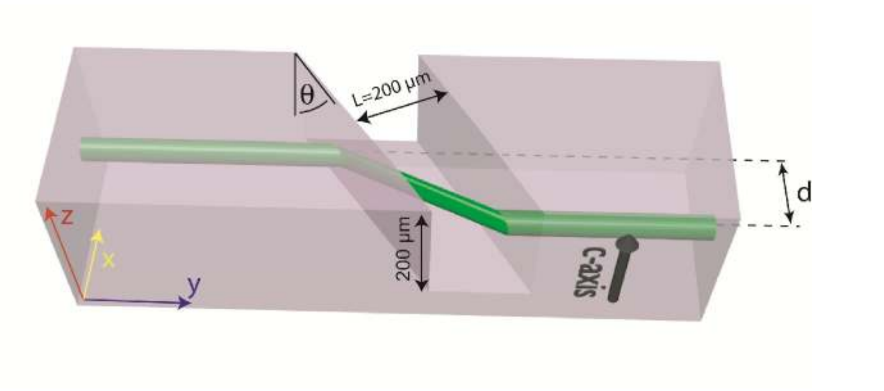


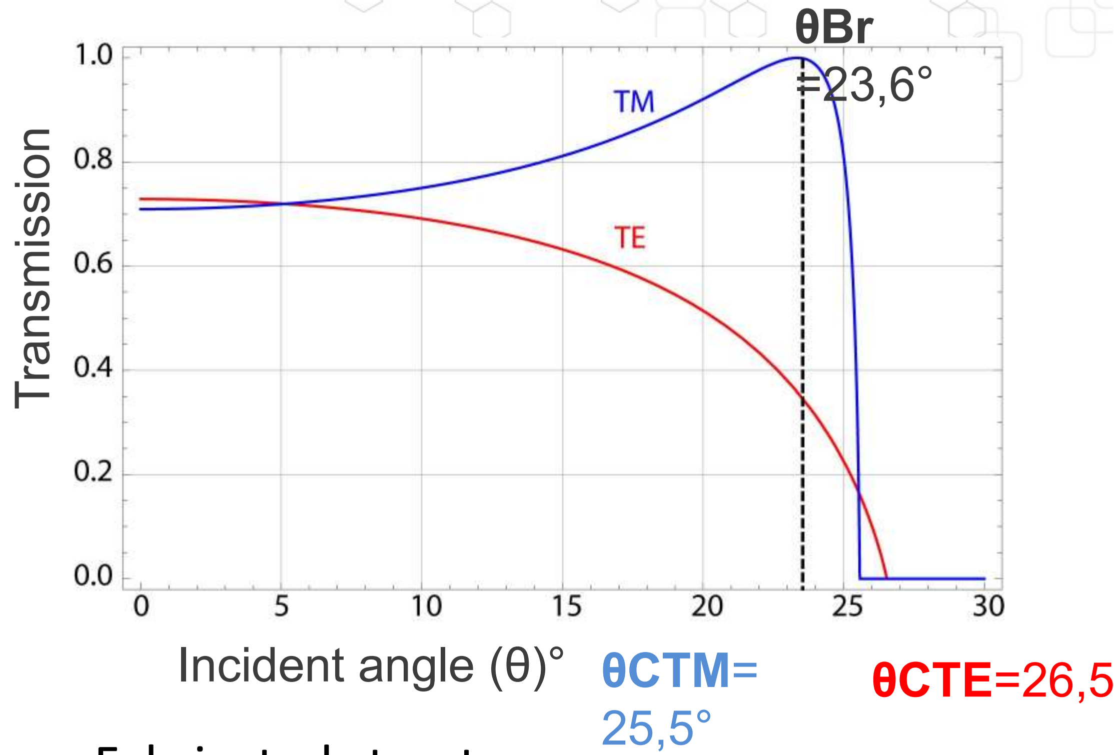
$$d = L\tan\left(\arcsin\left(\frac{n_{LN}}{n_c}\sin\theta\right)\right)$$

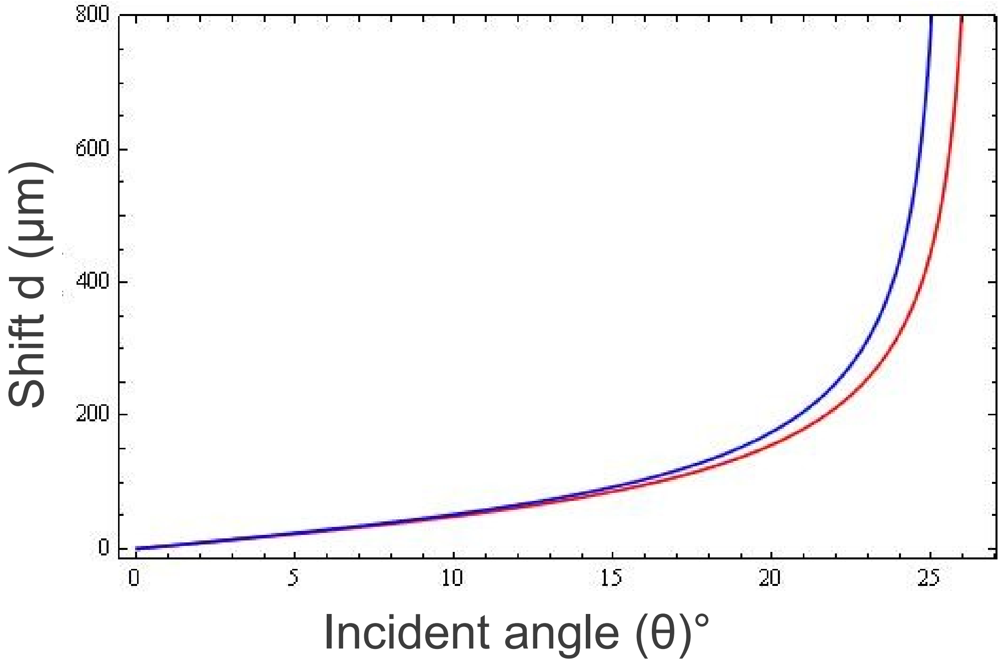
When incident angle θ approach the critical angle

- Beam shift d
- Beam distortion
- Beam transmission T

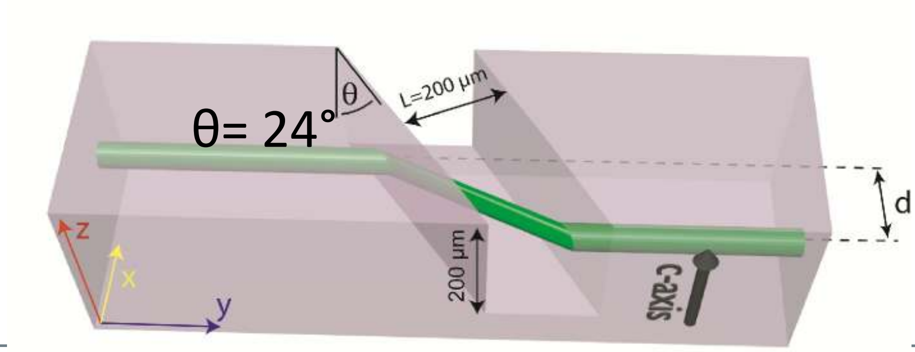
Influence of channel tilt angle







Fabricated structures



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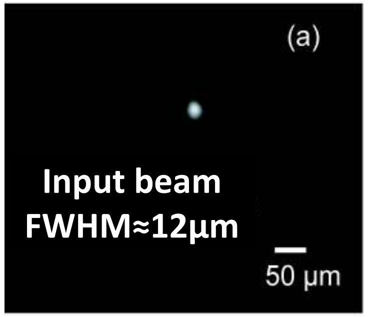
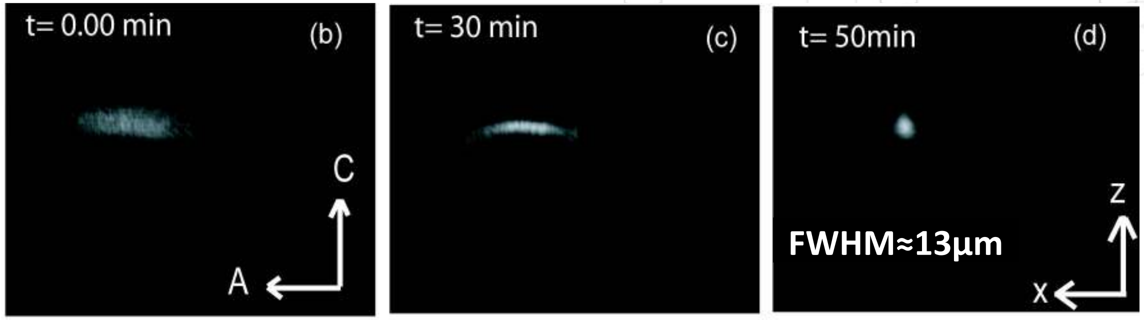
Experimental results

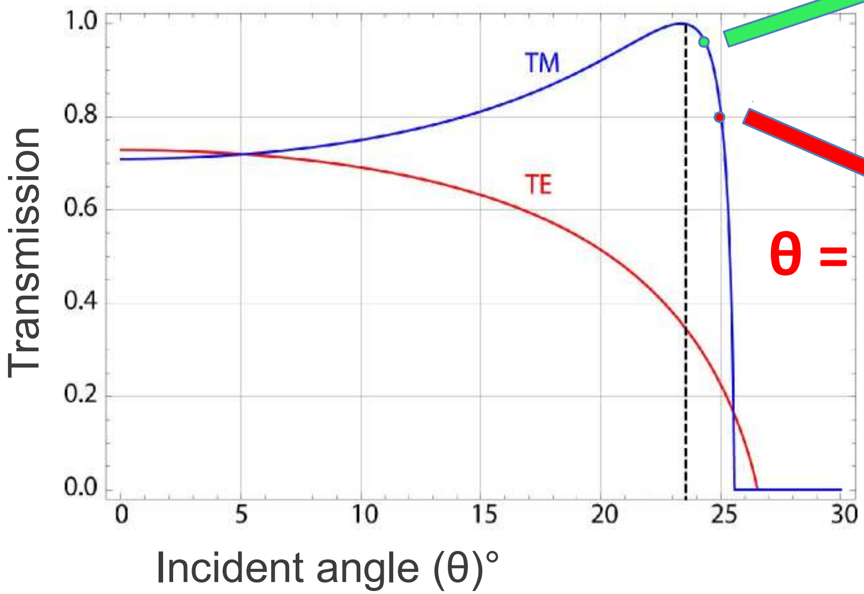
Parameters :
λ = 532nm,
ordinary polarization (TM), P = 20µW, ΔT=20°C





θ = 24,6°

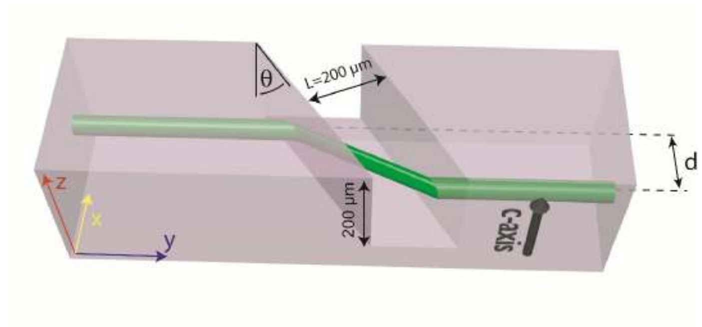
Successful self-trapping

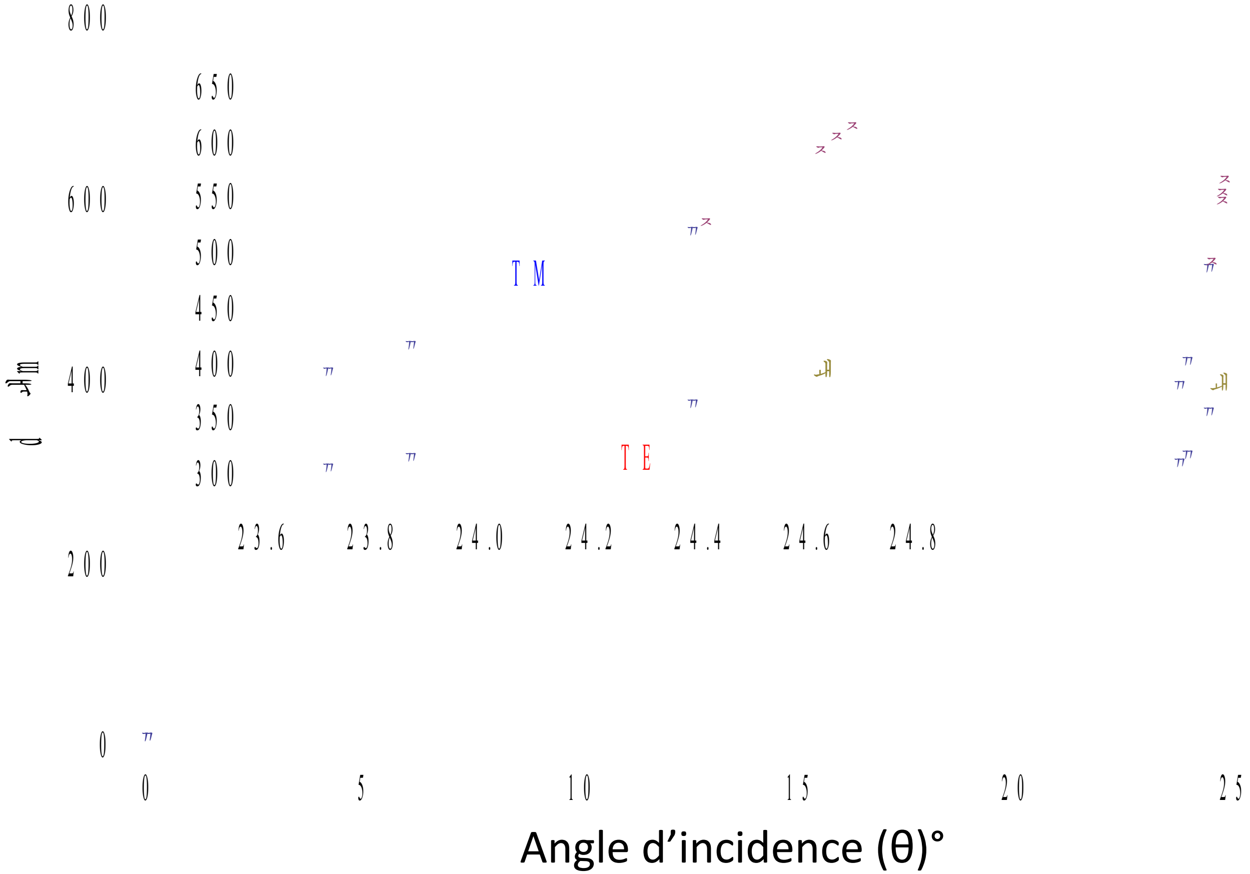


θ = 25°

Unsuccessful self-trapping

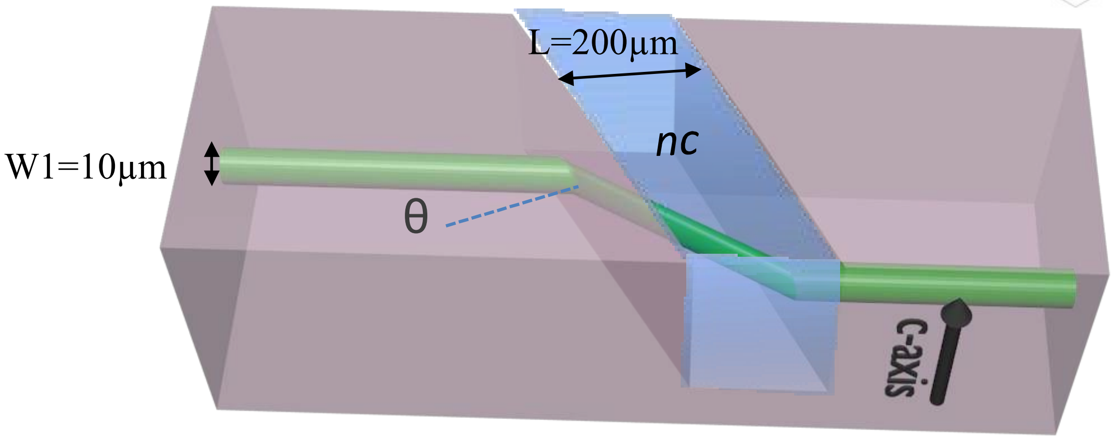
Experimental results





Beam self-focusing is obtained for both TE and TM polarizations for incident angle close to critical angle

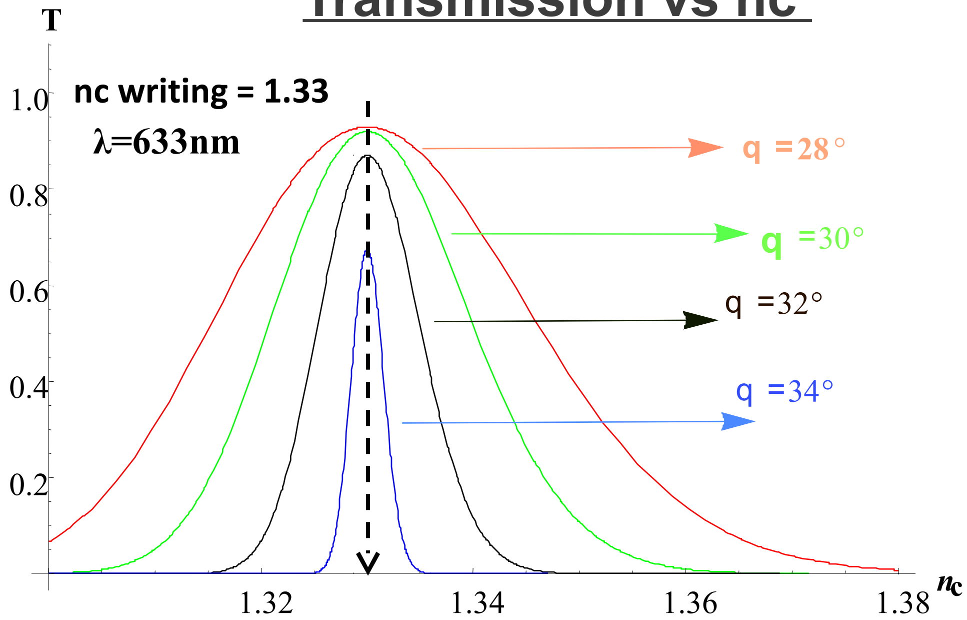
Potential for sensing devices



Fabrication : Waveguide written with ref. liquid

Use : Transmission highly dependent on test liquids index

Sensor sensitivity and span can be adjusted with θ value



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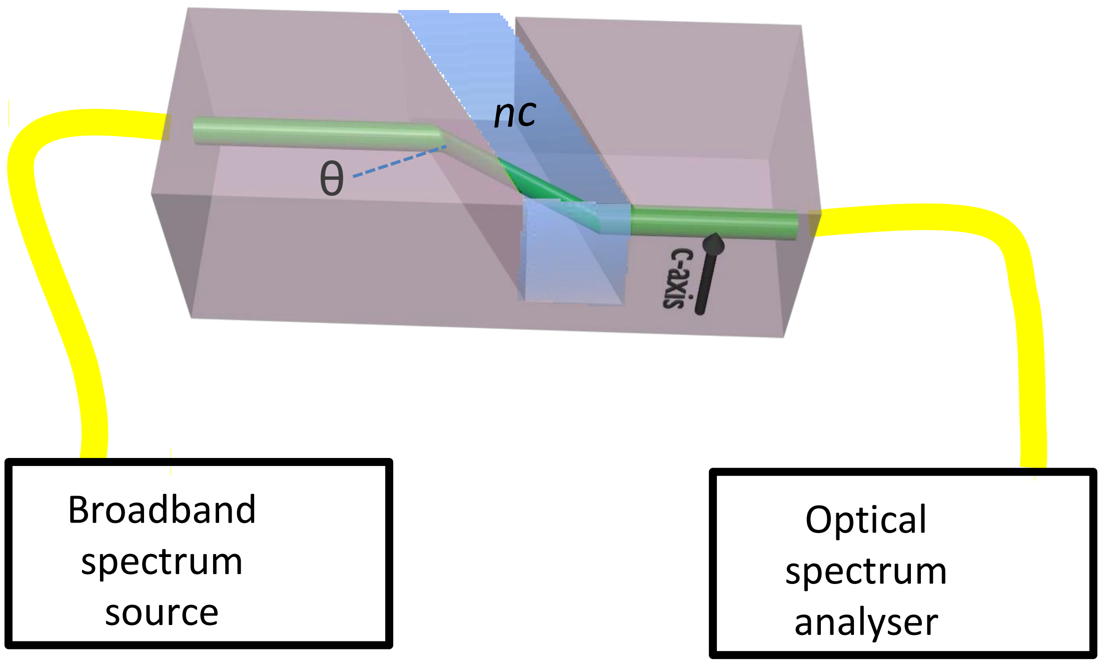
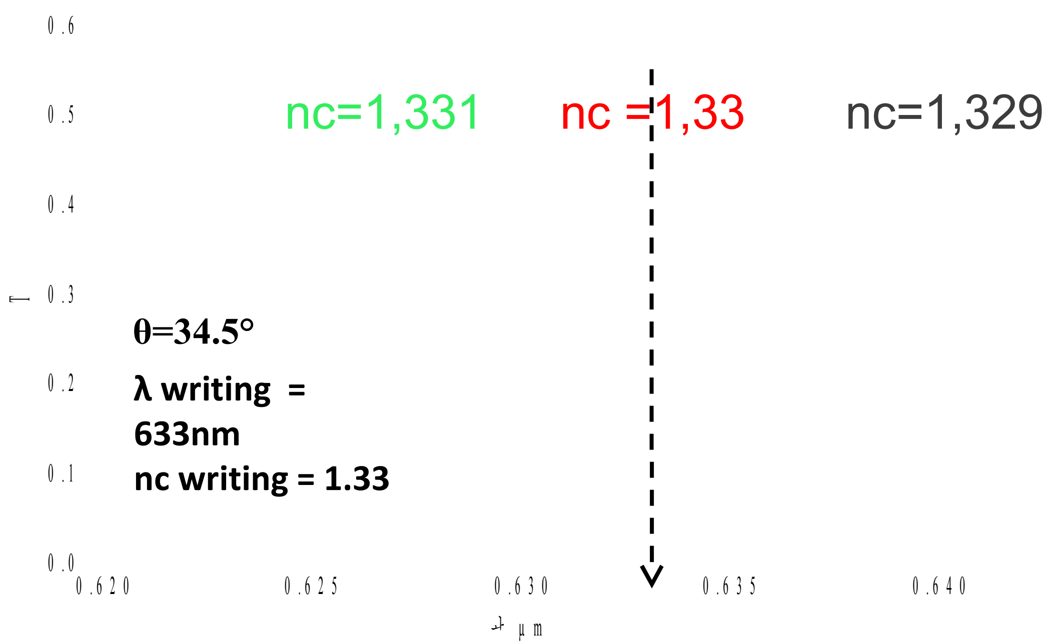
Potential for sensing devices/spectral filters



Transmission fct λ



Index sensor

$$\frac{dn_c}{d\lambda} \approx 10^{-4} / nm$$

Sensitivity can reach 10-6

Spectral filter

- Spectral width adjustable with θ
- Central wavelength tunable with fluid

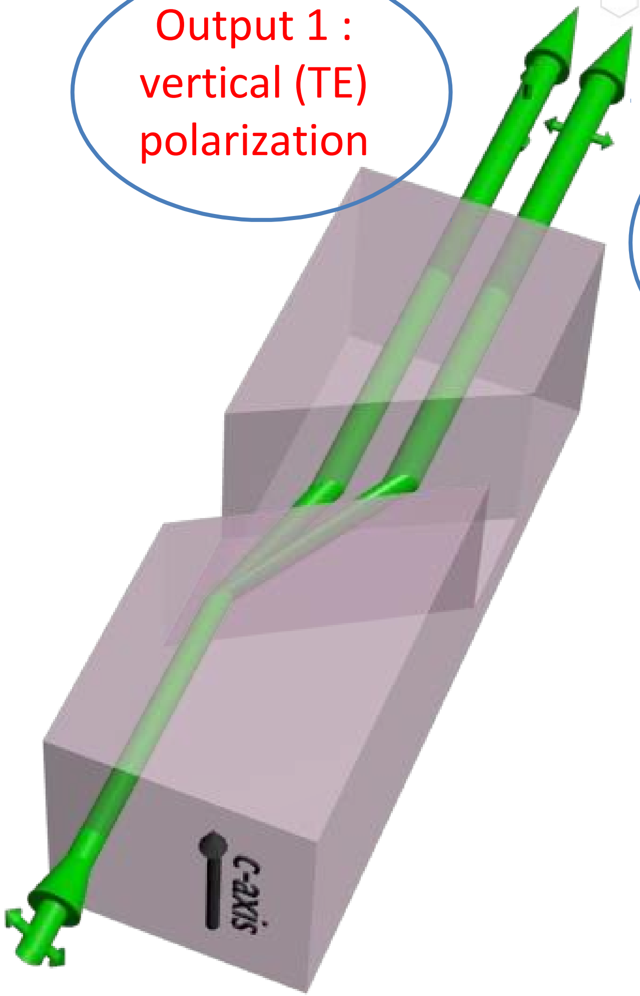
Potential for integrated optical components

Beam shift d depends on polarization !

Material birefringence can be used to design an **integrated polarization separator :**

Output 1 : vertical (TE) polarization

Output 2 : horizontal (TM) polarization

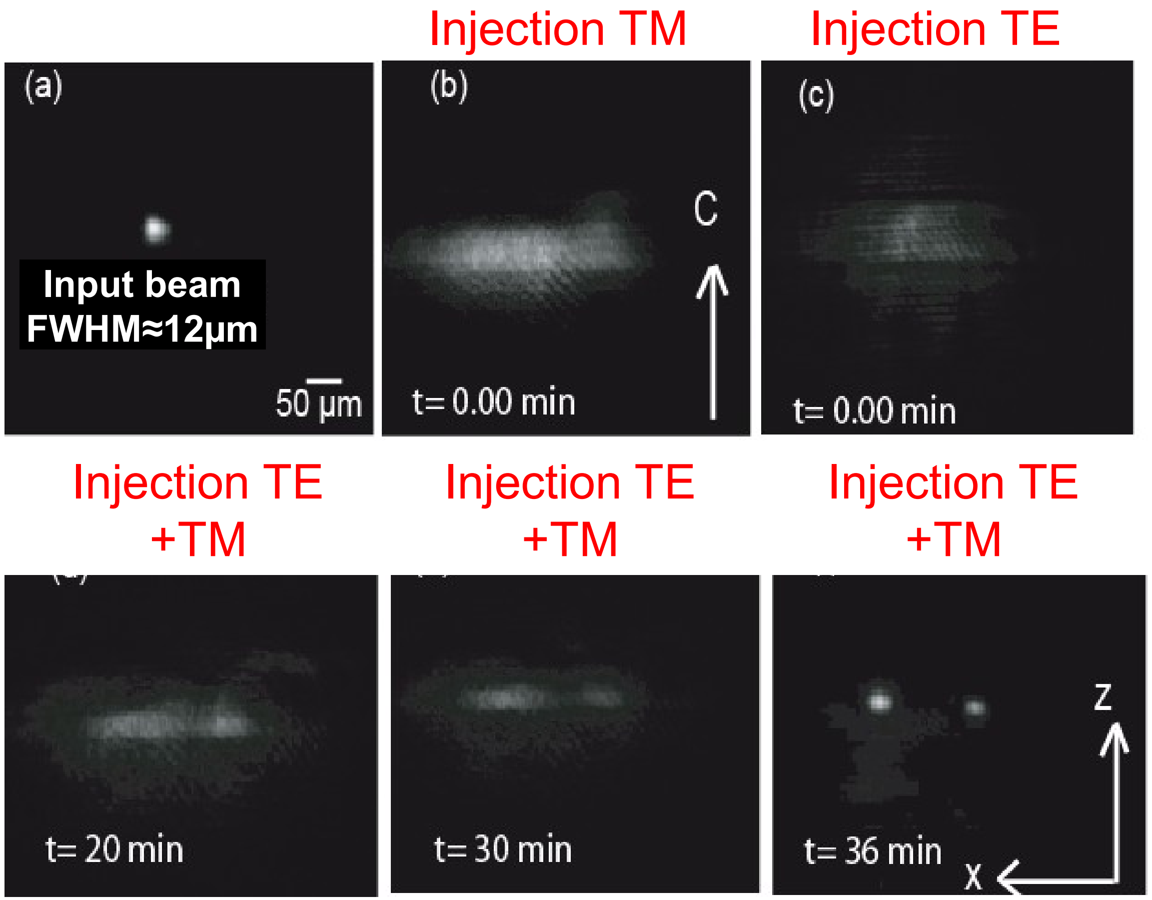


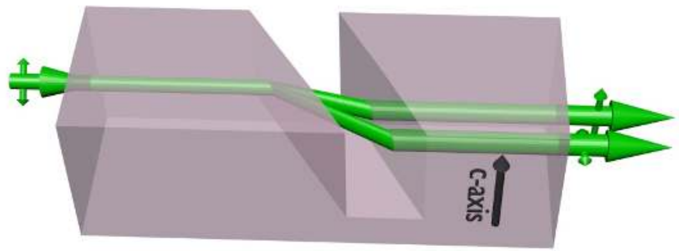
Input arbitrary polarization

Al Fares et. al., Self-trapped beams crossing tilted channels to induce guided polarization separators",Appl. Phys. Lett, **103,** 041111 (2013)

Fabrication of a polarization separator

Parameters :
λ = 532nm,
P= 20µW,
θ = 23.9°
ΔT=20°C



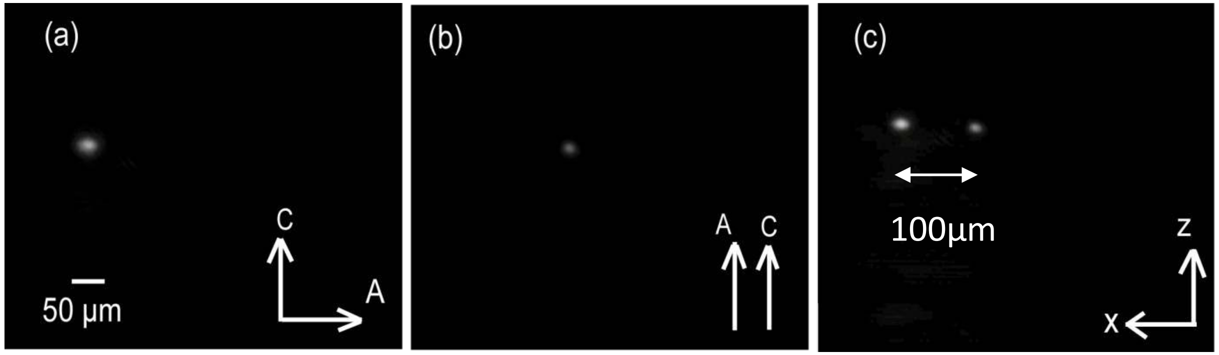


The polarization separator is inscribed in a one step self-writting process.

Test of polarization separator

Input polarization TM TE TM+TE

Detected intensity



Properties of component :

- **Extinction ratio TE/TM > 20db**
- **Transmission 68% for TM et 25% for TE**

Conclusions

- ❑ **Ability of self-trapped beams to induce unique automatically adapted buried waveguides crossing channels have been demonstrated**

- ❑ **Integrated components based on LiNbO3 have been fabricated**
  - **Index sensor**
  - **Integrated polarization separator**

Perspectives

- ❑ **More elaborated devices taking advantage of self-aligned waveguides can be developed :**
  - **High sensitivity sensors, tunable filters, couplers to optical resonators**

- ❑ **Use of other materials such as photopolymers (low cost and permanent structuring)**