Tunable Fabry-Pérot cavities for the interrogation of Fiber Bragg Gratting sensors

June, 5th 2015, Pisa University

Matthieu Gosselin, PhD cyclo XXX

Summary

- Fiber Bragg Gratting
- Light filter : Fabry-Pérot Cavity
- Liquid crystal filters
- Electro mechanic filters
- Conclusion

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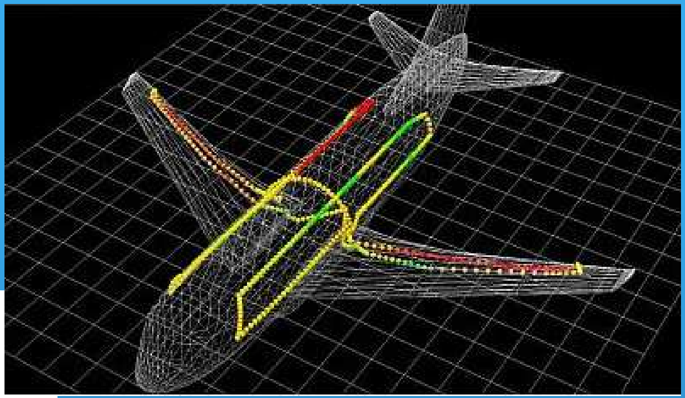
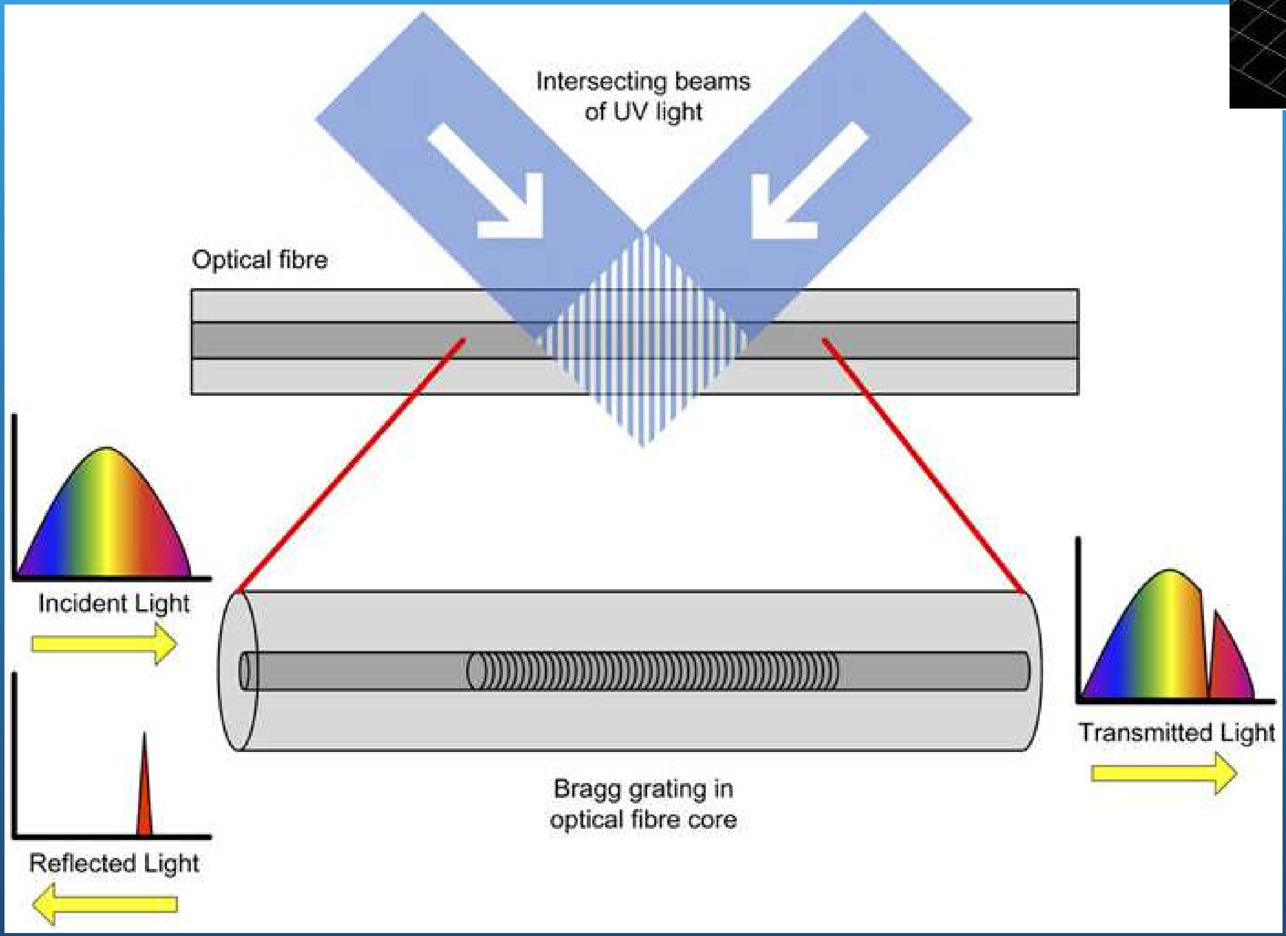
Fiber Bragg Grating



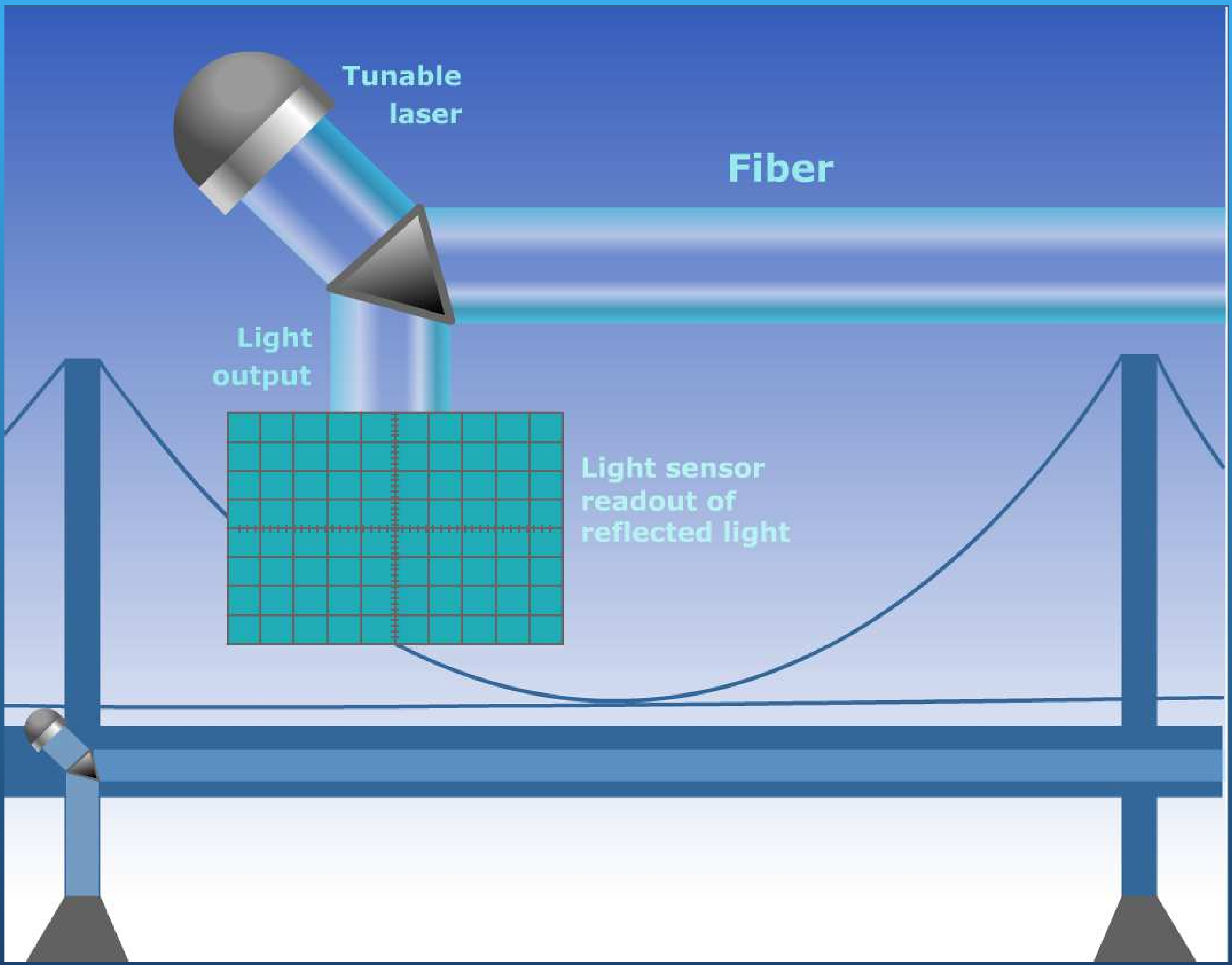


Reflected wavelength depends on:

- The refractive index
- The number of layers
- The thickness of the layers

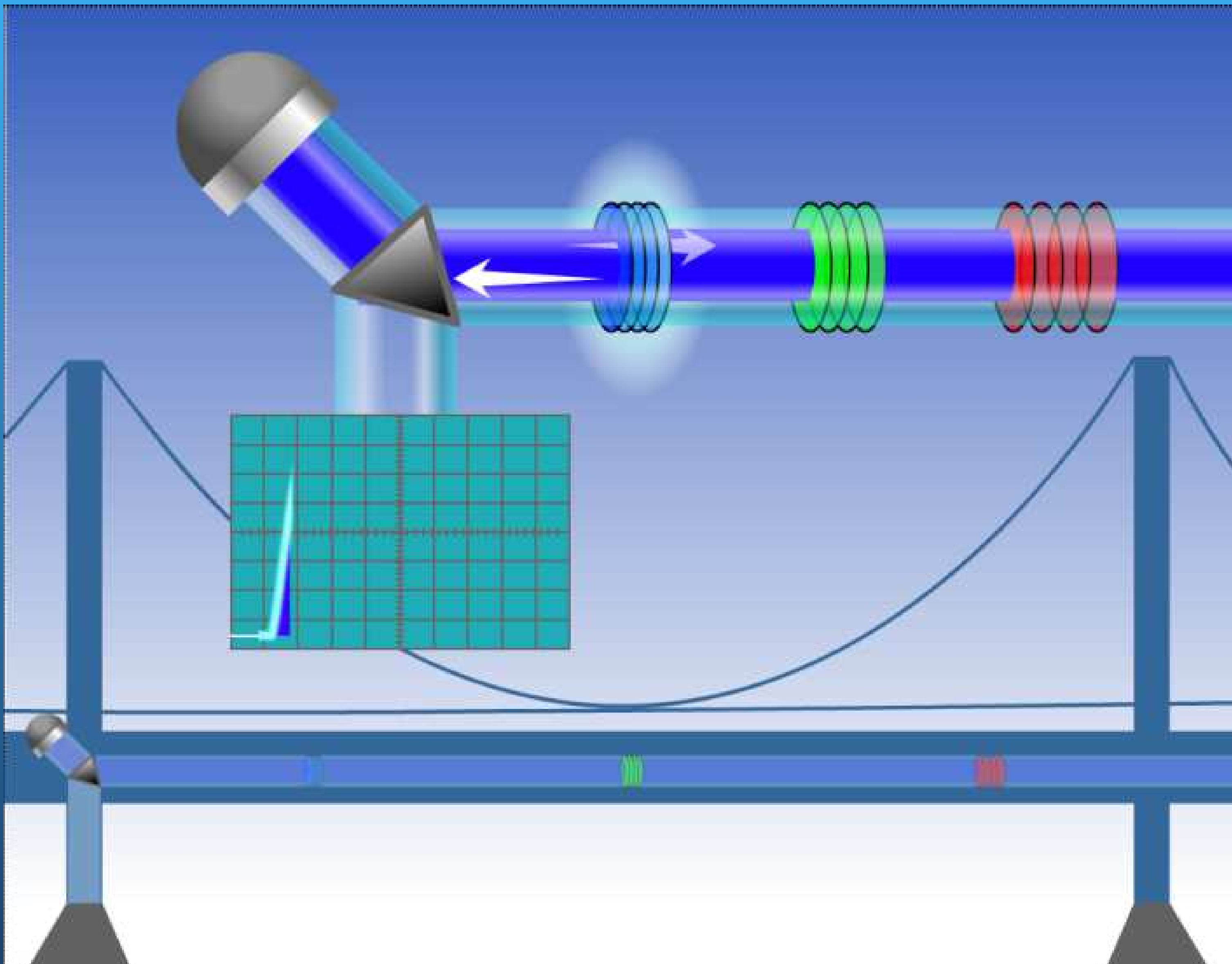
Ian Johnson, David Webb Aston University Birmingham, UK

Fiber Bragg Grating



Credit: Zina Deretsky, National Science Foundation

Fiber Bragg Grating



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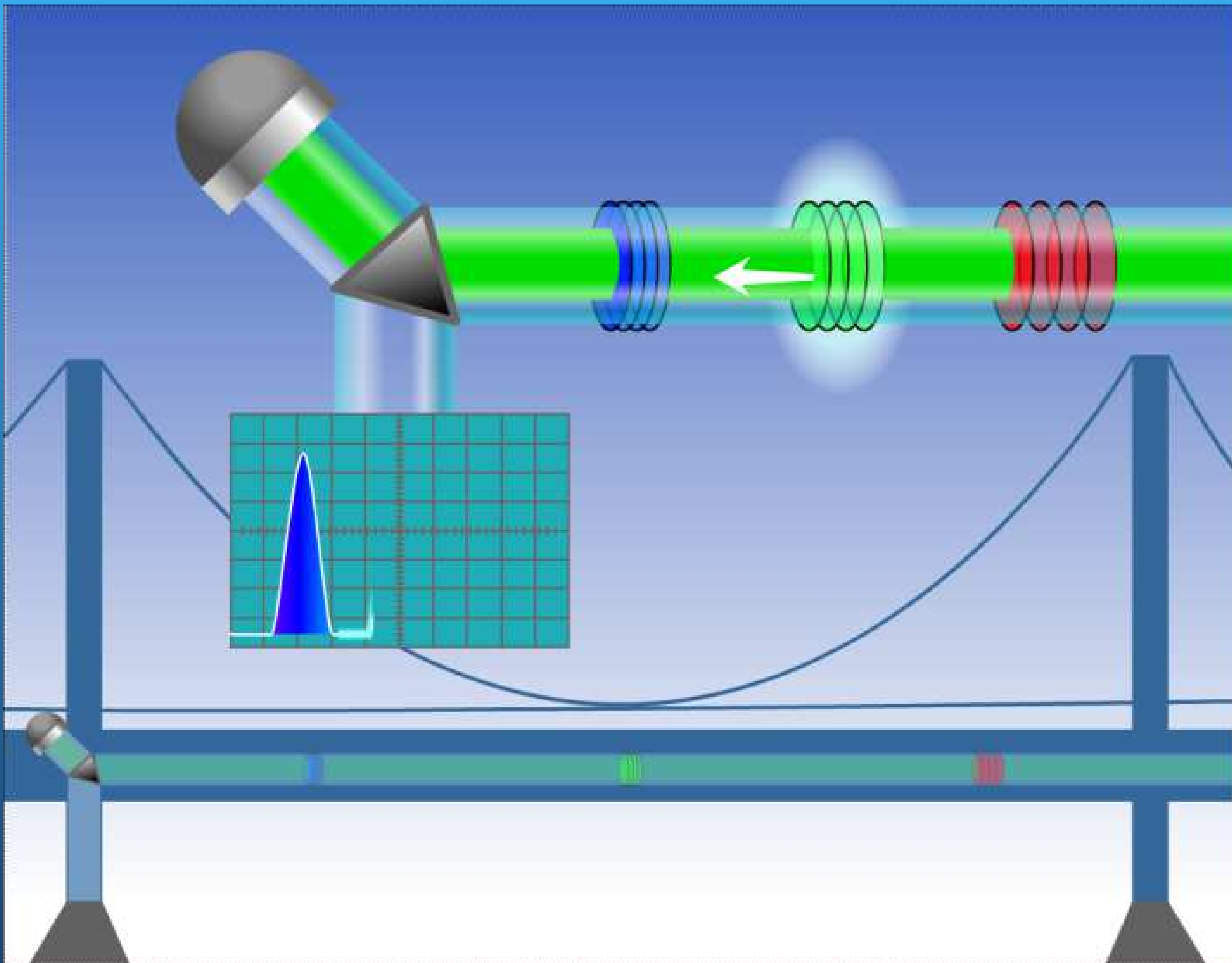
Fiber Bragg Grating



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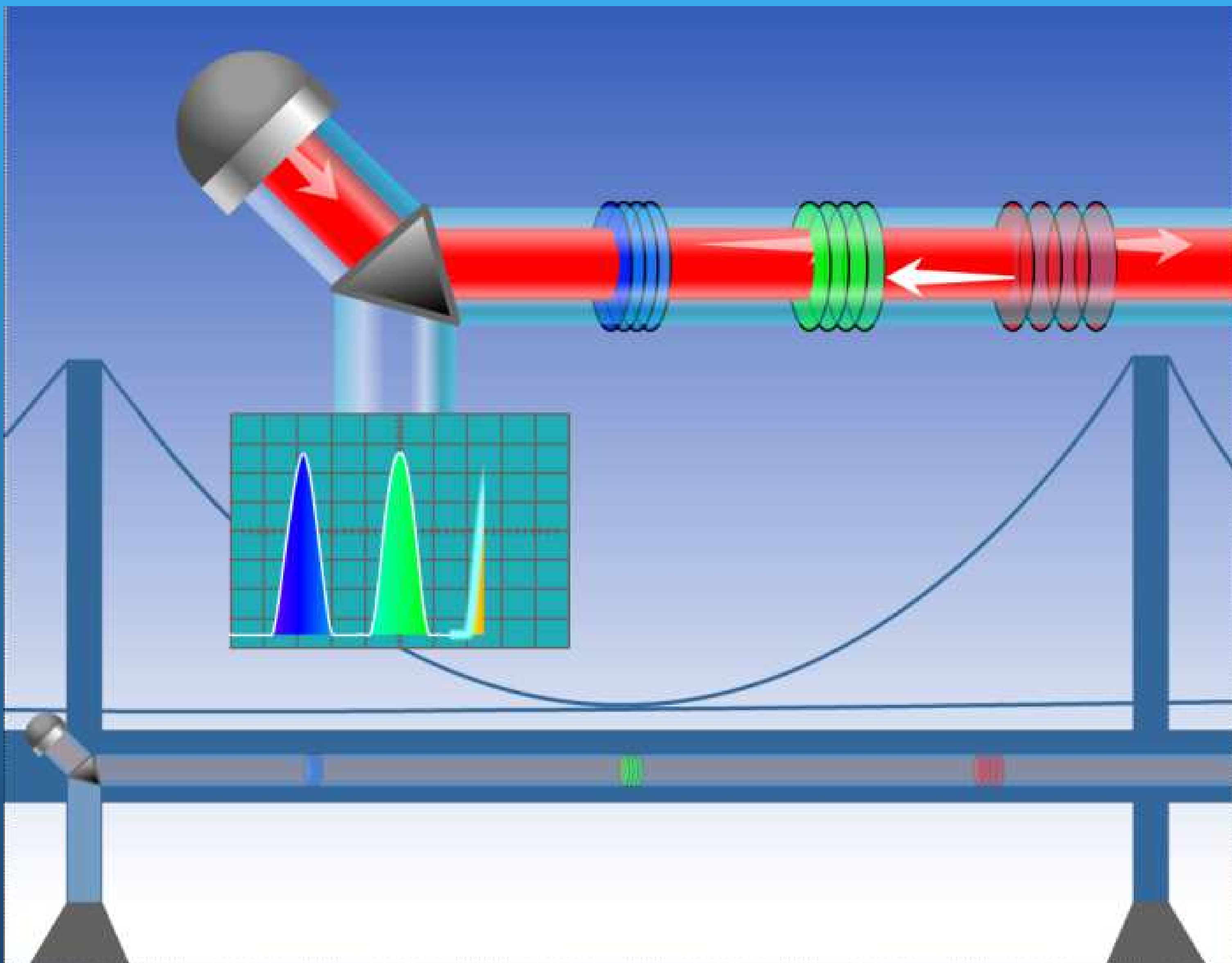
Fiber Bragg Grating



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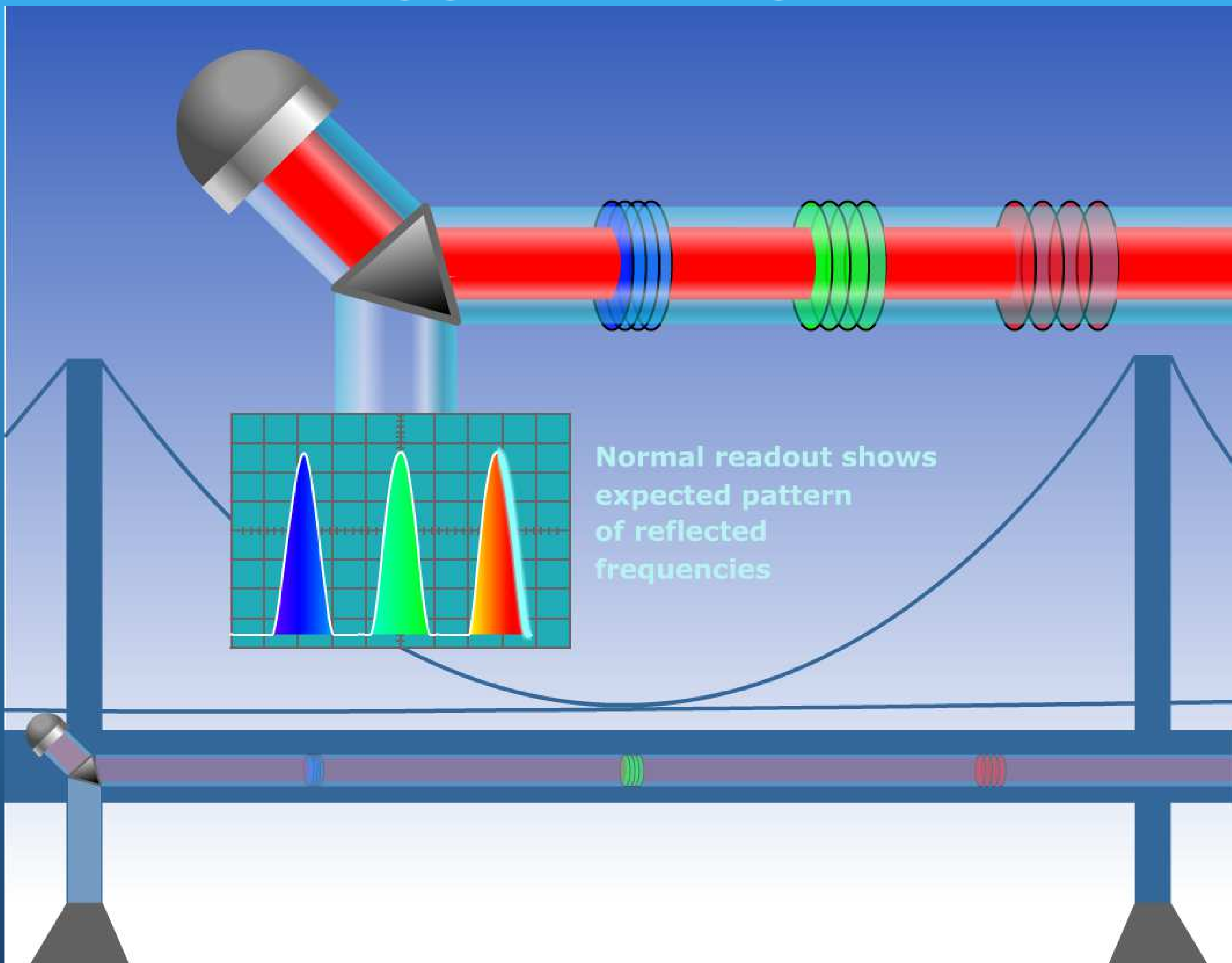
Fiber Bragg Grating



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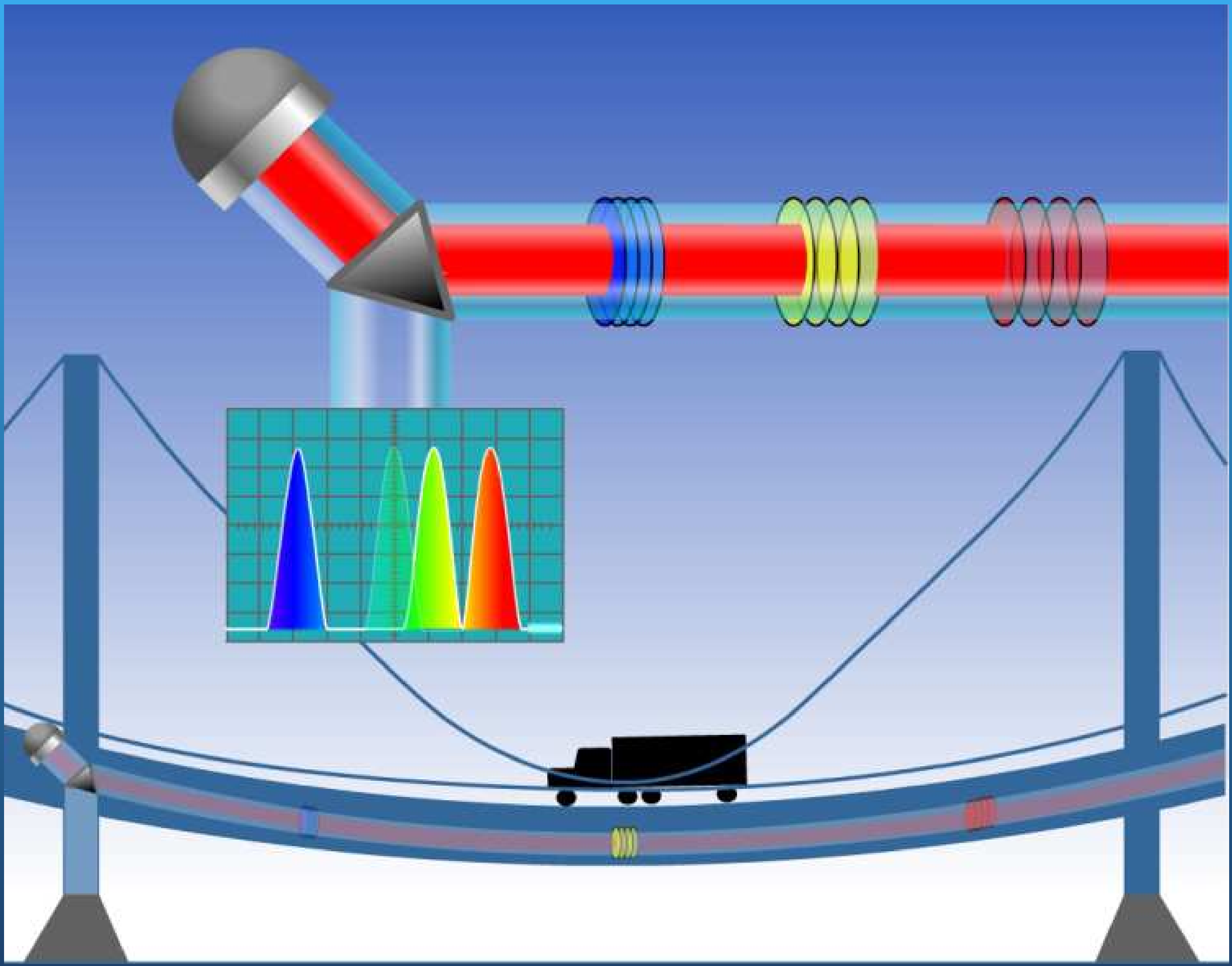
Fiber Bragg Grating



Credit: Zina Deretsky, National Science Foundation

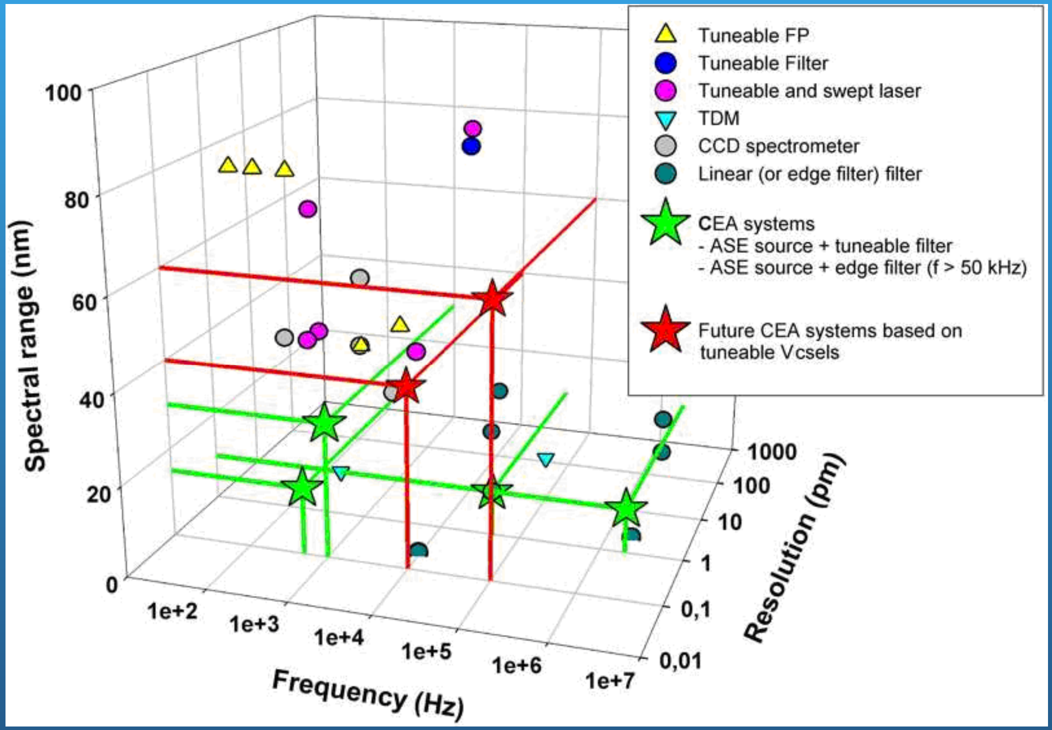
Need for a tunable light source

<u>Main criteria</u>

- Spectral range
- Frequency
- Resolution

<u>But also :</u>

- Price
- Ease to build
- …



➢ Find a compromise

Summary

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Fabry-Pérot Cavity

Constructive interferences between two partially reflective surfaces

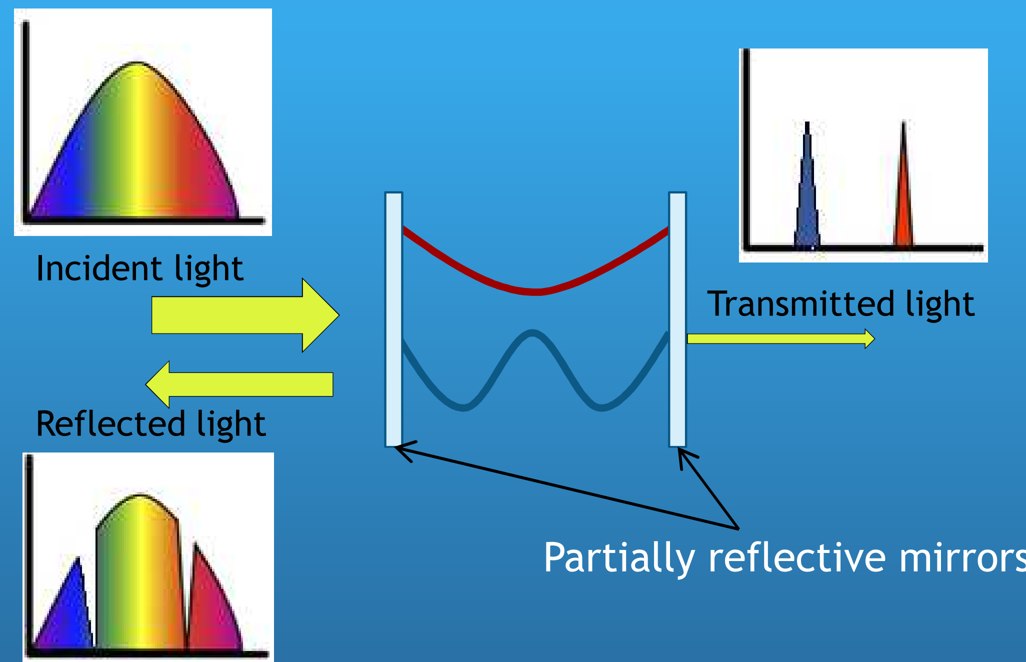
Passing wavelengths :

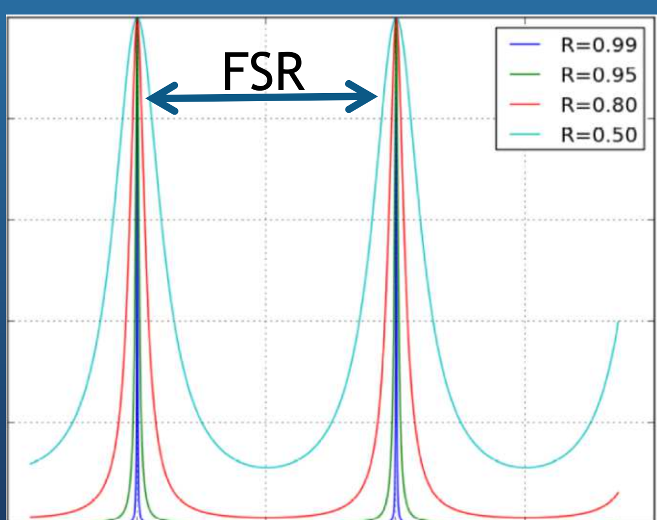
$$\lambda_k = \frac{2nL}{k}$$

n : refractive index intra-cavity

L : cavity thickness

k : integer number





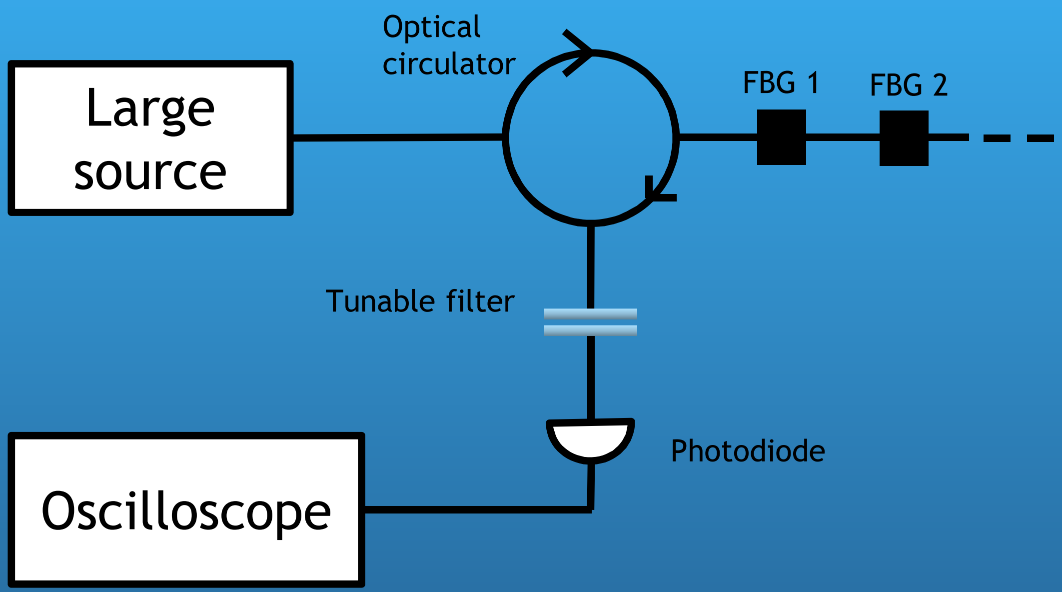
$$FSR = \frac{\lambda^2}{2nL}$$

$$Finesse = \frac{FSR}{FWMH}$$

- The smaller the thickness, the higher the FSR

- The higher the reflectivity, the higher the finesse

Fabry-Pérot Cavity



- Large source is cheaper
- Filter are cheap to build

- Analyzing a time response and not a spectral response

=> Faster than spectrometer
=> Need to perfectly know the response of the tunable filter

Tuning the passing wavelengths: $$\lambda_k = \frac{2nL}{k}$$

=> Changing the refractive index : liquid crystal properties
=> Changing the length of the cavity : electro-mechanics forces

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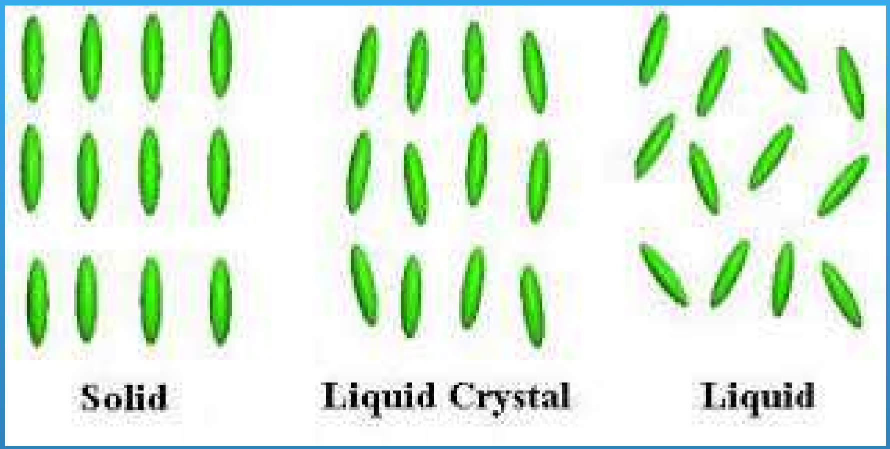
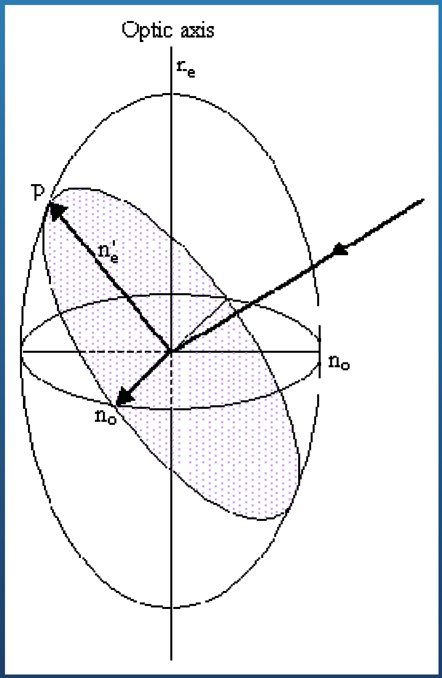
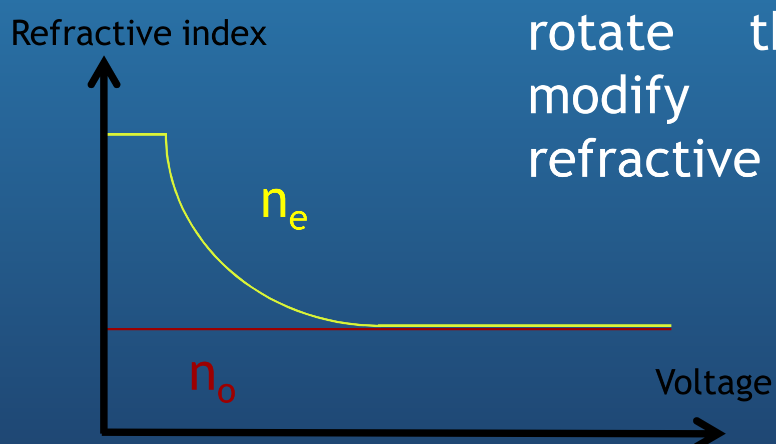
Liquid crystal



Structure between the solid and the liquid

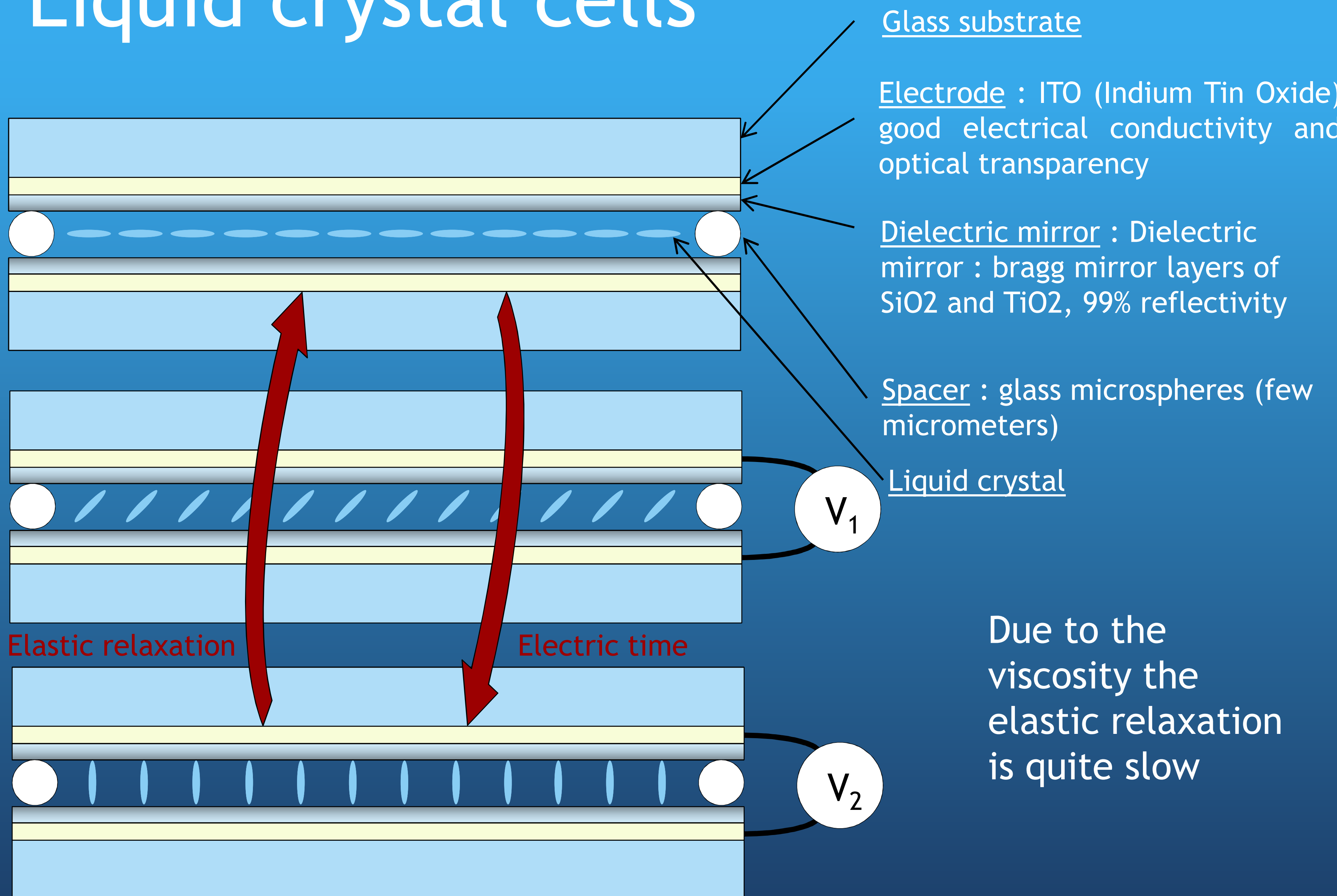
Depending on its polarization the light can see different refractive index : ordinary and extraordinary





By applying a voltage, we can rotate the molecule and modify the extraordinary refractive index

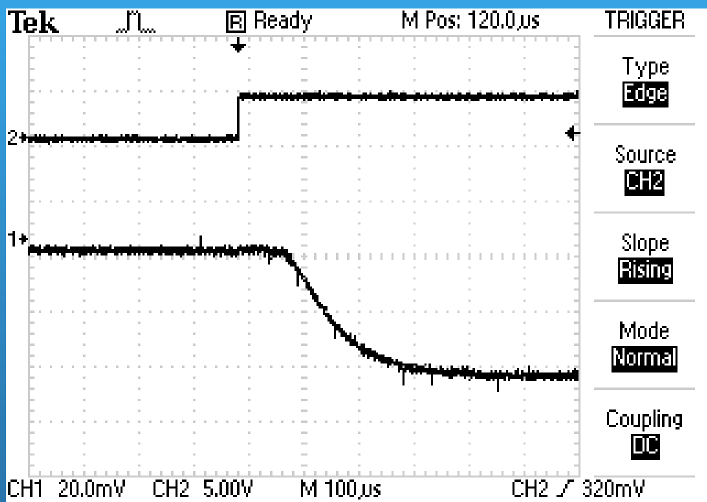
Liquid crystal cells



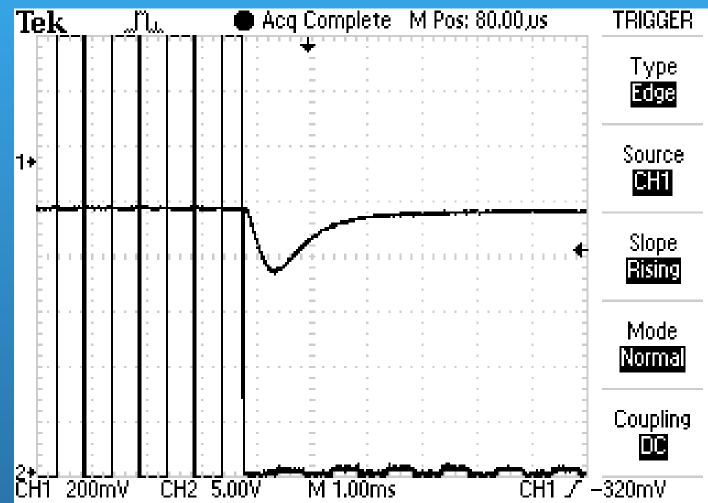
Due to the viscosity the elastic relaxation is quite slow

Results : frequency

Electric time : 300 µs



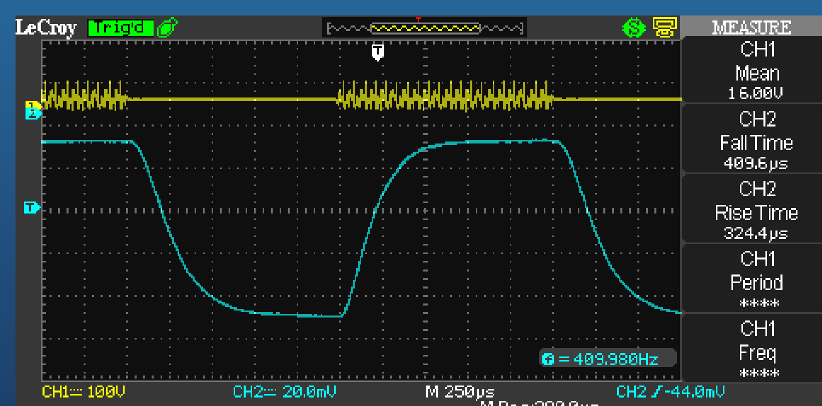
Elastic time : 2 ms



=> Limited by the elastic relaxation, f ~ 500Hz

Improvements :

PSLC : Polymer Stabilize Liquid Crystal, polymer structure to constraint the molecule and improve the elastic time



Best frequency obtained : 7kHz

Results : spectral range

Depends on the birefringence of the liquid crystal

$$\frac{\Delta\lambda}{\lambda} = \frac{\Delta n}{n_e}$$

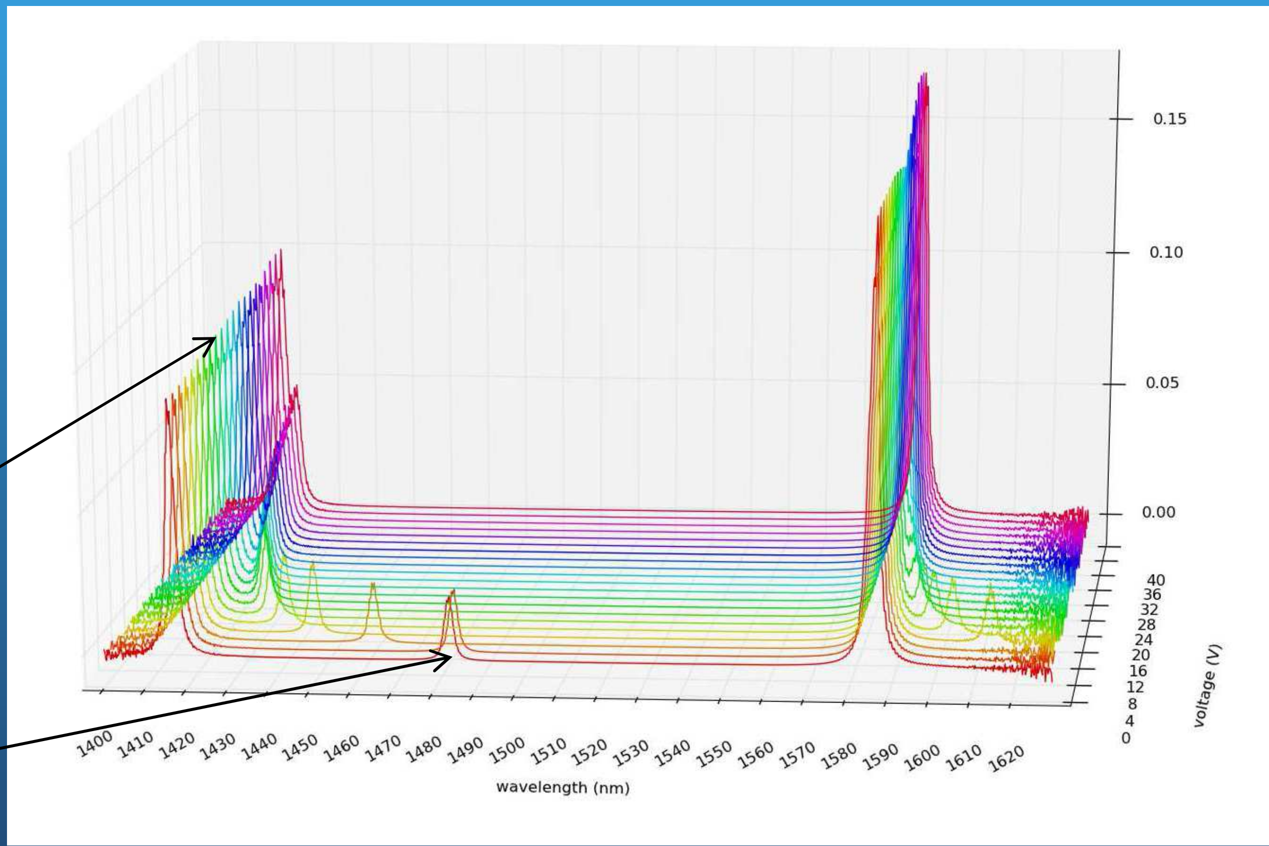
<u>Liquid Crystal E44</u>

$n_o = 1.51$
$n_e = 1.65$

Spectral range
~ 150nm

Ordinary peak

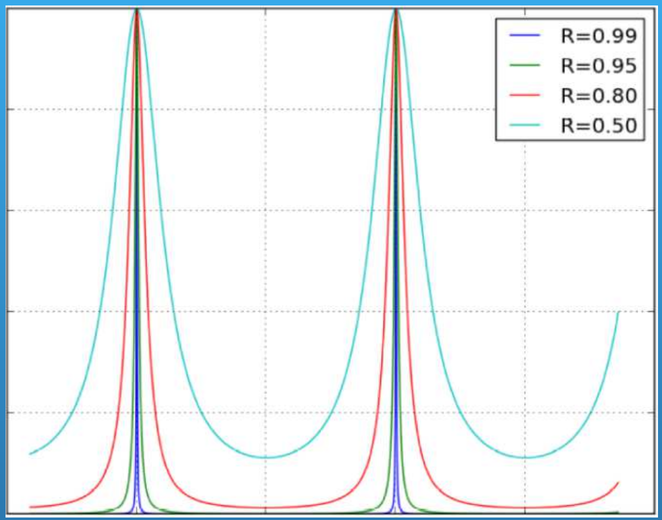
Extraordinary peak



With PSLC : 70nm

With pure liquid crystal : 145nm

Results : resolution



$$Finesse = \frac{FSR}{FWMH} \approx \frac{\pi R^{1/2}}{1-R}$$

- Losses intra cavity due to the absorption of the liquid crystal, lower finesse

- Losses increased with the polymer structure

With PSLC : 2nm

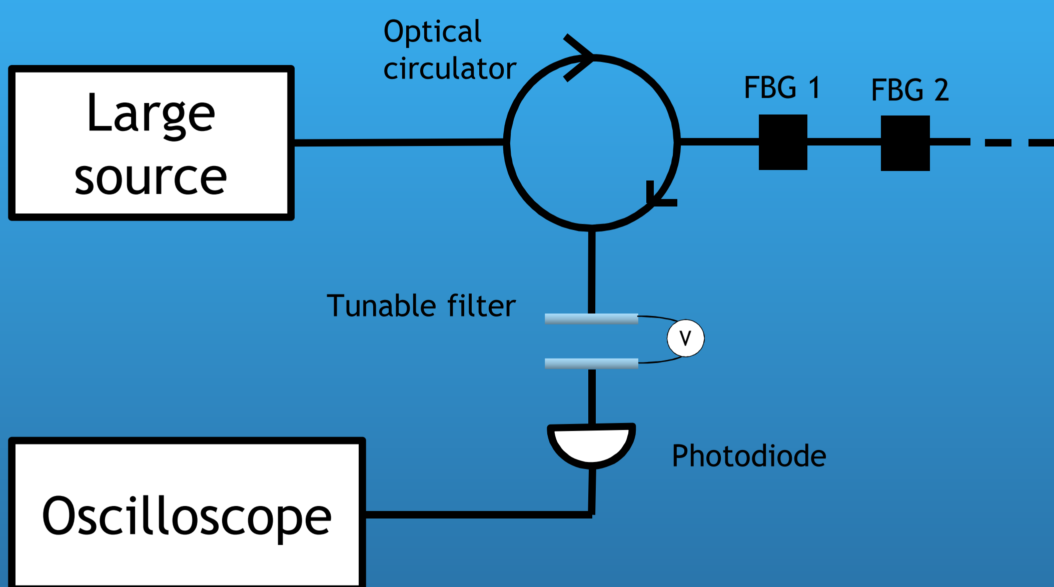
With pure liquid crystal : 500 µm

Filters characteristics

Cell	E44 PSLC	E44	MLC21-57
Spectral range (nm)	70	145	100
Frequency (kHz)	7	0.5	1
Resolution (nm)	2	1	0.5
Losses	Medium	Low	Low

=> Different filters for different applications

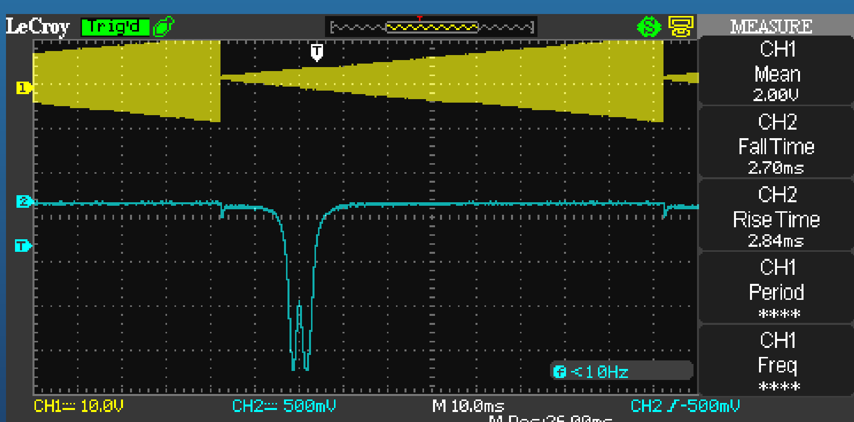
Results in the final set-up



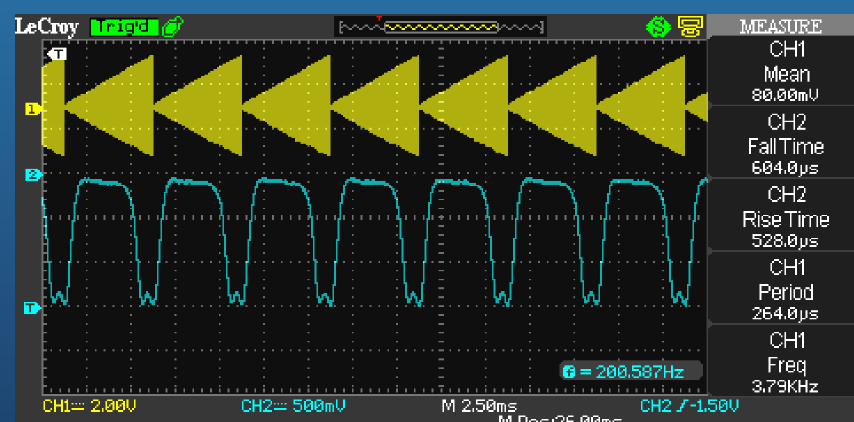
Increasing the voltage:

If the detection time of the peak changes, the corresponding FBG is under constraint

=> 1nm difference beween FBG1 et FBG2 can be distinguished at 200hz



1 Hz



200 Hz

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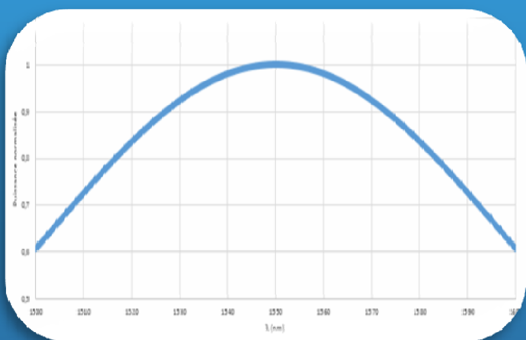
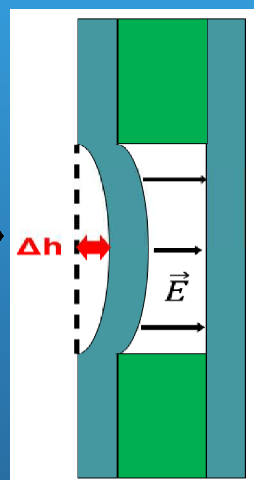
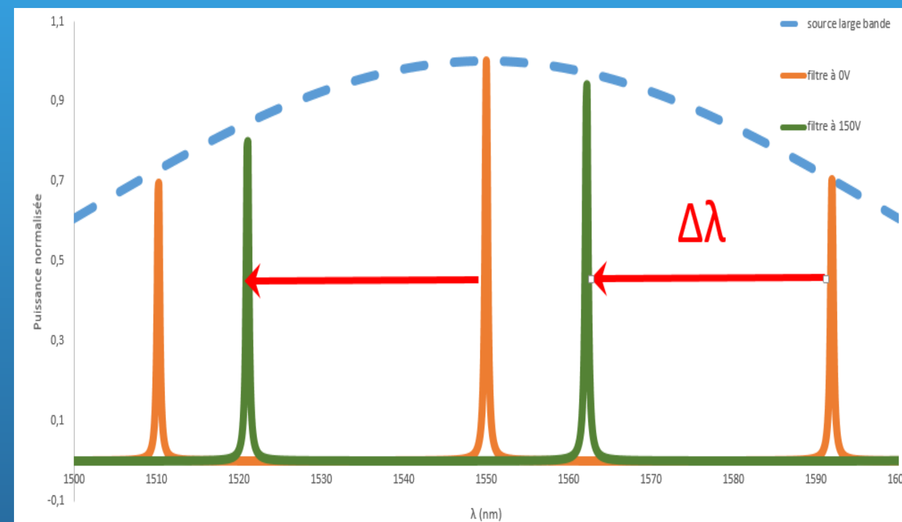
Glass membrane resonance

Electrostatic force between the two membranes

Incident light



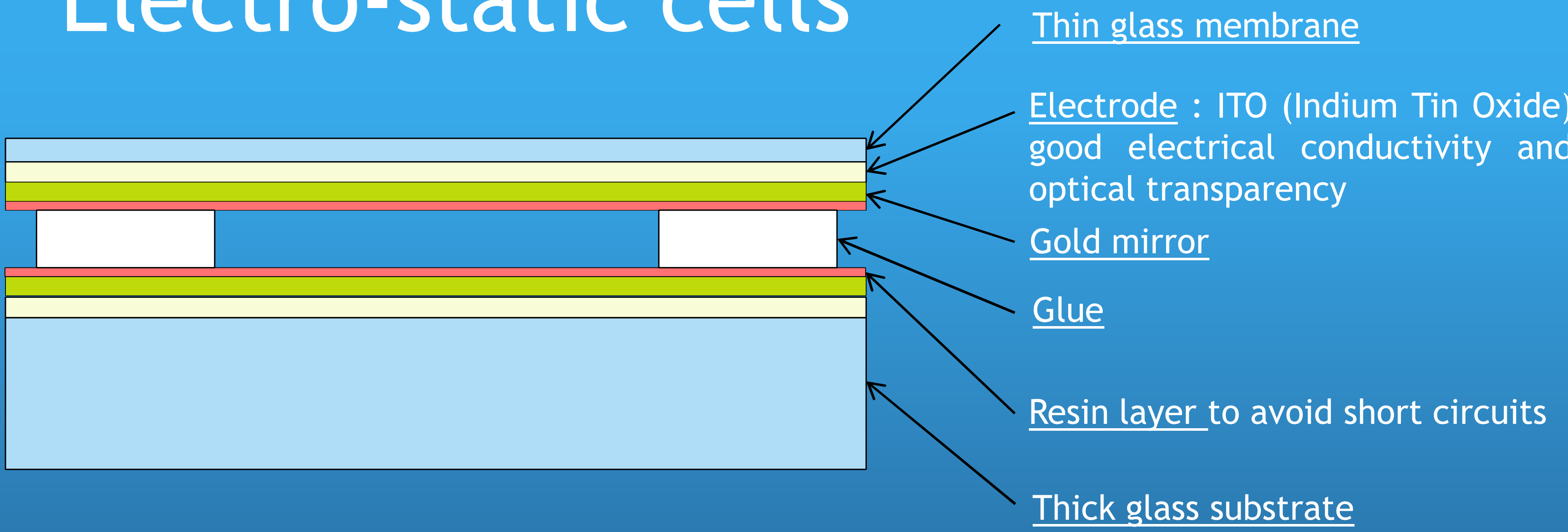


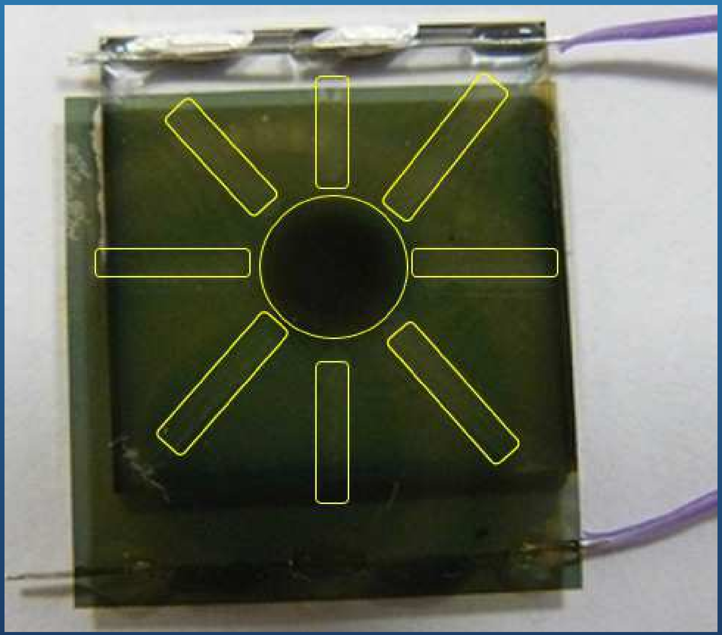


Spectral range:

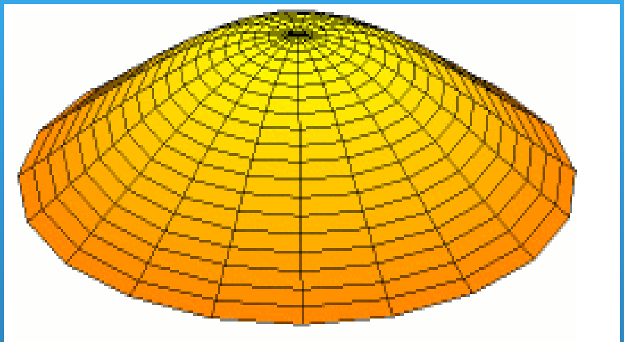
$$\Delta\lambda = \frac{\lambda * \Delta h}{h}$$

Electro-static cells





Glass membrane resonance



- E Young modulus
- v Poisson coefficient
- d Membrane diamater
- h intracavity thickness
- P electrostatic pressure

Membrane displacement

$$W = -\frac{P * R^4 * 3(1 - v^2)}{16 * E * h^3}$$

Resonance frequency (fundamental mode)

$$\omega i = 2\pi * Ai * \left(\frac{h}{d^2}\right) * \sqrt{\frac{E}{\rho(1-v^2)}}$$

Membrane resonance - Results

Membrane thickness (µm)	Spectral range (nm)	Resonance frequency (kHz)
105	120	20
215	15	18.4
550	5	13.7

- Results seems to be better but the excited mode depends on many things which make the manufacturing difficult

- Similar characteristics to what can be done with others technologies like MEMS but less expensive

- More absorption in gold than in dielectric mirror, lower resolution

- No possibilities of miniaturization

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Conclusion

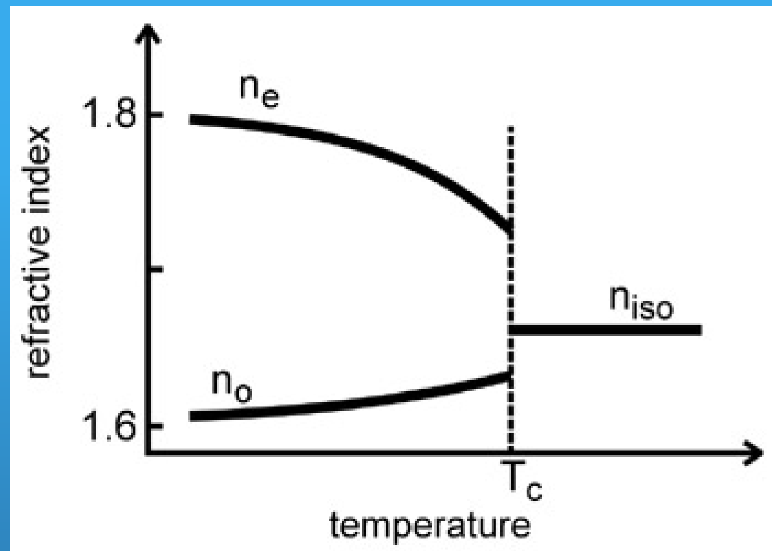
- Not replacing the existing interrogators

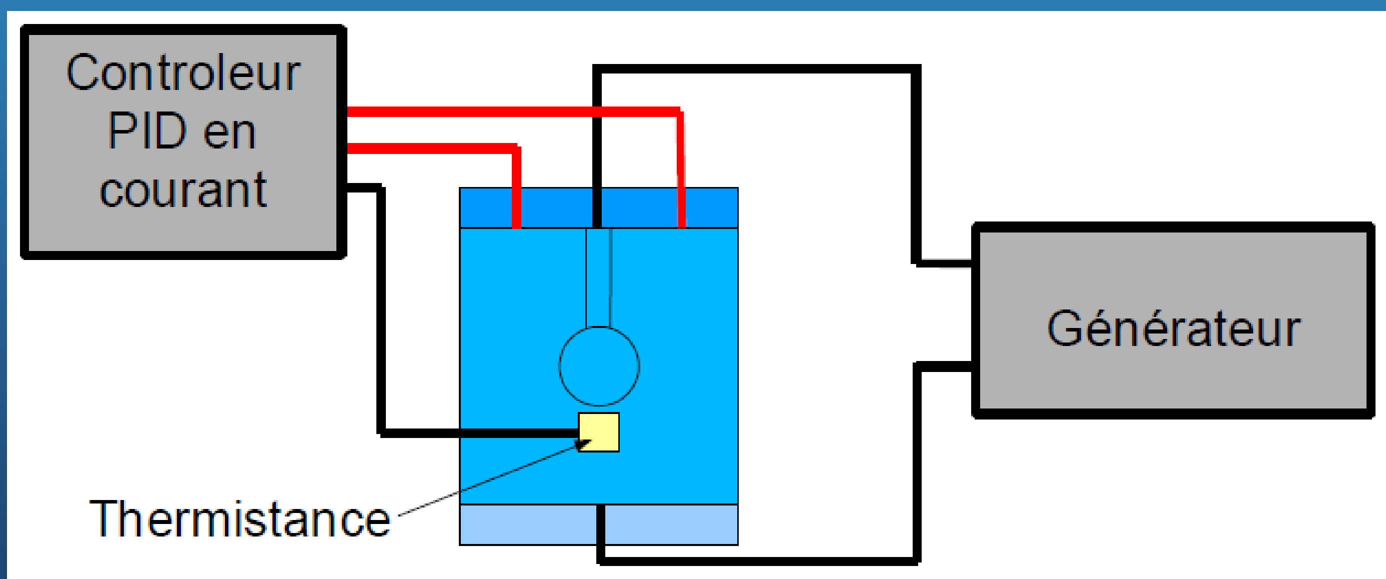
- Crystal liquid filters
  easy to build and cheap
  characteristics can be easily adjust

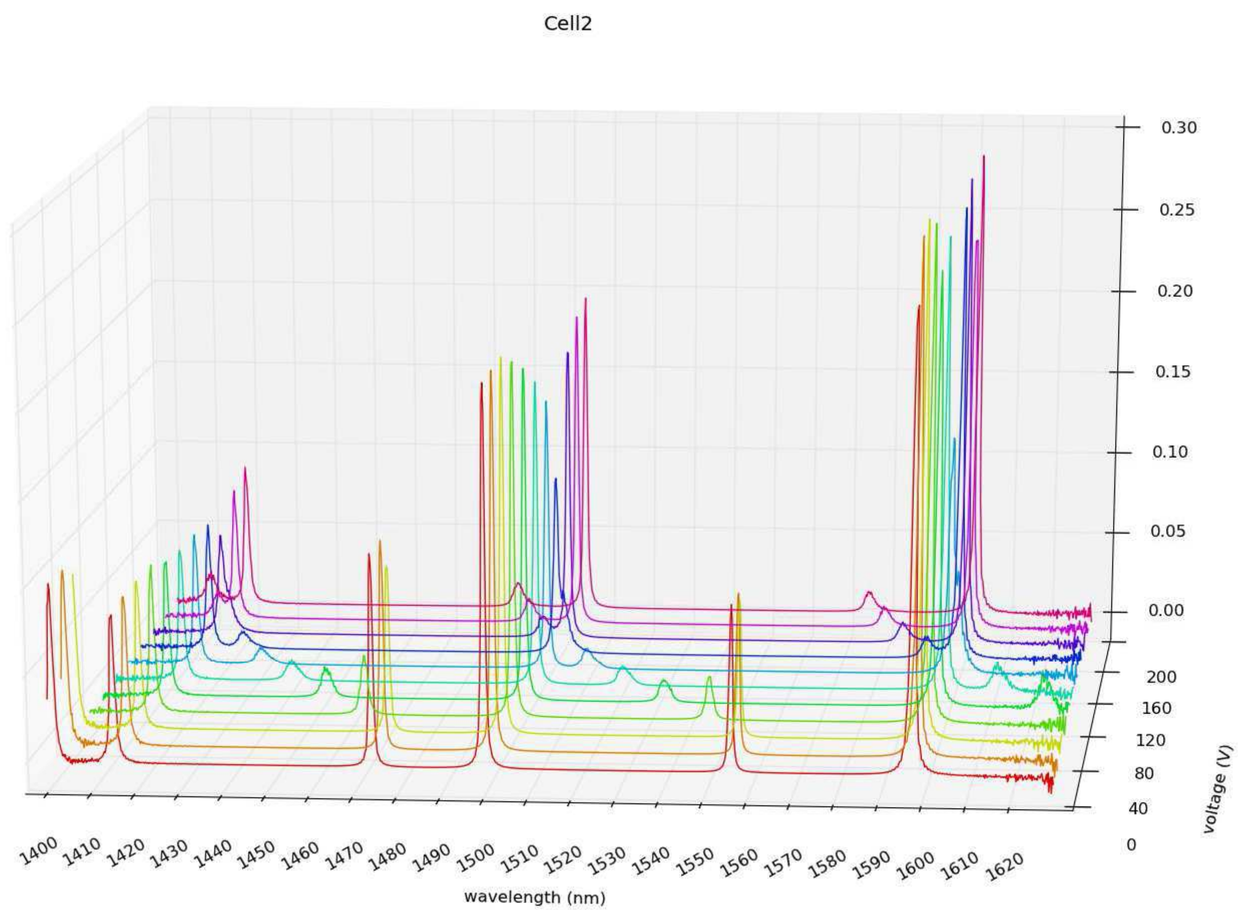
- Electro-static filters
  much higher frequencies
  more difficult to build
  less resistant
  no miniaturization

Thank you for your attention! Any questions?

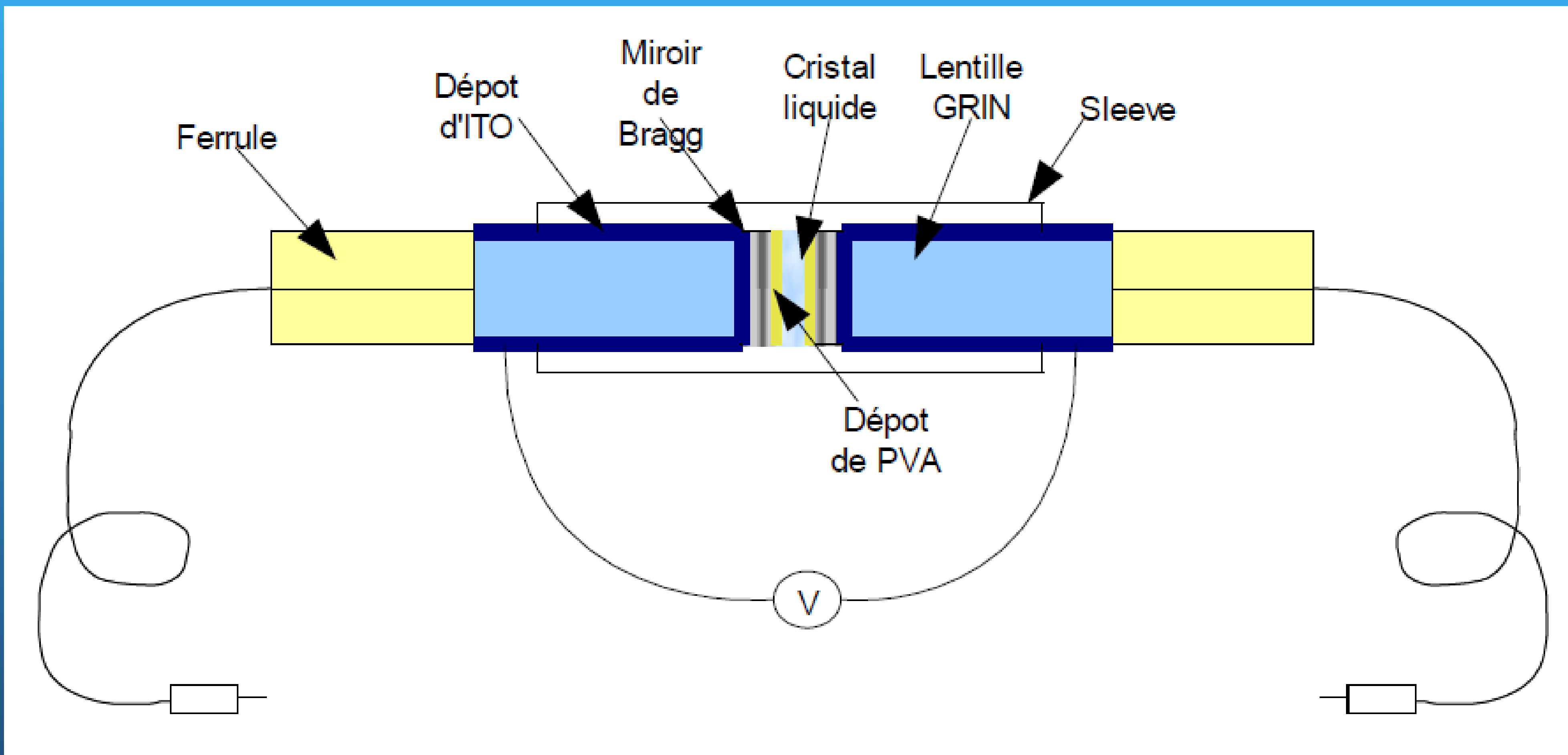
Back up slides

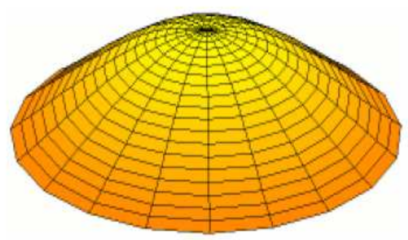
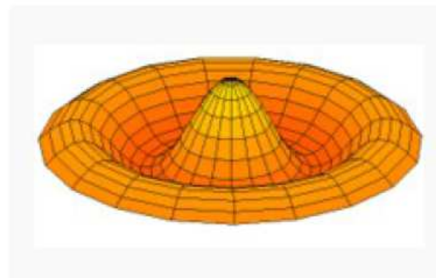
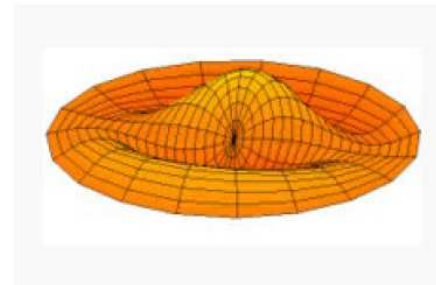

refractive index
1.8
1.6
ne
no
niso
Tc
temperature

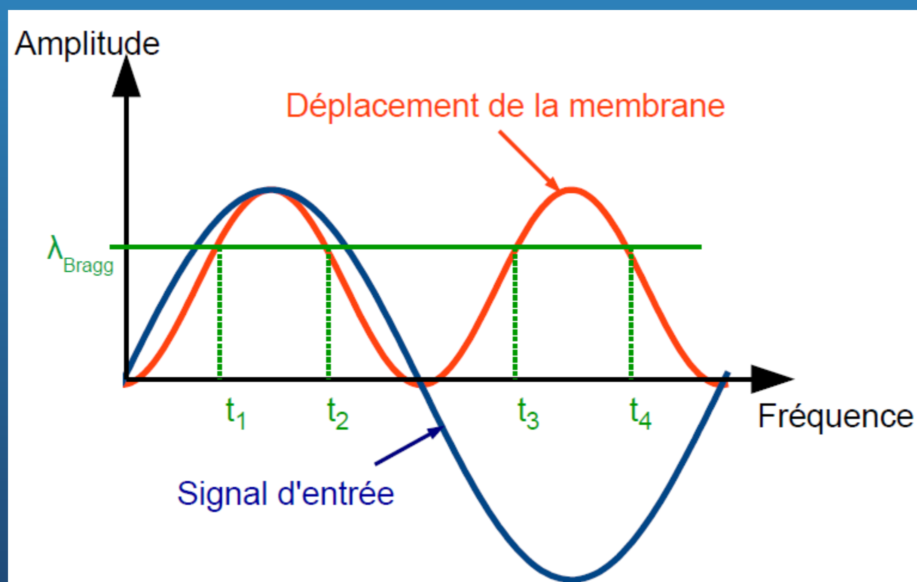

Controleur PID en courant
Générateur
Thermistance

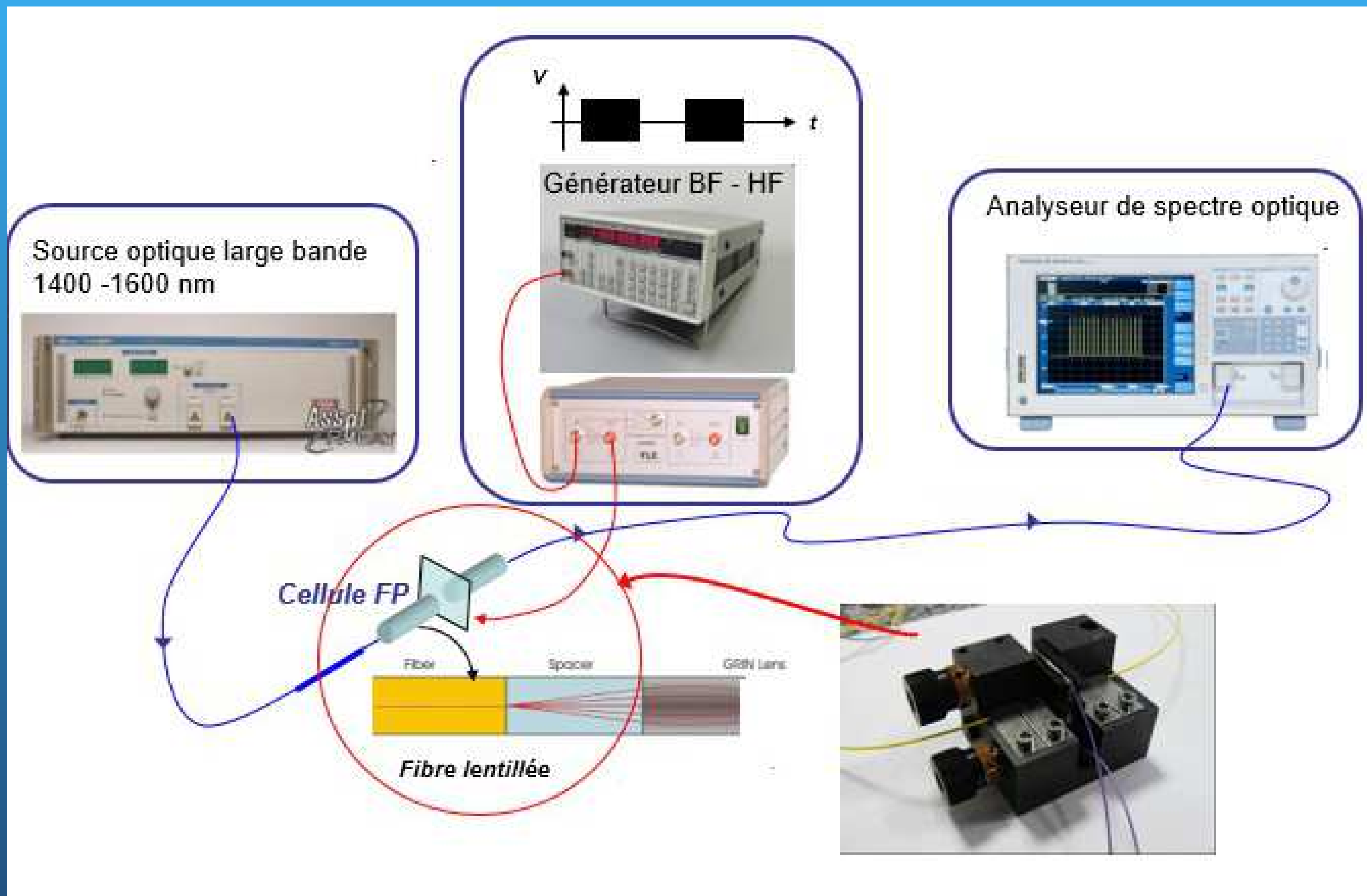

Cell2
0.30
0.25
0.20
0.15
0.10
0.05
0.00
200
160
120
80
40
0
voltage (V)
1400 1410 1420 1430 1440 1450 1460 1470 1480 1490 1500 1510 1520 1530 1540 1550 1560 1570 1580 1590 1600 1610 1620
wavelength (nm)

k	λk ordinaire (nm)	λk extraordinaire (nm)
1	25,670	28,050
2	12,835	14,025
3	8,557	9,350
4	6,418	7,013
5	5,134	5,610
6	4,278	4,675
7	3,667	4,007
8	3,209	3,506
9	2,852	3,117
10	2,567	2,805
11	2,334	2,550
12	2,139	2,338
13	1,975	2,158
14	1,834	2,004
15	1,711	1,870
16	1,604	1,753
17	1,510	1,650
18	1,426	1,558
19	1,351	1,476
20	1,284	1,403


Ferrule
Dépot d'ITO
Miroir de Bragg
Cristal liquide
Lentille GRIN
Sleeve
Dépot de PVA
V

Mode fondamentale (u01)	Mode Propre(u03)	Mode Propre (u12)
		





Source optique large bande
1400 -1600 nm
V
t
Générateur BF - HF
Analyseur de spectre optique
Cellule FP
Fiber
Spacer
GRIN Lens
Fibre lentillée