Coherent Light and Vibrating Films

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Nov 04, 03

Postdoctoral Summer Research Programme 2003
Funded by BAe Systems / Al-Yamamah Programme
Administrated by the British Council

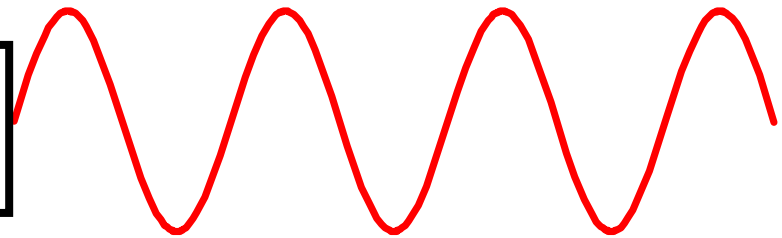
University College London

Department of Medical Physics and Bioengineering

Lasers and Endoscopy Group - Dr. Paul Beard

Coherent Light?

Laser



Continuous Wave

Narrow Band

What is special about light?

$\lambda \sim 0.5\ \mu m$

- Wavelength very short

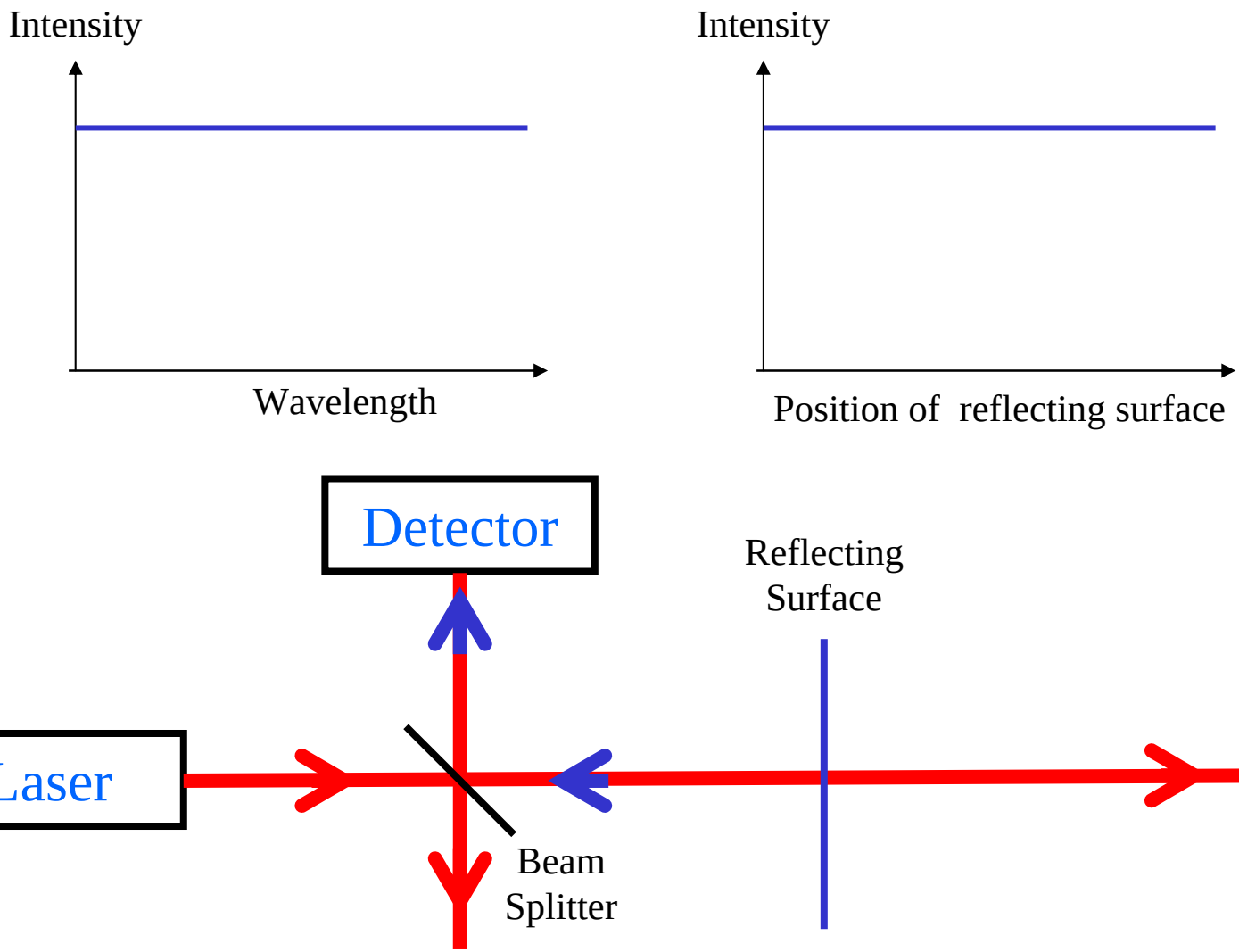
  → help to detect small displacements fraction of λ

- Availability of coherent sources

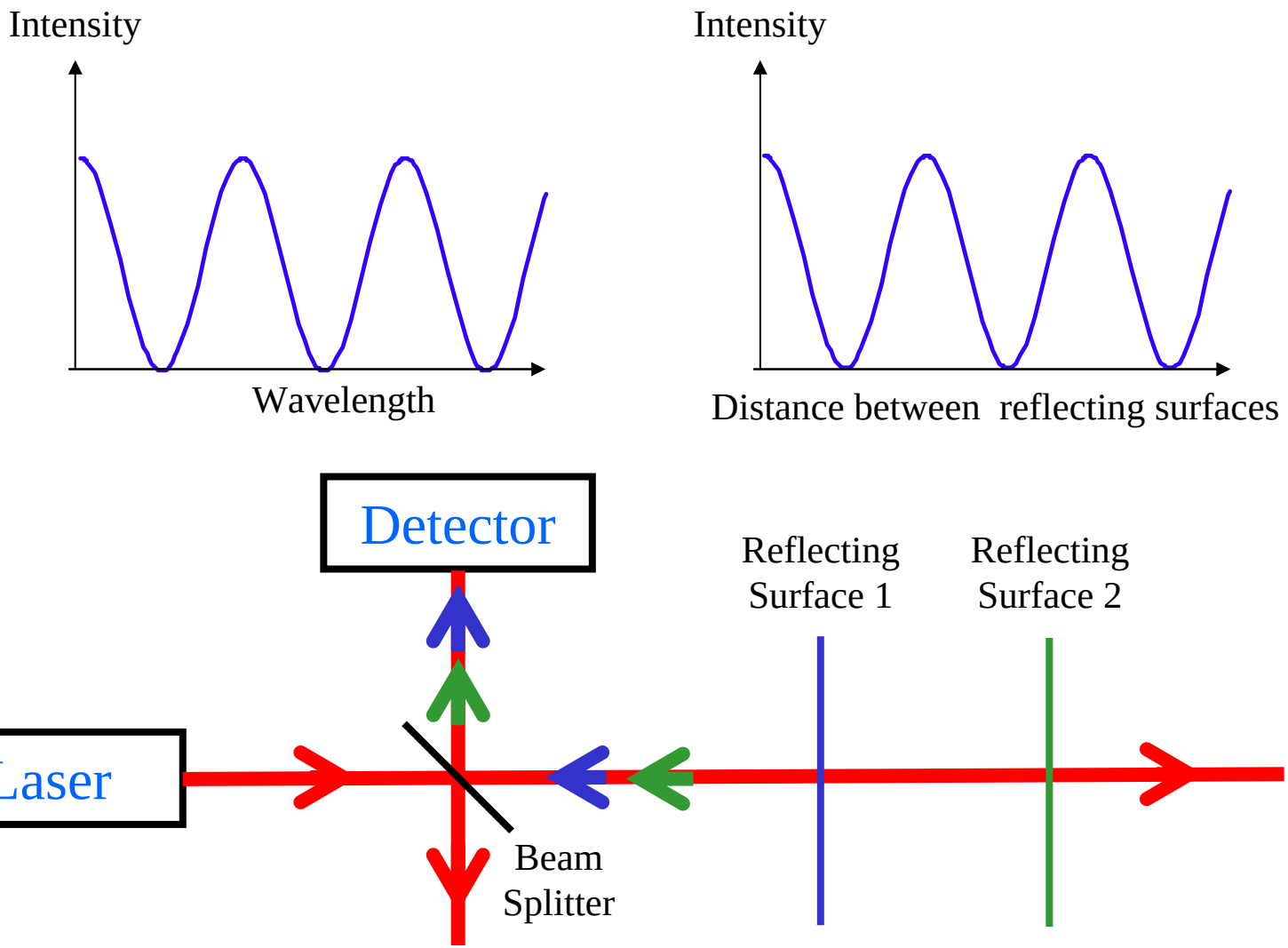
- Availability of effective and fast detectors

- Light beam can be easily steered and shaped by mirrors and lenses and guided through fibers

Simple Setup



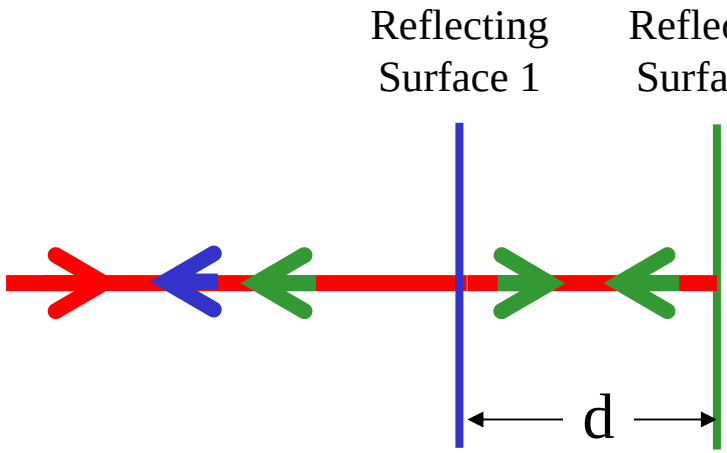
Improved Setup

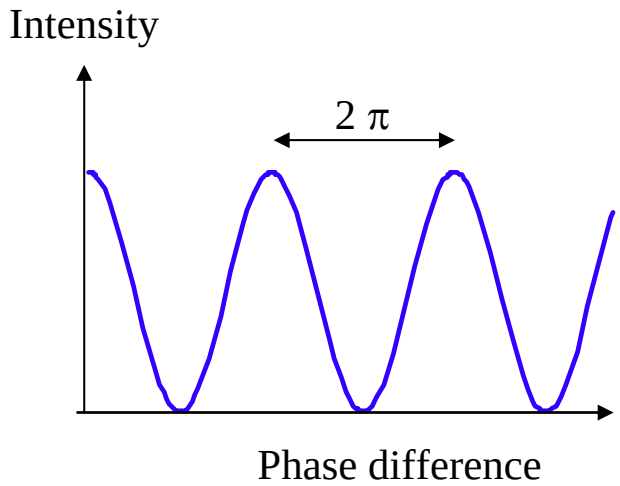


Why variation in intensity?

Wave interference

$$Phase\ difference = k(2d) = \frac{4\pi}{\lambda} d$$

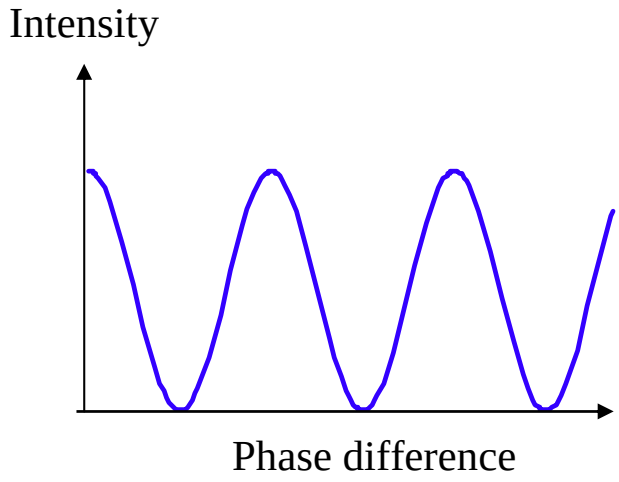




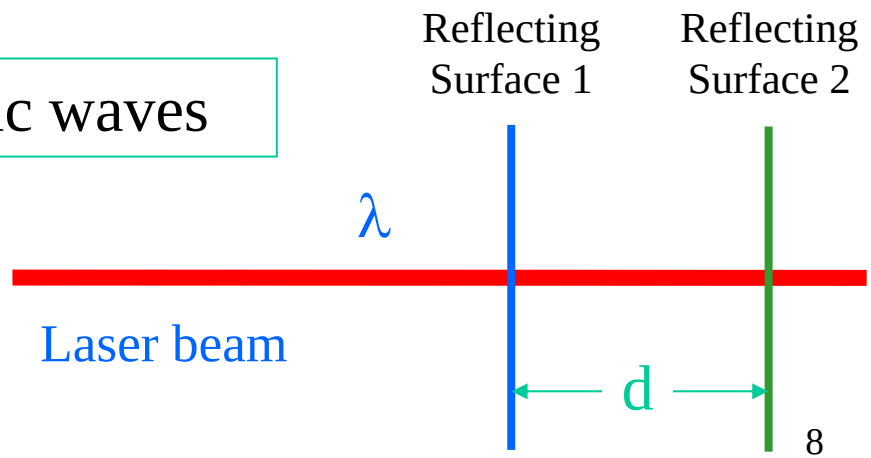
Fabry-Perót
Interferometer

Applications of Fabry-Perót Interferometer?

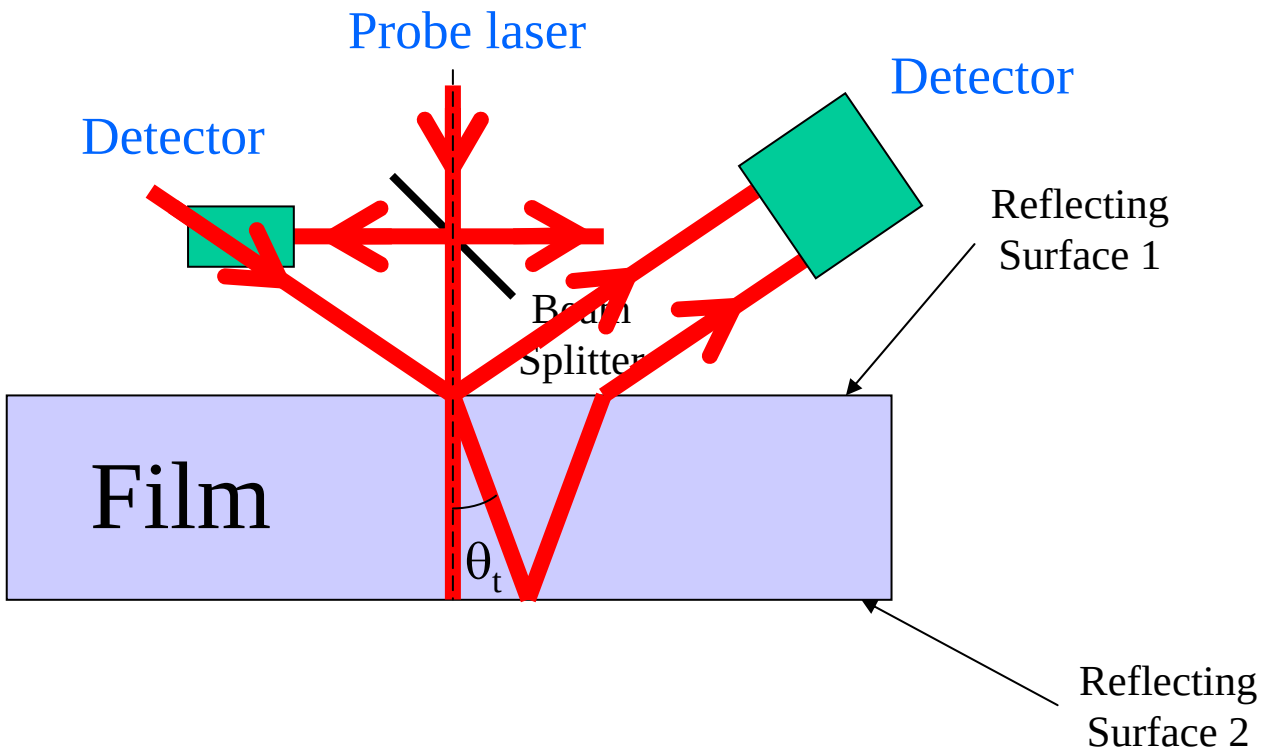
- Analyze light sources
  - ➢ Spectroscopy
- Monitor distance variations
  - ➢ Temperature
  - ➢ Stress
  - ✓ Ultrasonic waves



$$Phase\ difference = \frac{4\pi}{\lambda} d$$

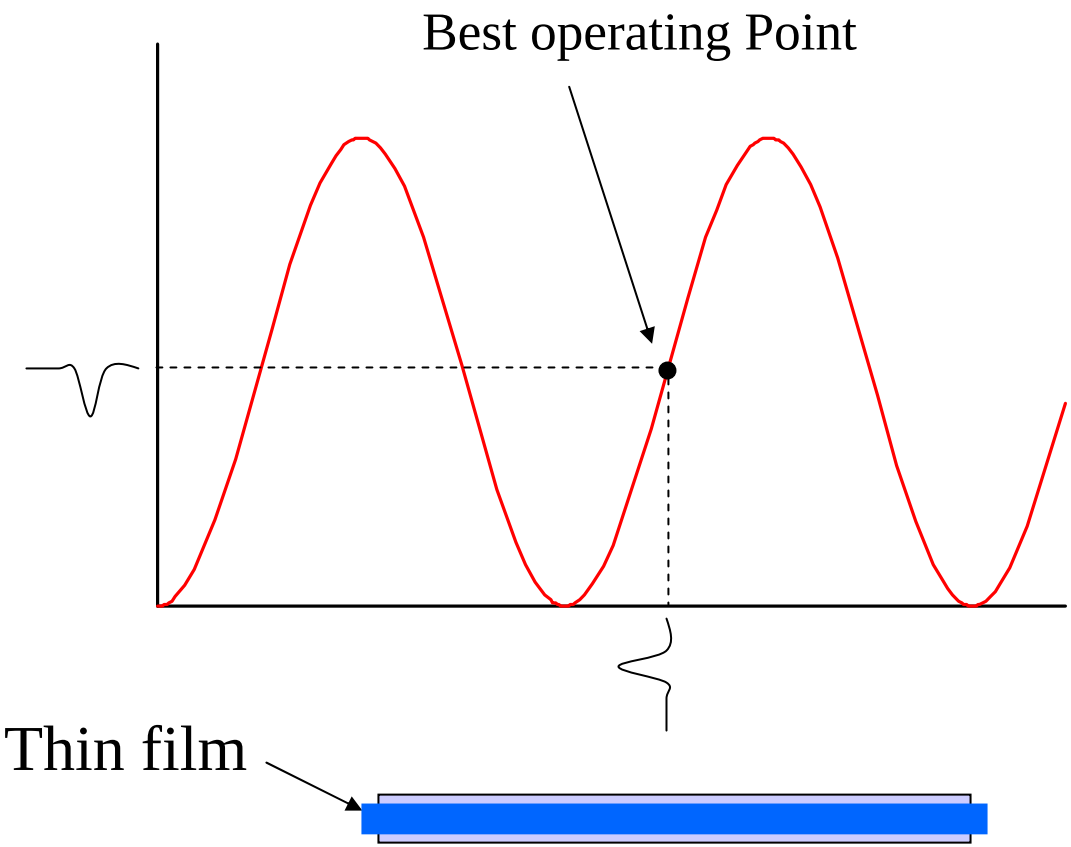


Fabry-Perót Interferometer = Thin film



$$Phase\ difference \equiv \delta = \frac{4\pi}{\lambda} n_f d \cos\theta_t$$

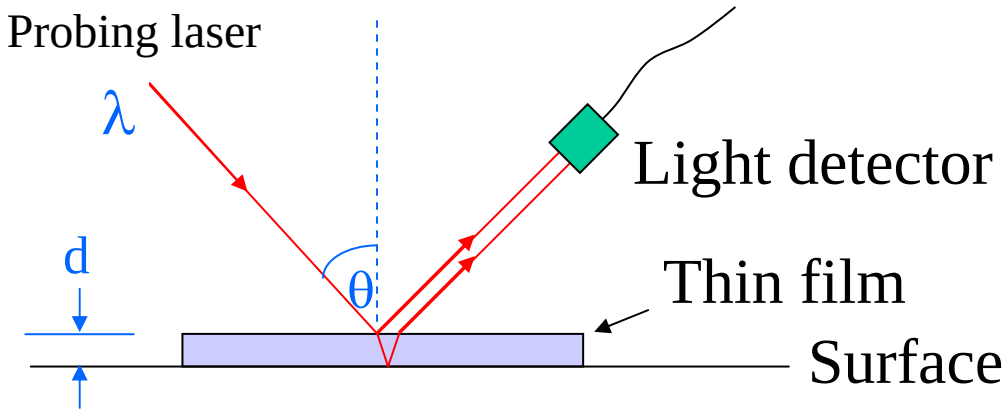
Operating point

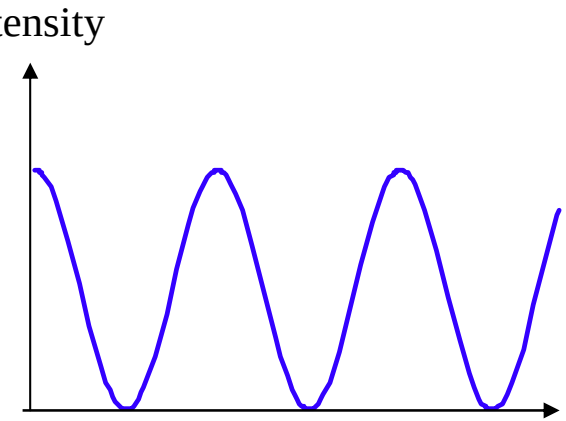


Phase difference

$$\delta \equiv \frac{4\pi}{\lambda} n_f d \cos\theta_t$$

Tuning the phase difference

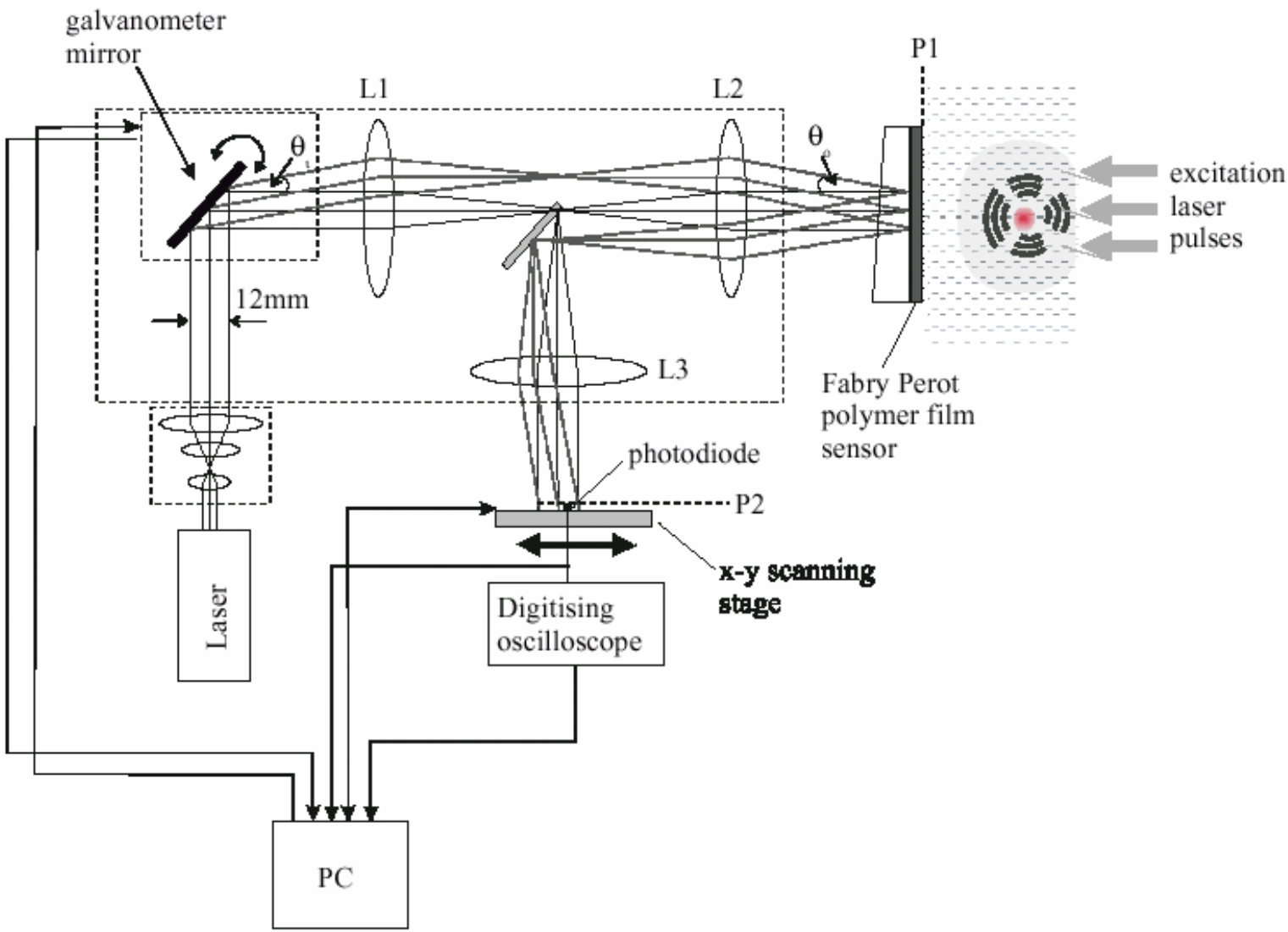




$$\delta \equiv \frac{4\pi d n_f}{\lambda} \cos\theta_t$$

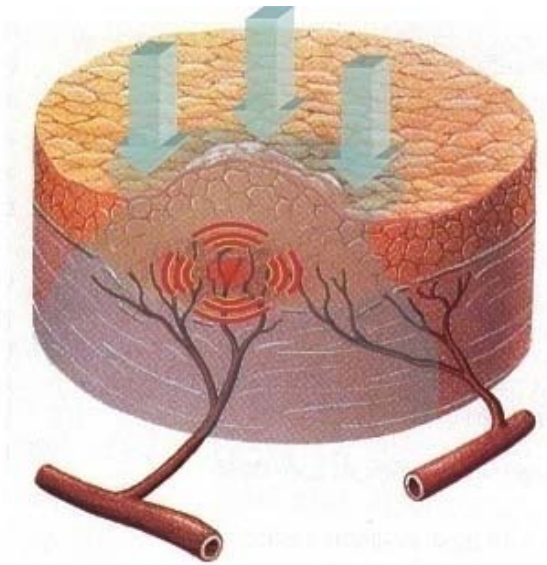
Change θ	Change λ
Steering optics complicated Fast	tunable lasers Expensive slow

Tuning with angle

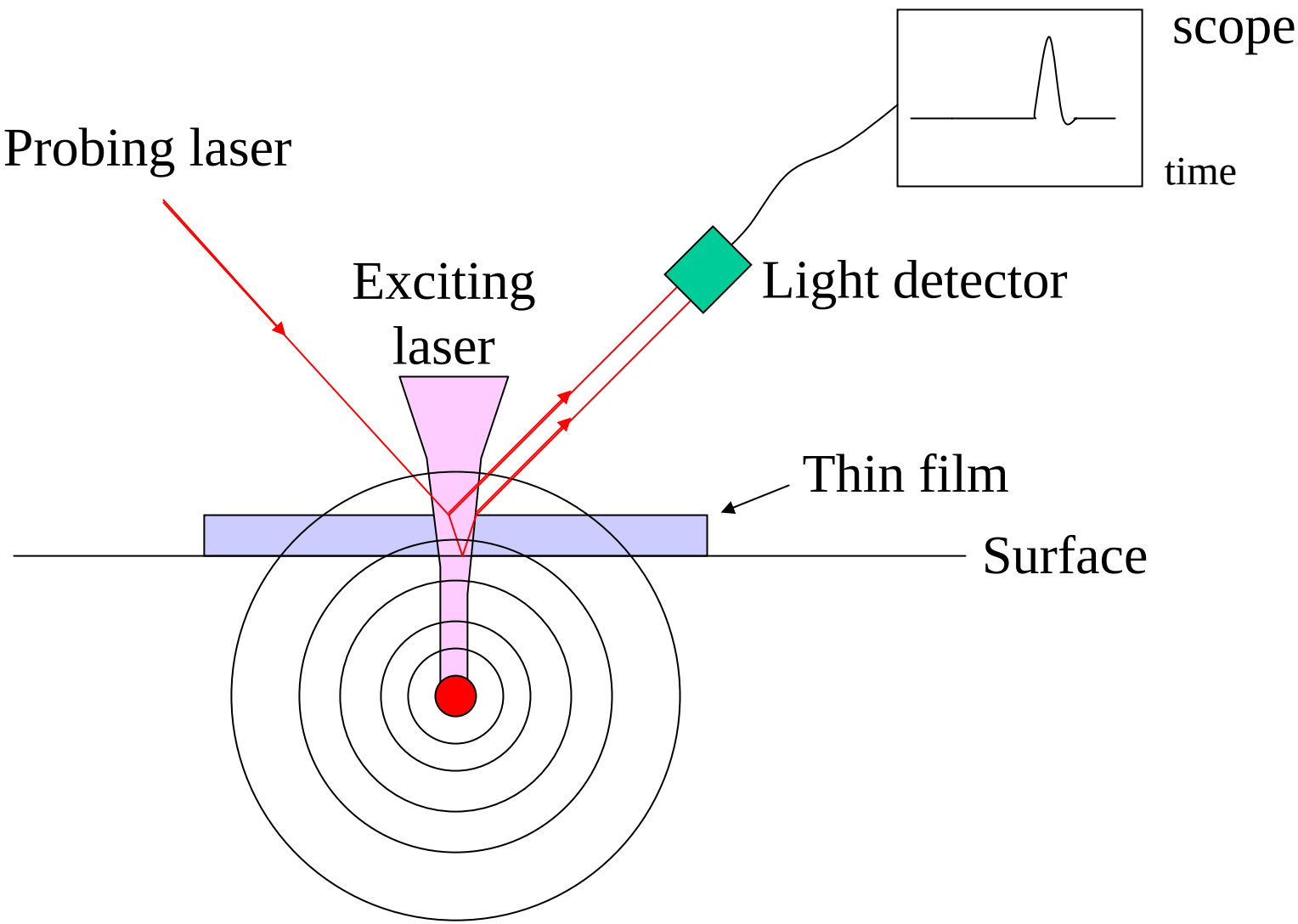


Applications of thin film-ultrasonic sensor at UCL?

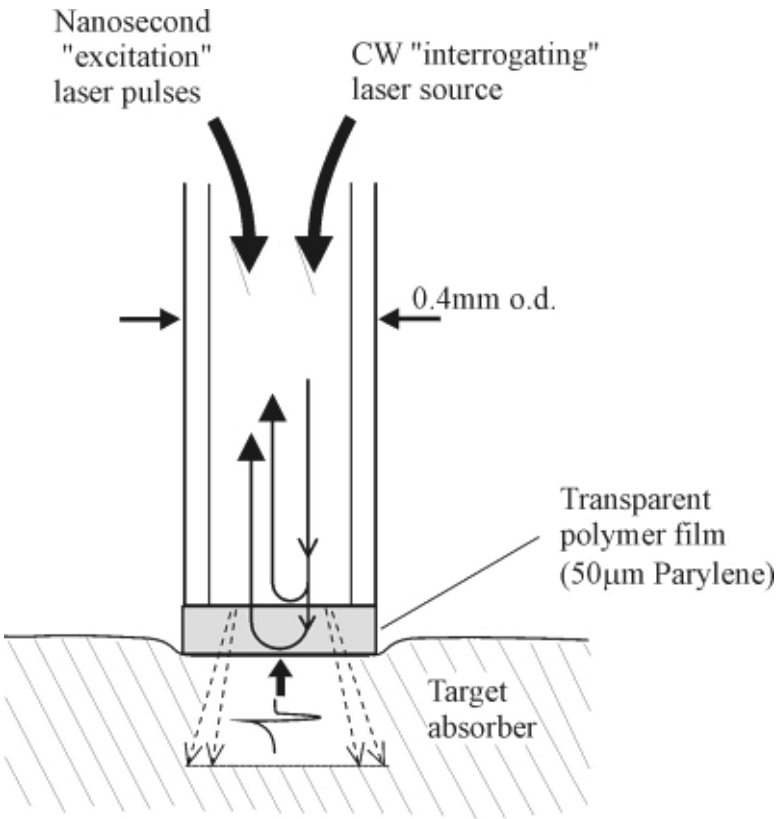
Imaging near-surface blood vessels

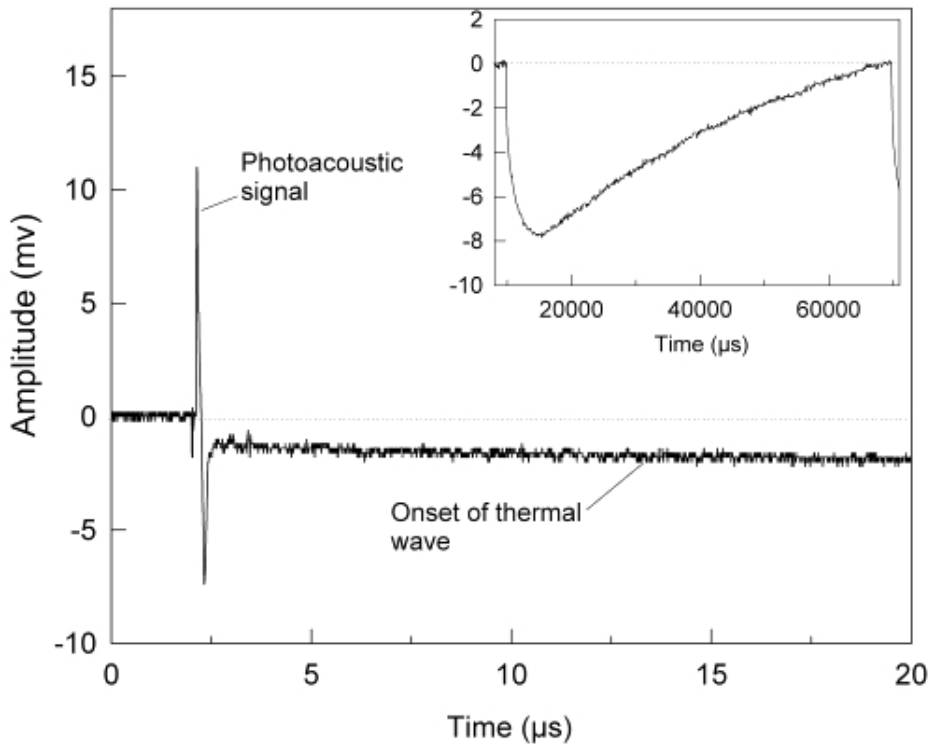


How to image near-surface blood vessels?



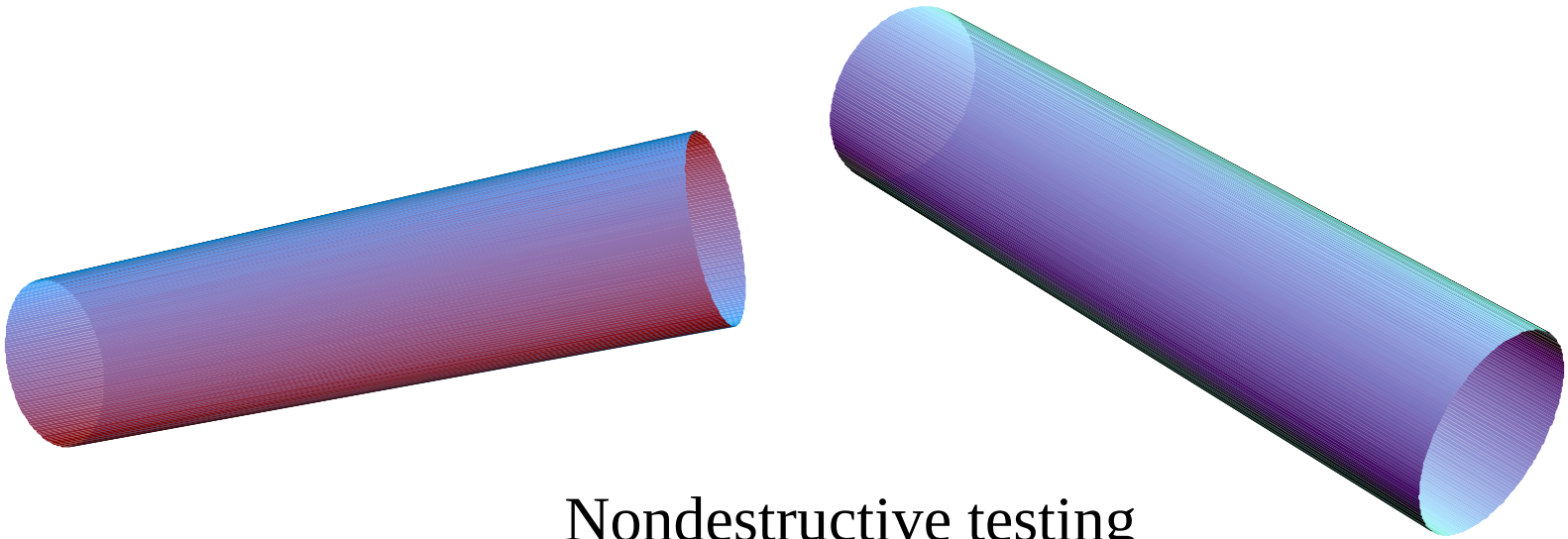
Another application: hydrophone





Sought application

Can we use a layer of paint
or a film glued on a pipe
as an ultrasonic sensor?

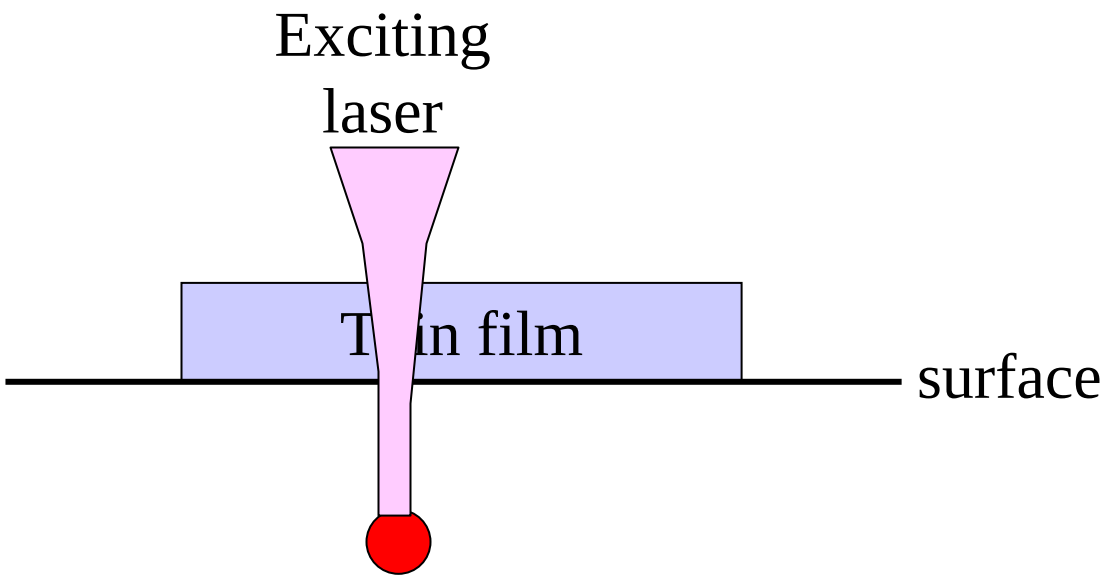


Nondestructive testing
of pipelines

Features of thin-film ultrasonic sensor

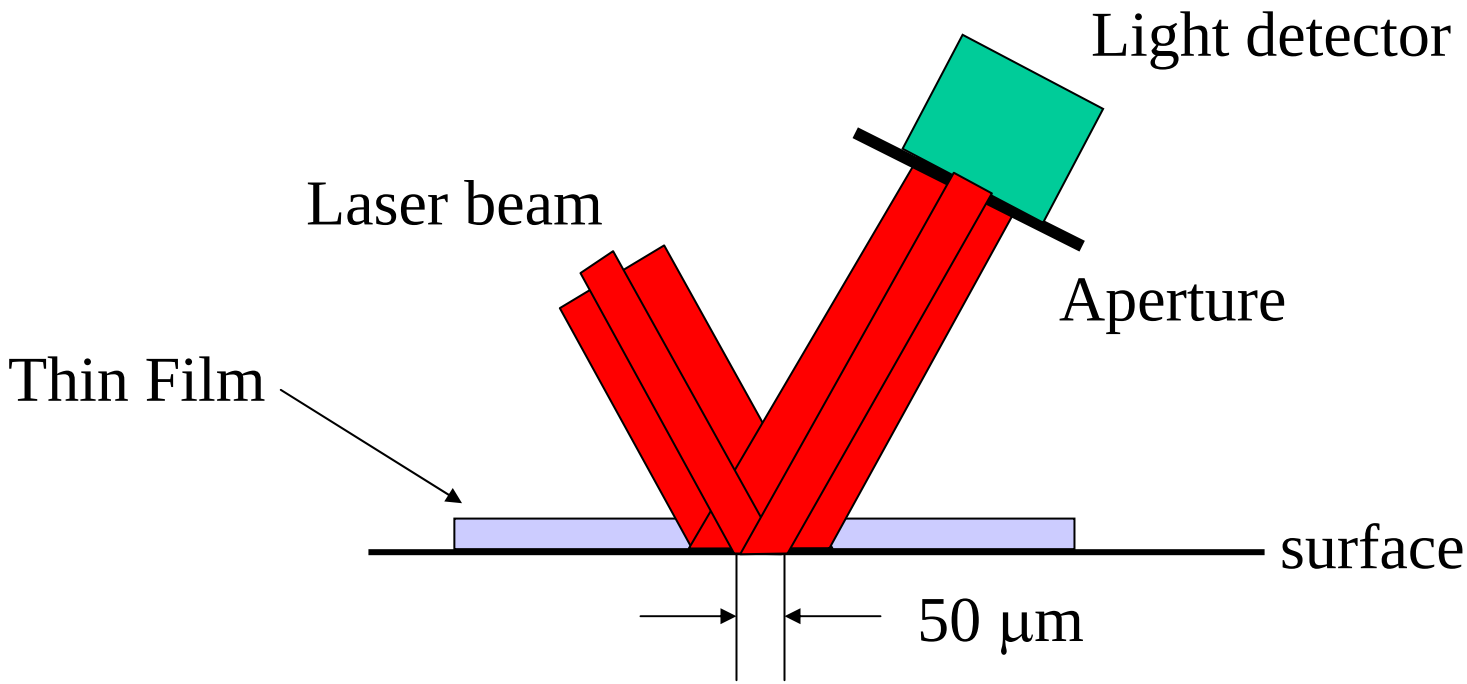
- Used with the exciting pulsed laser
- High spatial resolution
- Broadband (high temporal resolution)
- Sensitive

Used with exiting pulsed laser

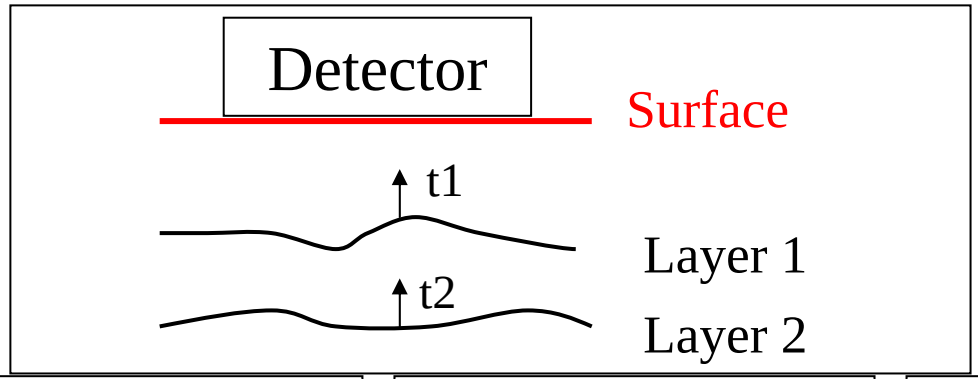


High Spatial Resolution

Limited by interrogating laser spot size



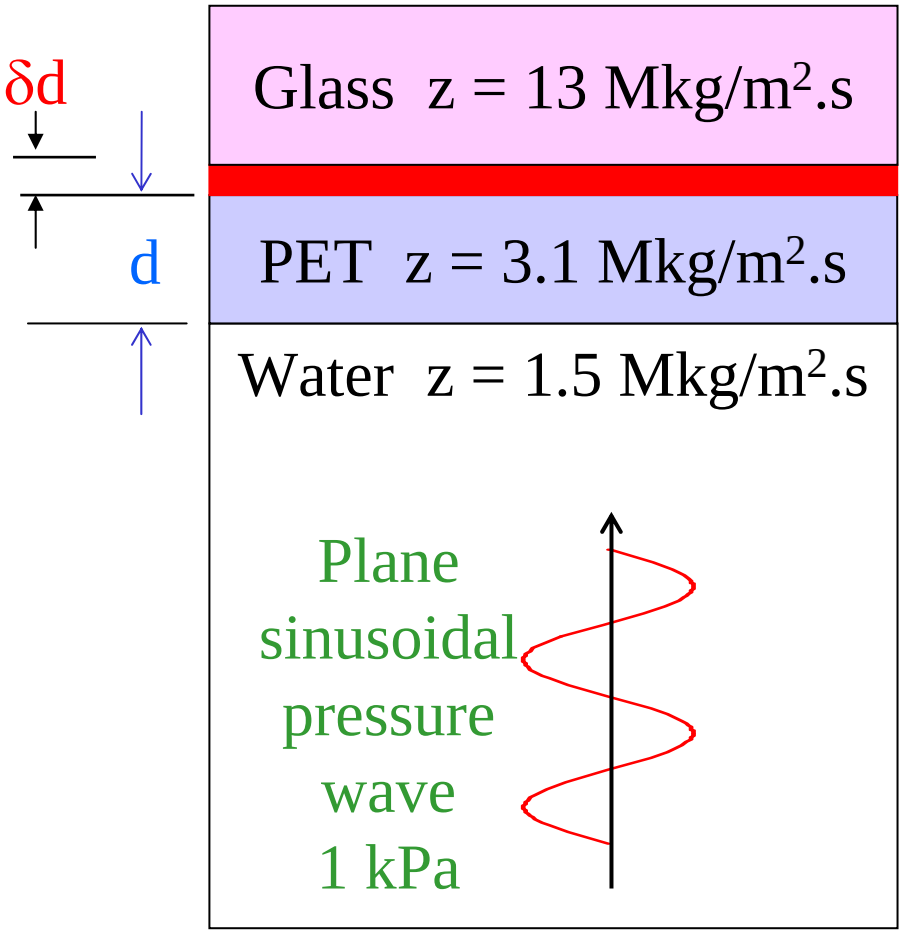
Broadband detection?

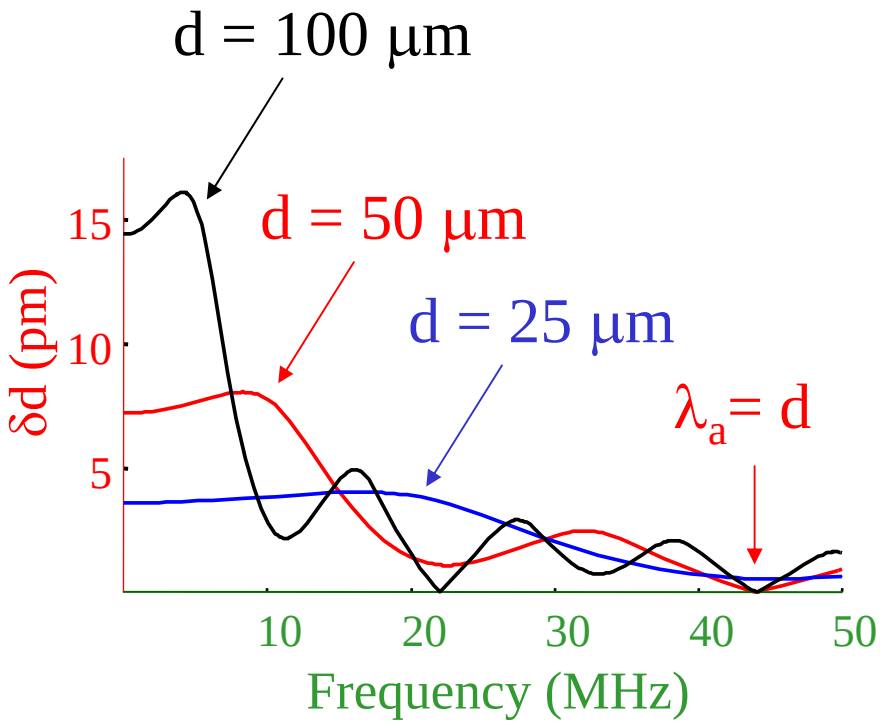


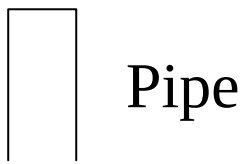
50 μm resolution ~
30 MHz bandwidth

original pulse	broadband detector	narrowband detector
time	time	time
time	time	time

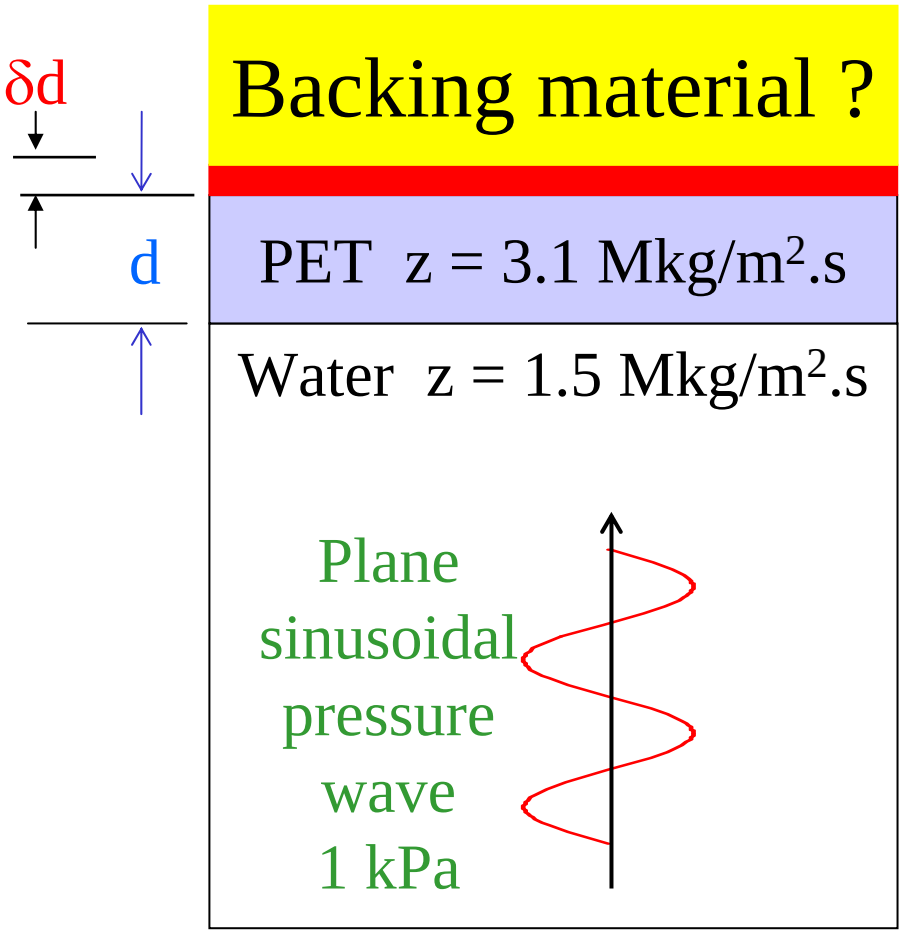
Band of detection – Simple model



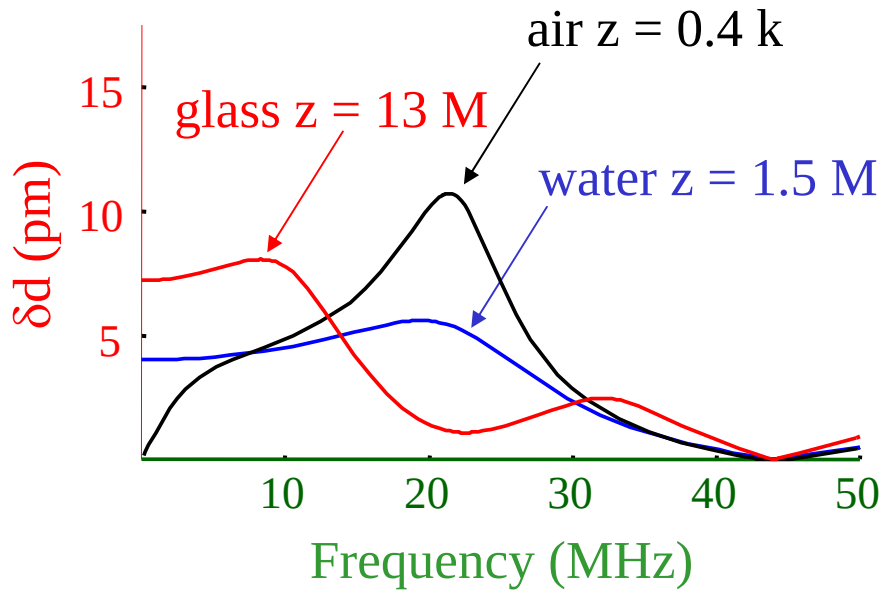




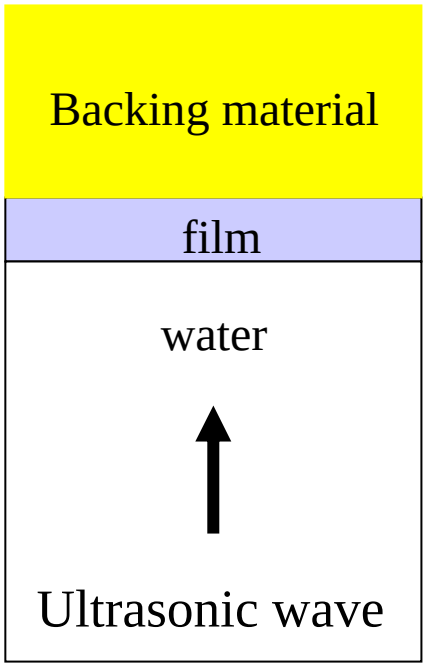
Band of detection – Different backing

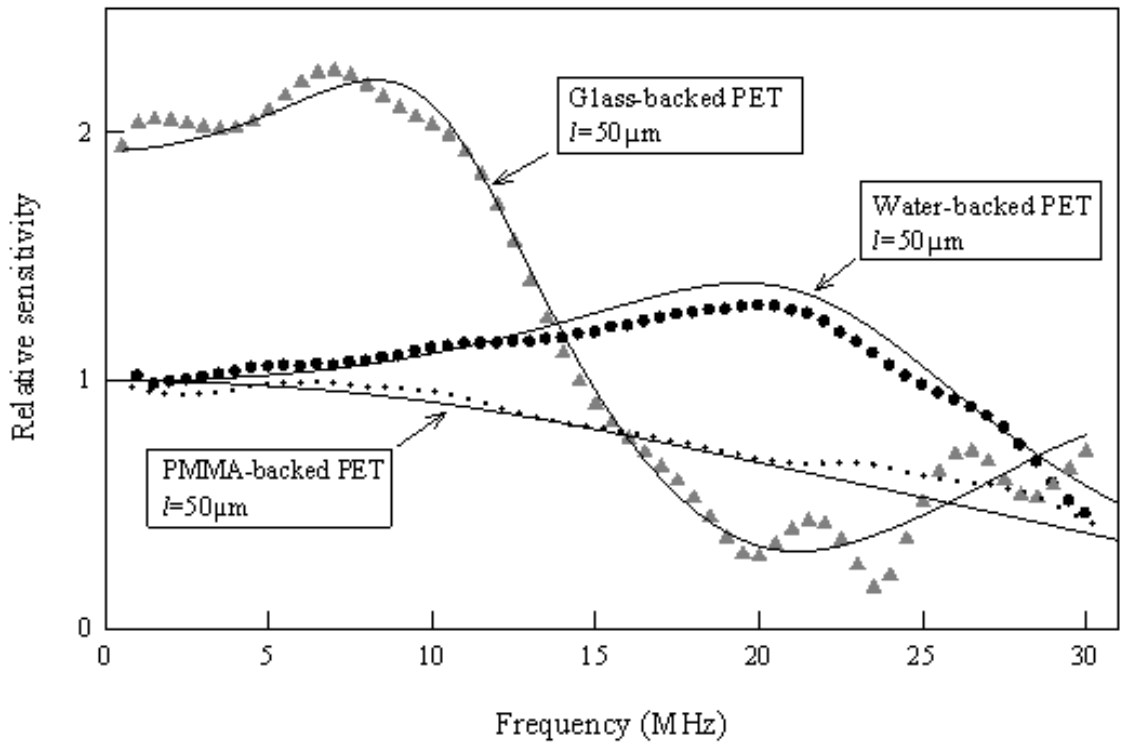


d = 50 μm



Band of detection – Experimental results





Sensitivity

Ultrasonic energy

Optical phase shift

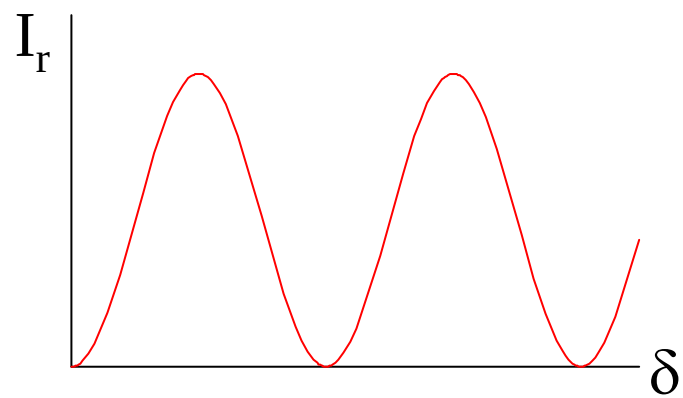
Thickness and index of refraction

Intensity modulation

Elastic and photo-elastic properties of the film and its surroundings

Slope of the transfer function

Polymer films



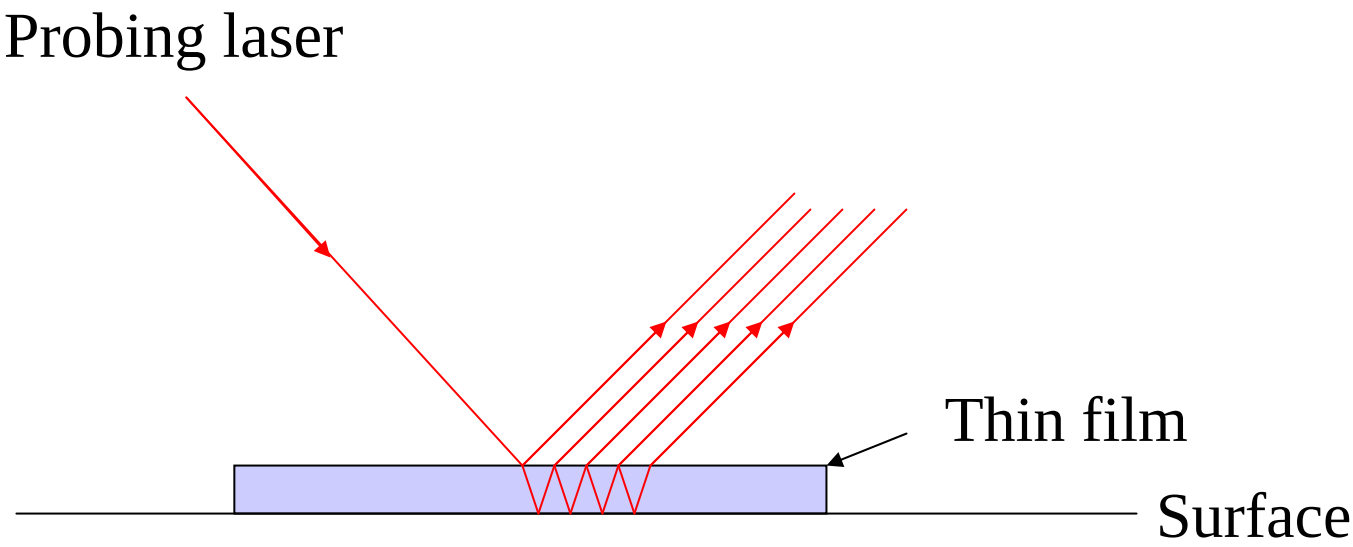
Strategy to Increase Sensitivity

High reflectivity

High laser power

Higher Sensitivity: Higher Reflectivity

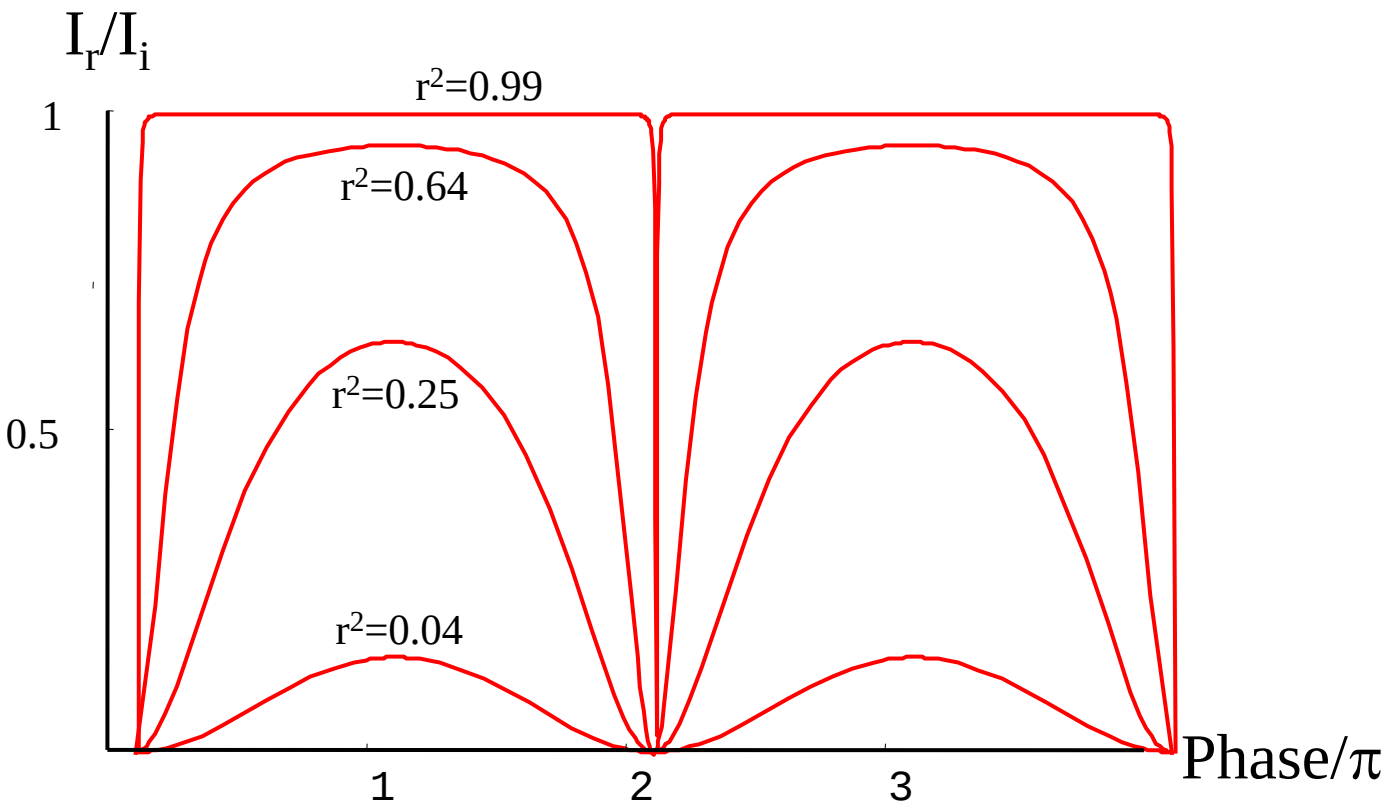
Thin film with high reflectivity coatings



$$I_r = I_i\left(1 - \frac{1}{1 + F\sin^2\left(\frac{\delta}{2}\right)}\right)$$

$$F = \frac{4r^2}{(1-r^2)^2}$$

Higher Sensitivity: Higher Reflectivity



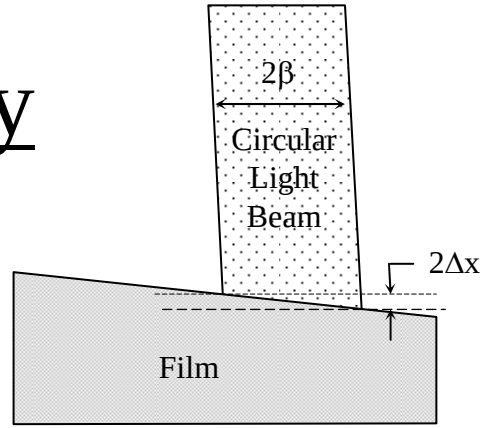
Theoretical gain in sensitivity

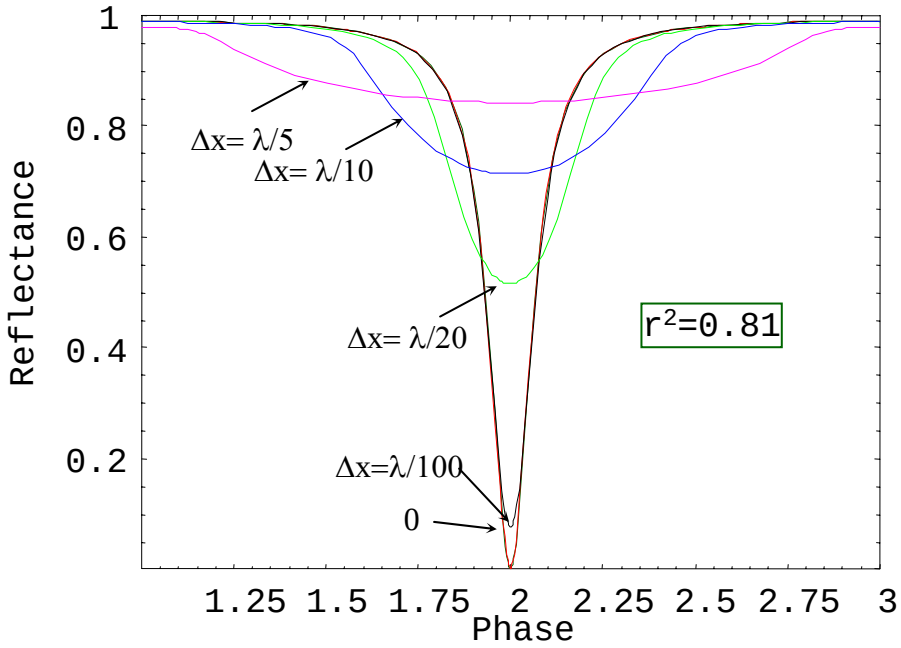
Amplitude reflectivity coefficient r	Reflectance at one surface r^2	Gain in sensitivity compared to uncoated film
0.9	0.81	66
0.97	0.95	250
0. 999	0.998	6253

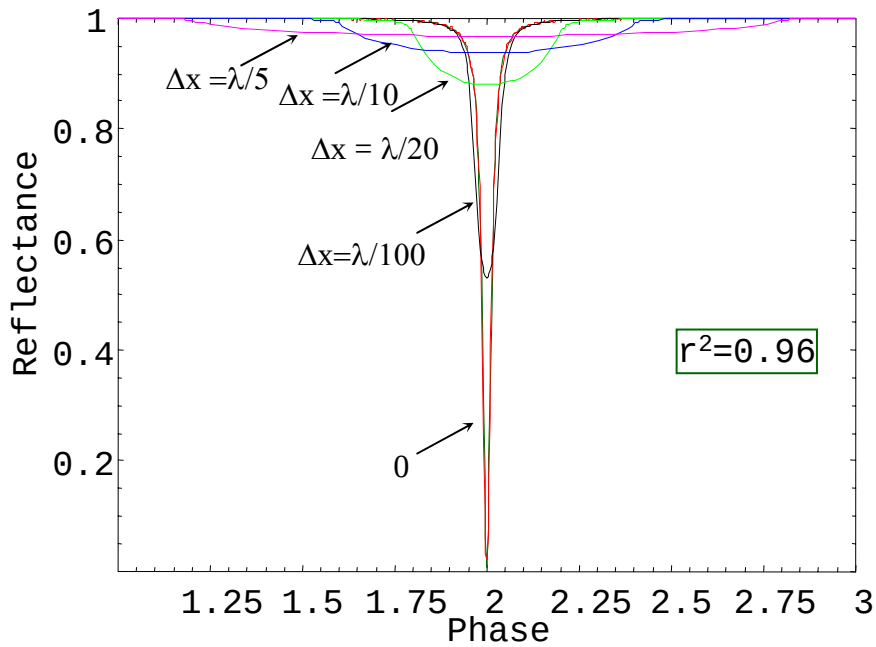
Practical limitations of sensitivity

- Quality of the reflecting surfaces
- Parallelism of the two surfaces
- Optical beam diffraction

Practical limitations of sensitivity



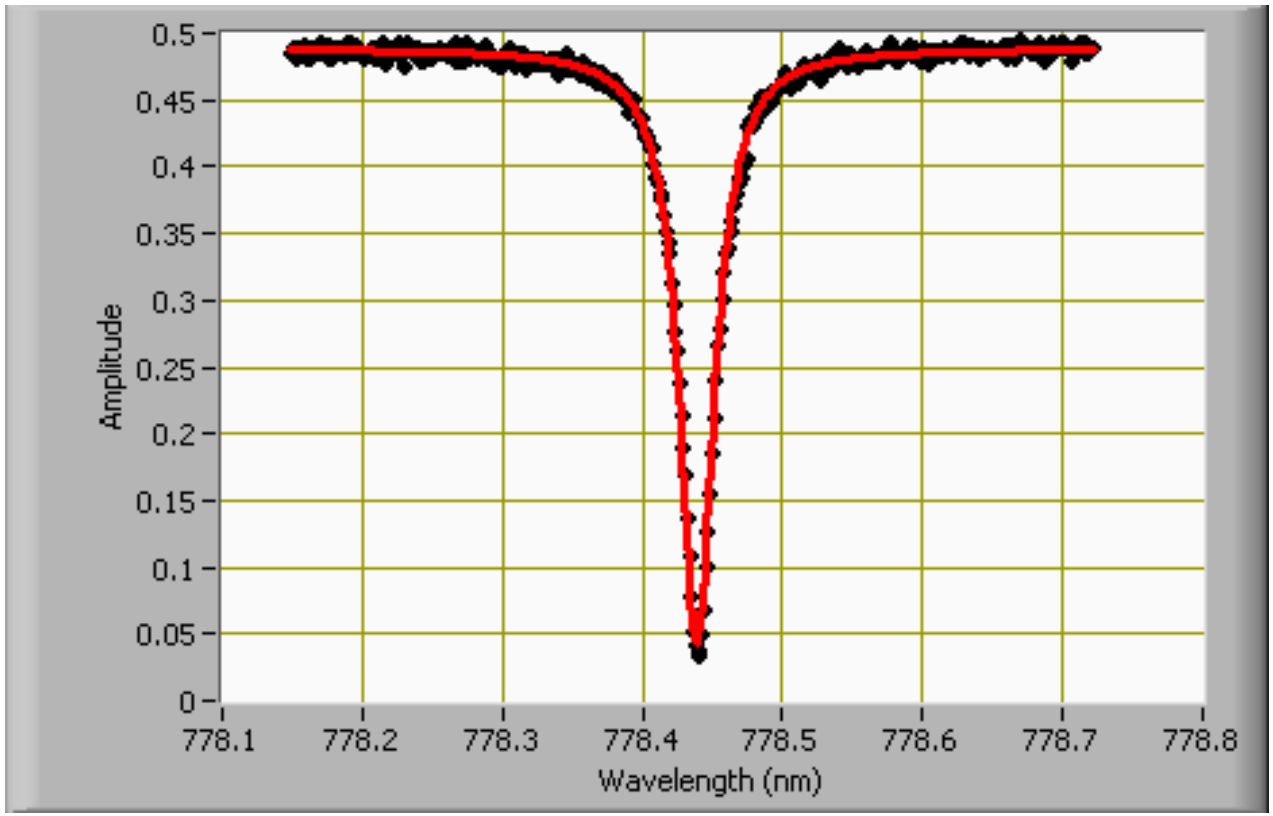




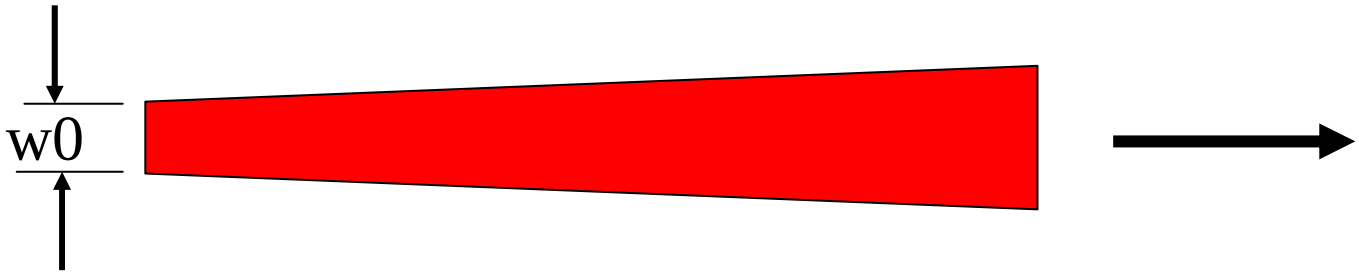
Practical limitations of sensitivity: experiment

Etalon : flatness and parallelism are $\lambda/100$ over 10 mm diameter

$d = 100\ \mu m$



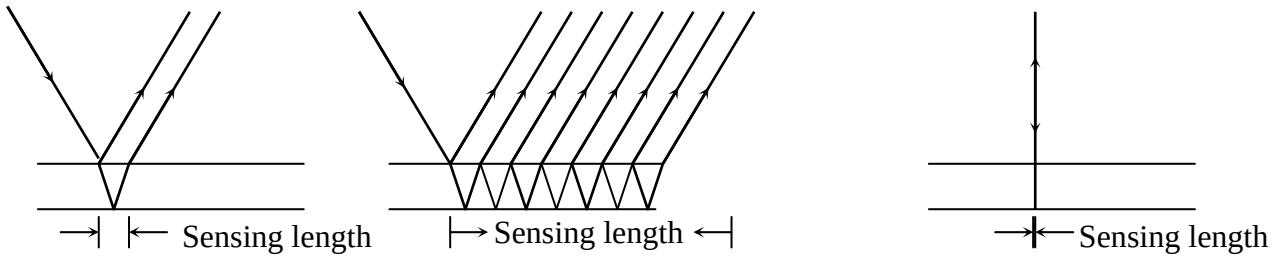
Practical limitations of sensitivity: beam diffraction



Diffraction angle $\theta \sim \frac{\lambda}{w0}$

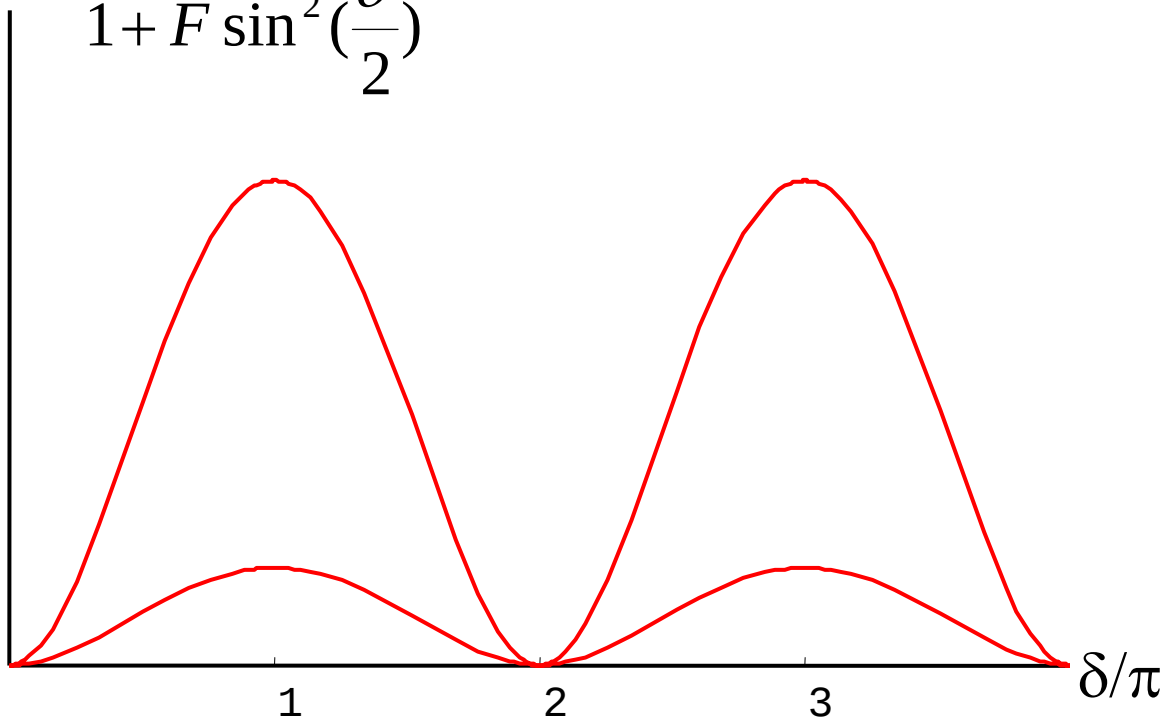
For beam waist of 50 μm, parallelism of λ/100 over 10 mm is more important than beam diffraction for an etalon of 100 μm thickness and 0.95 reflectivity

High reflectivity and walk off?

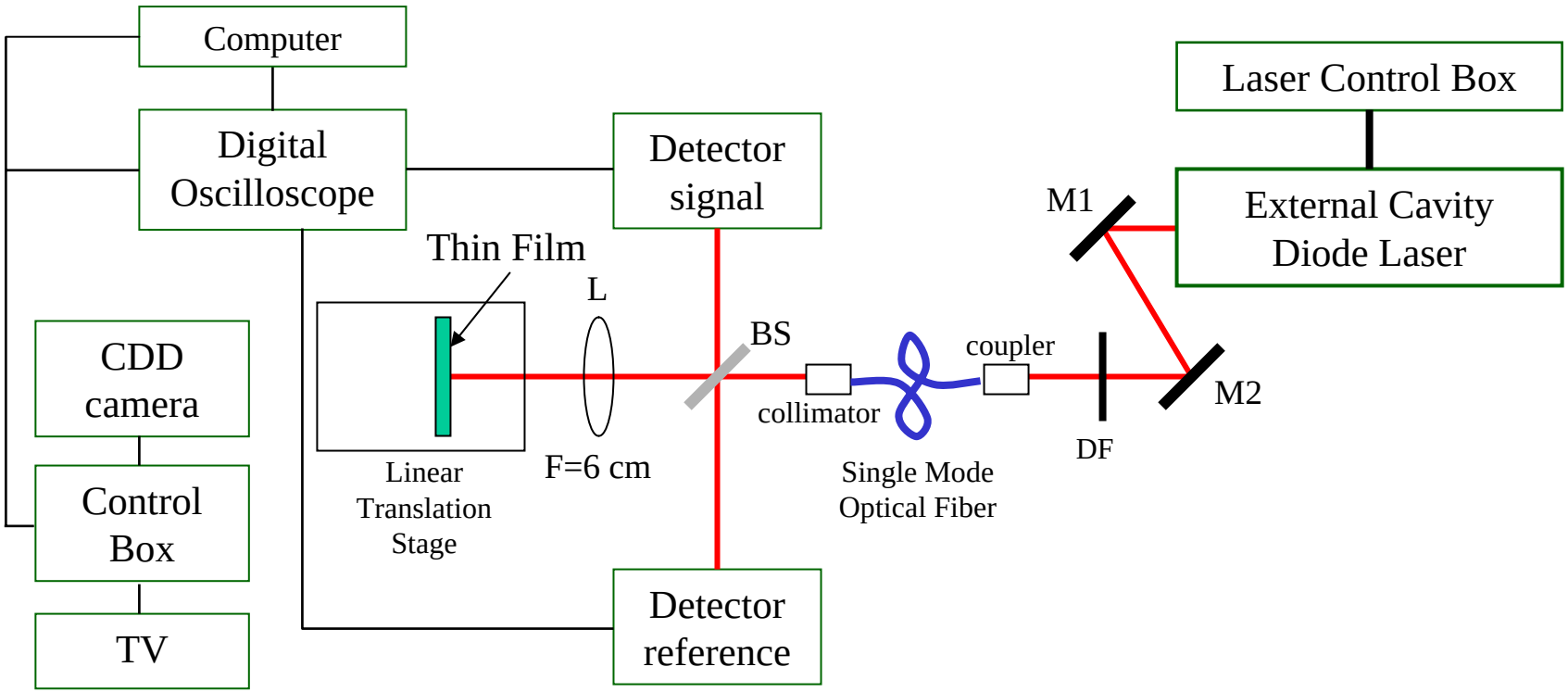


Higher Sensitivity: Higher Laser Power

$$I_r = I_i\left(1 - \frac{1}{1 + F\sin^2\left(\frac{\delta}{2}\right)}\right)$$

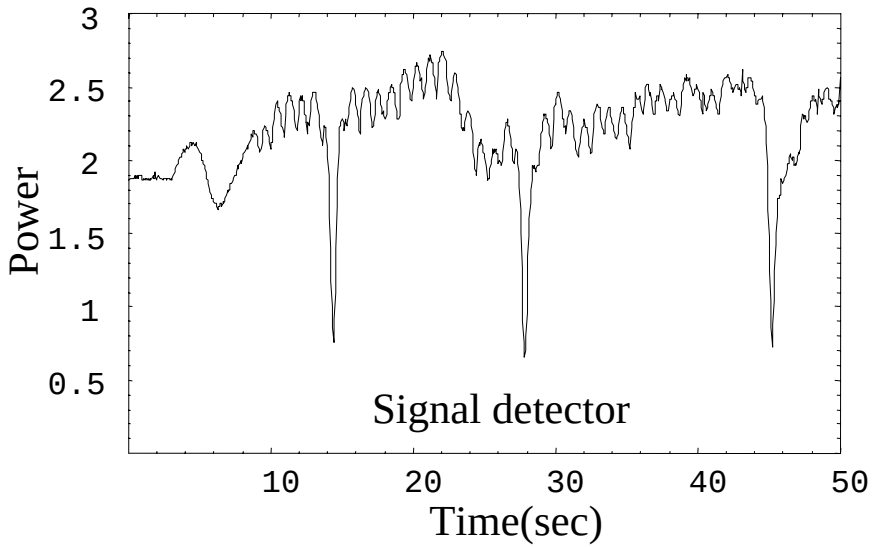


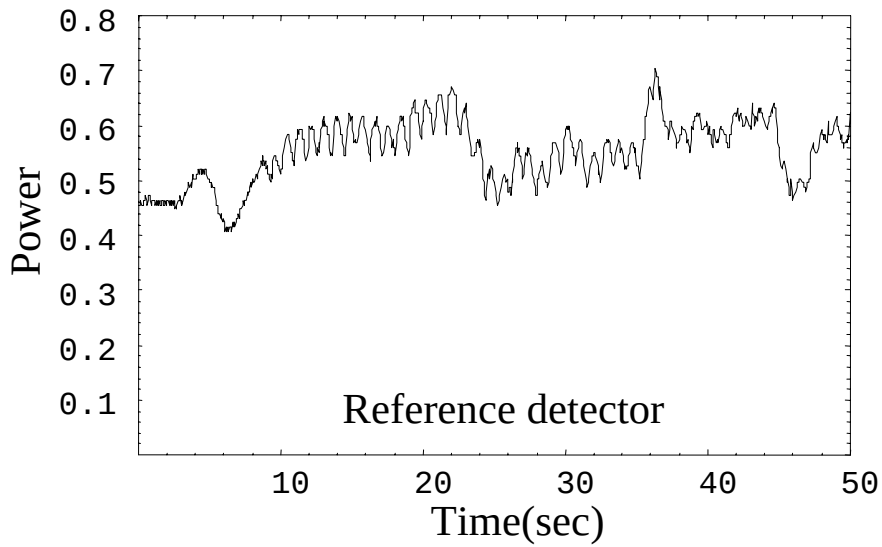
Experimental Setup

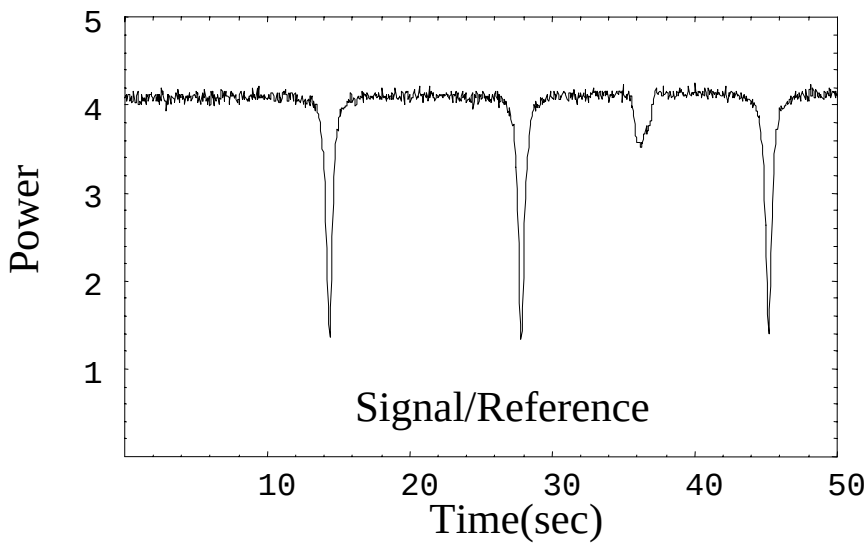


Experimental Setup

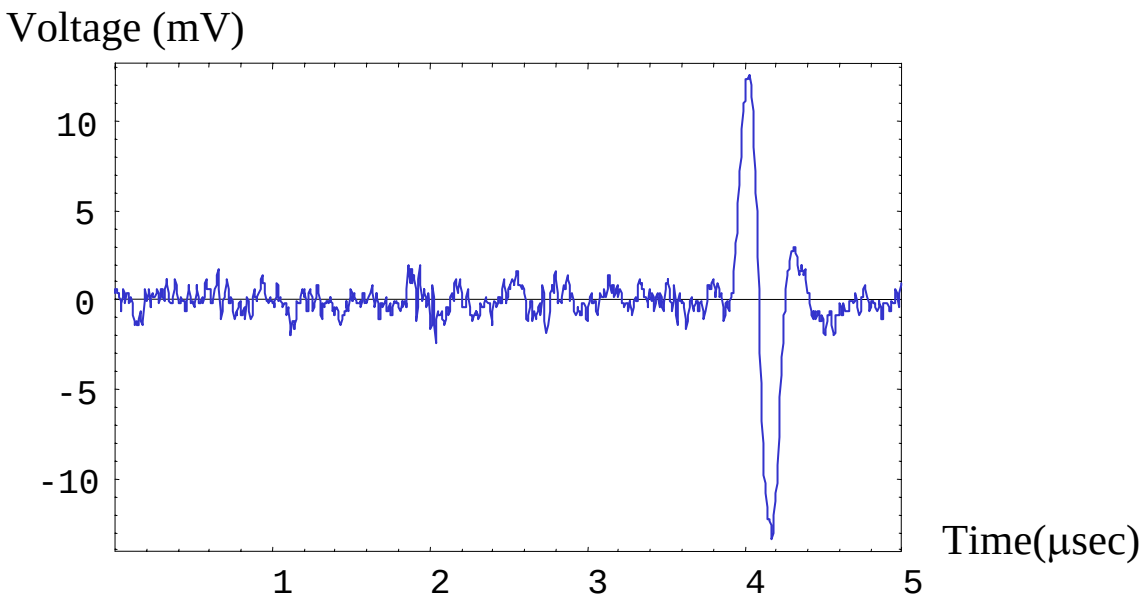
Typical Transfer Function



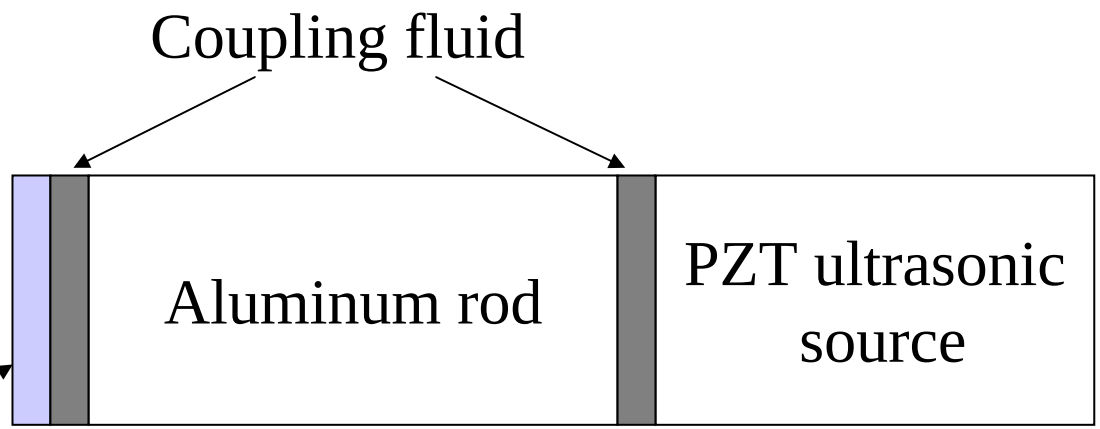




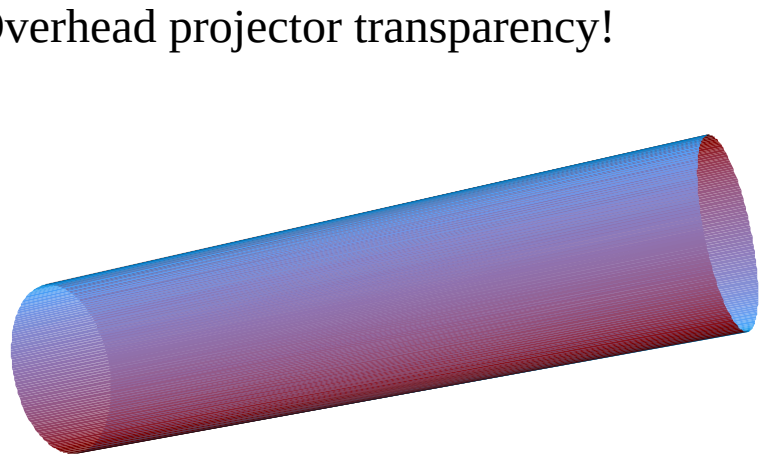
Typical ultrasonic pulse from the setup

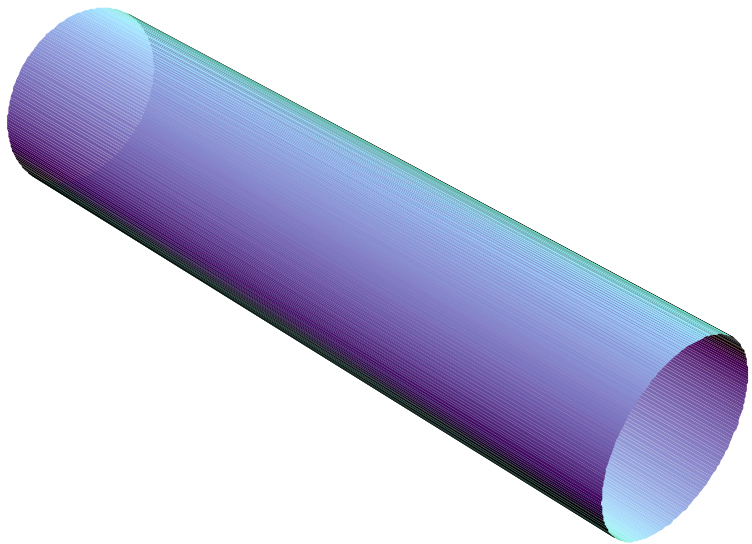


Film on metallic surfaces

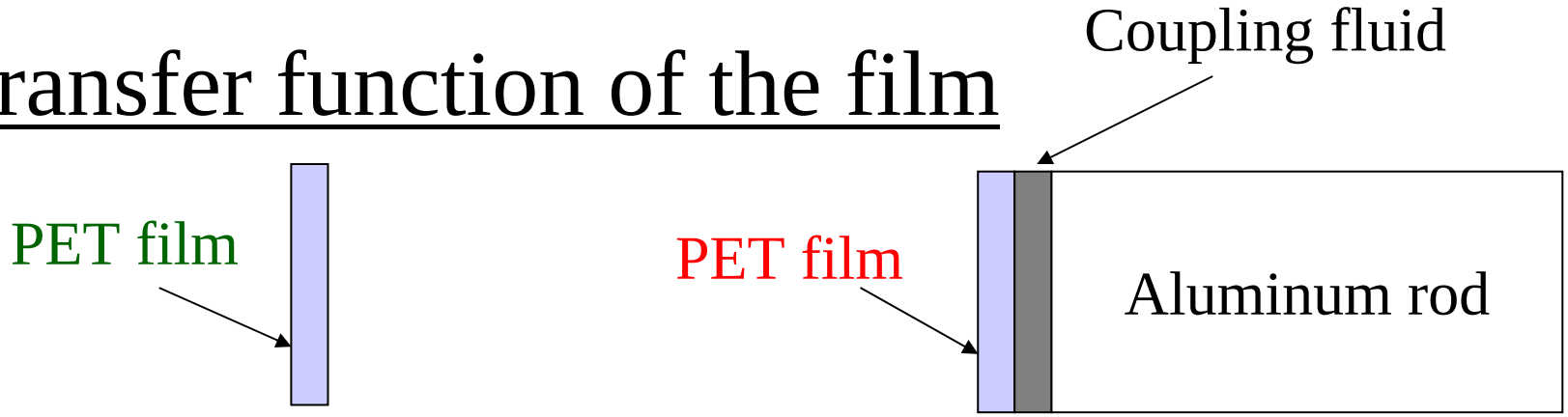


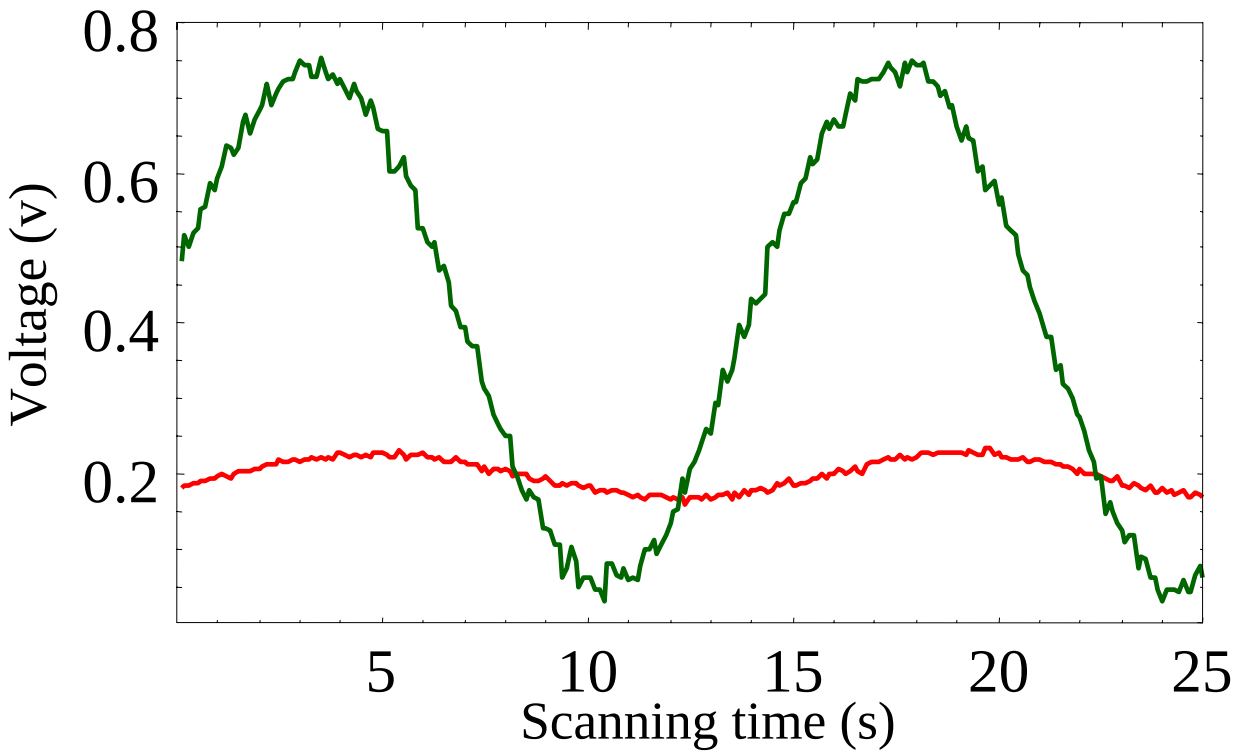
Overhead projector transparency!





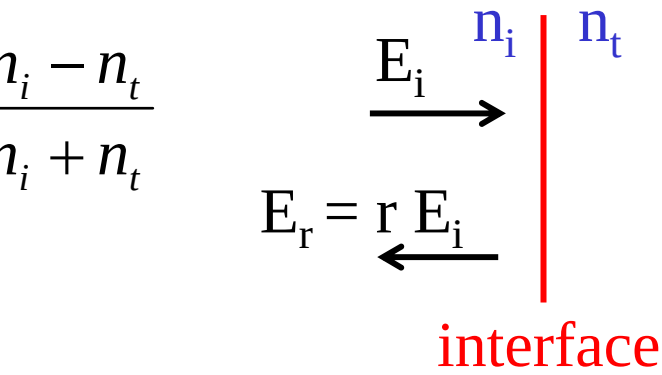
Transfer function of the film

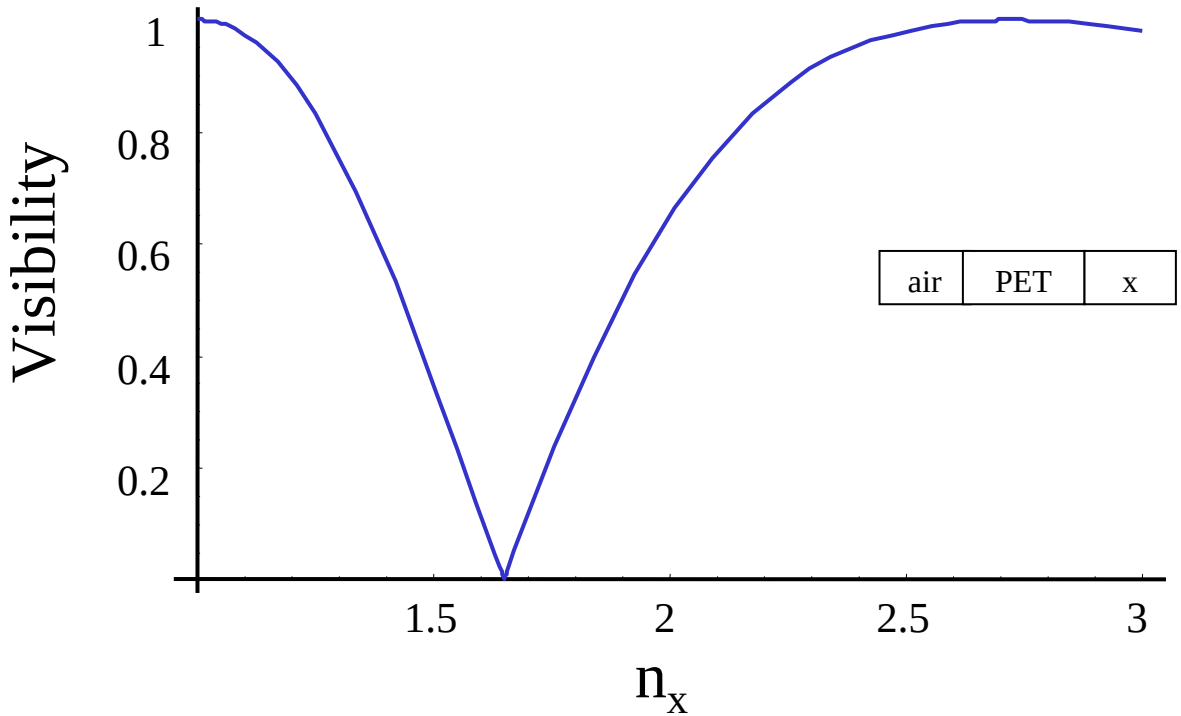




Why lost visibility?

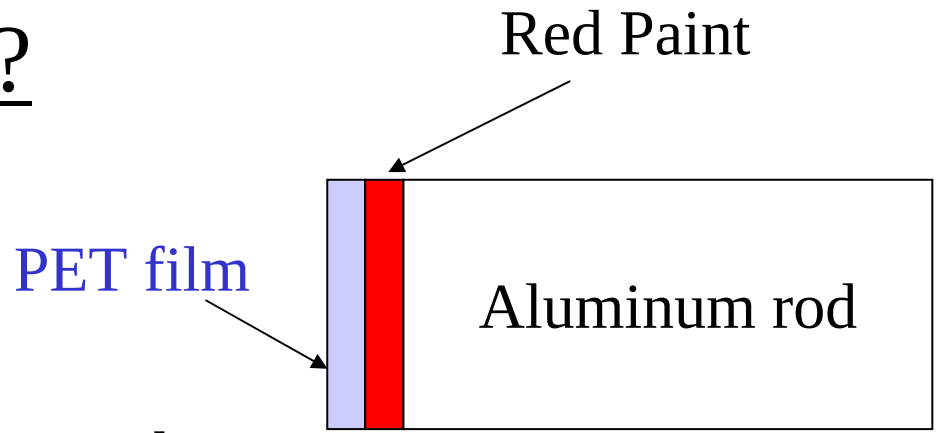
$$r = \frac{n_i - n_t}{n_i + n_t}$$



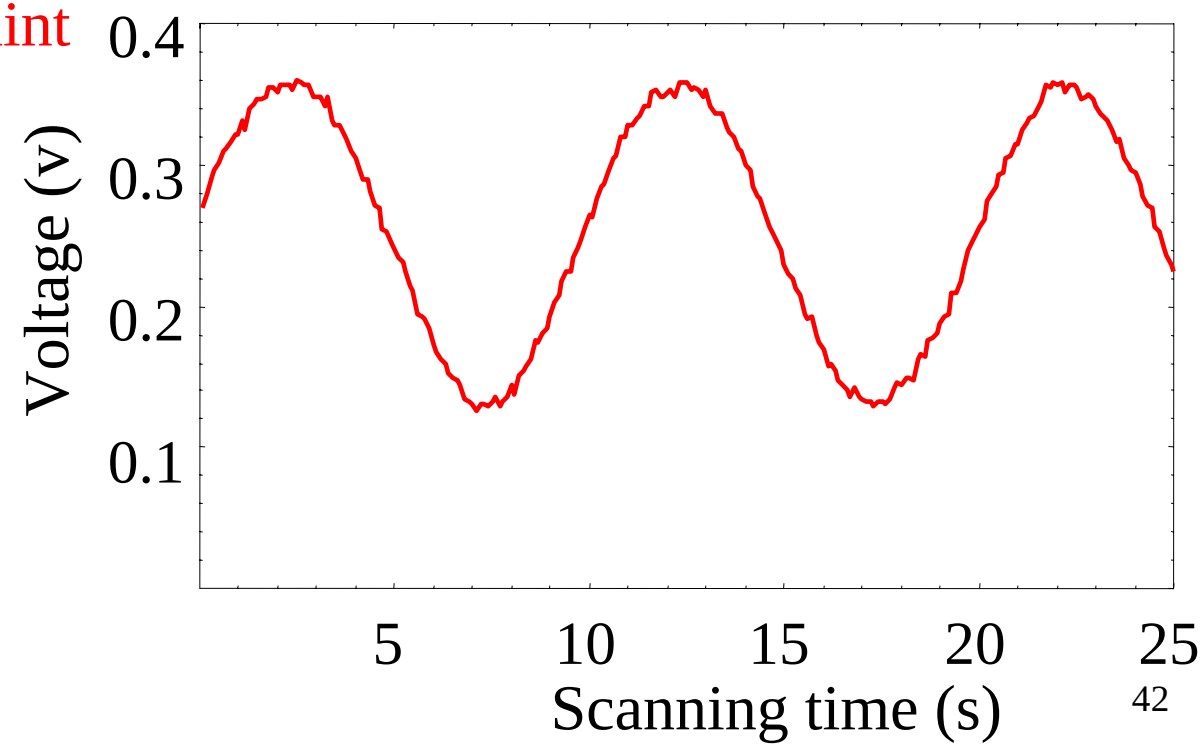


Increase visibility?

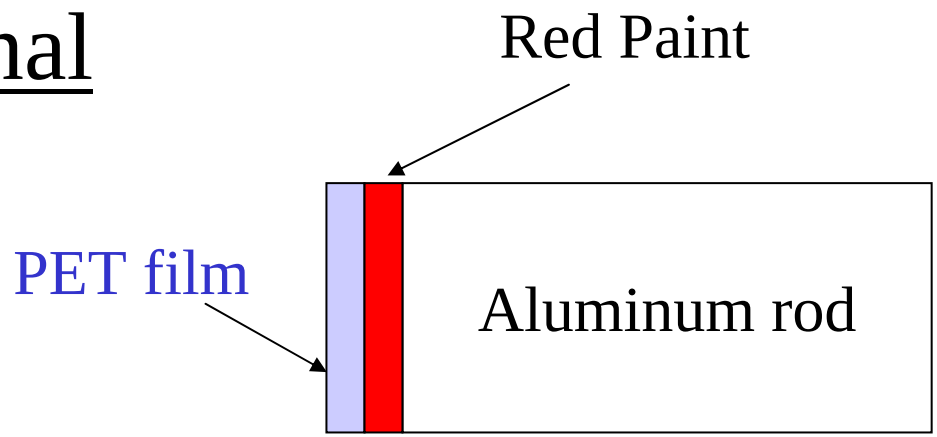
- Use coating layers
  Expensive

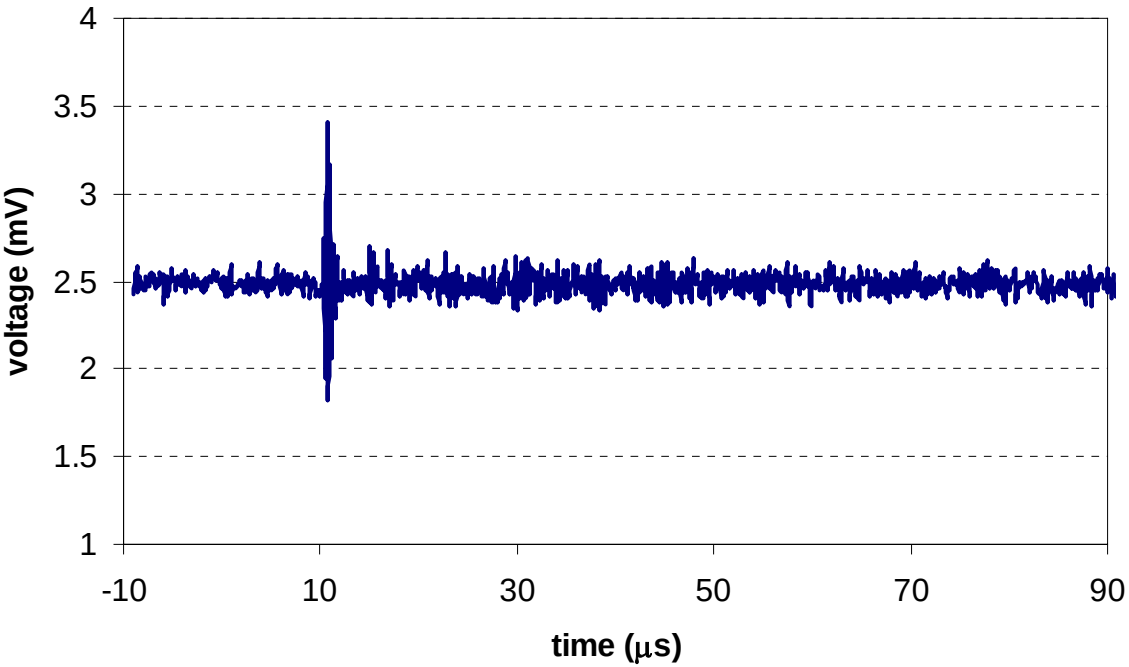


- Use colored coupling material
  Red paint



Ultrasonic Signal





d = 120 μm

δd = 0.3 nm

Thank You For Your Listening

- KFUPM
  Physics Department

- Al-Yammamah Programme
  BAe Systems
  The British Council

- University College London
  Department of Physics and Bioengineering
  Lasers and Endoscopy Group
  Dr. Paul Beard