# Optical Fibre Sensors

- Non-Electrical
- Explosion-Proof
- (Often) Non-contact
- Light, small, snakey => “Remotable”
- Easy(ish) to install
- Immune to most EM noise
- Solid-State (no moving parts)
- Multiplexing/distributed sensors.



# Applications

- Lots of Temp, Pressure, Chemistry
- Automated production lines/processes
- Automotive (T,P,Ch,Flow)
- Avionic (T,P,Disp,rotn,strain,liquid level)
- Climate control (T,P,Flow)
- Appliances (T,P)
- Environmental (Disp, T,P)



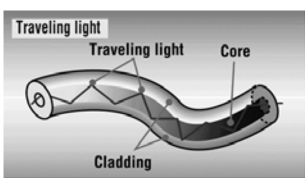
# Optical Fibre Principles

Cladding: glass or Polymer

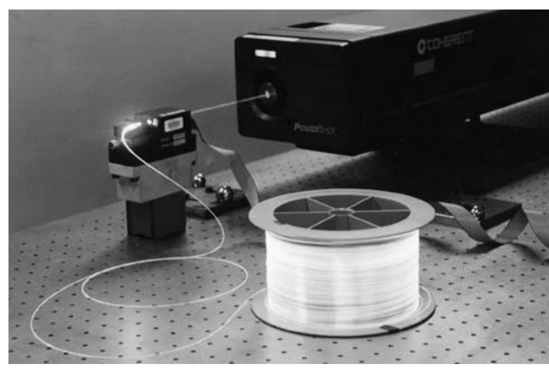
Core: glass, silica, sapphire

TIR keeps light in fibre

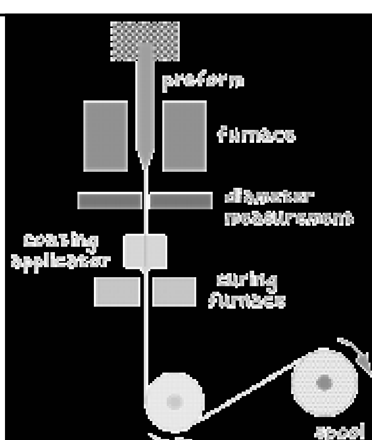
Different sorts of cladding: graded index, single index, step index.



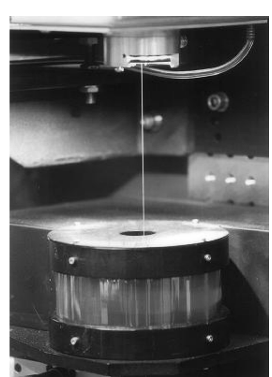
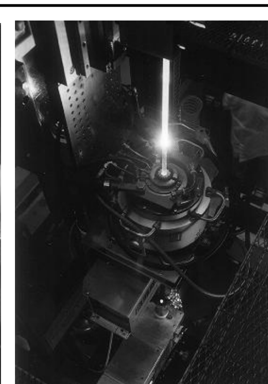




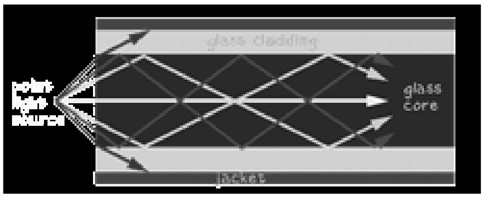




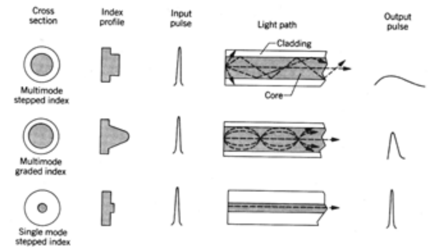




# Optical Fibre Principles

- Snell's Law: $n_1 sin\theta_1 = n_2 sin\theta_2$
- $\theta_{crit} = arcsin(n_2/n_1)$
- Cladding reduces entry angle
- Only some angles (modes) allowed




# Optical Fibre Modes





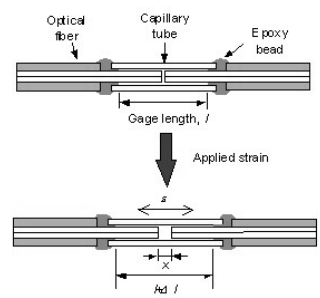

# Phase and Intensity Modulation methods

- Optical fibre sensors fall into two types:
  - Intensity modulation uses the change in the amount of light that reaches a detector, say by breaking a fibre.
  - Phase Modulation uses the interference between two beams to detect tiny differences in path length, e.g. by thermal expansion.



# Intensity modulated sensors:

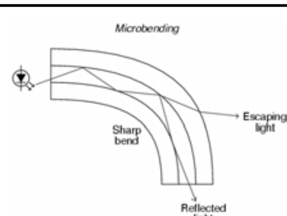
- Axial displacement: $1/r^2$ sensitivity
- Radial Displacement

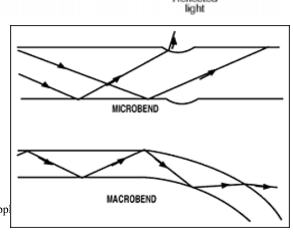





# Microbending (1)

Microbending
- Bent fibers lose energy
- (Incident angle changes to less than critical angle)



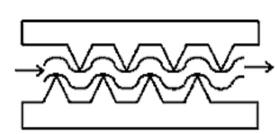






# Microbending (2):

Microbending
- "Jaws" close a bit, less transmission
- Give jaws period of light to enhance effect

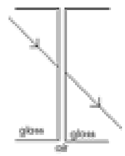
- Applications:
  - Strain gauge
  - Traffic counting

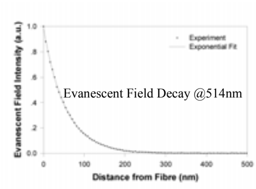


# More Intensity modulated sensors

Frustrated Total Internal Reflection:

- Evanescent wave bridges small gap and so light propagates
- As the fibers move (say car passes), the gap increases and light is reflected



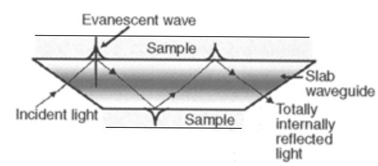

Evanescent Field Decay @514nm



# More Intensity modulated sensors

Frustrated Total Internal Reflection: Chemical sensing

- Evanescent wave extends into cladding
- Change in refractive index of cladding will modify output intensity






# Disadvantages of intensity modulated sensors

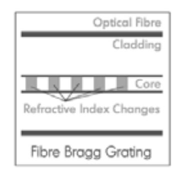
- Light losses can be interpreted as change in measured property
  - Bends in fibres
  - Connecting fibres
  - Couplers
- Variation in source power

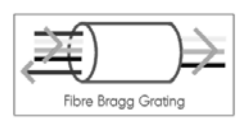


# Phase modulated sensors

Bragg modulators:

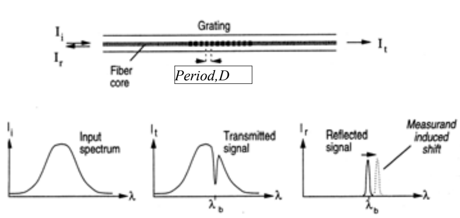
- Periodic changes in refractive index
- Bragg wavelenght ($\lambda_b$) which satisfies $\lambda_b=2nD$ is reflected
- Separation (D) of same order as than mode wavelength






## Phase modulated sensors

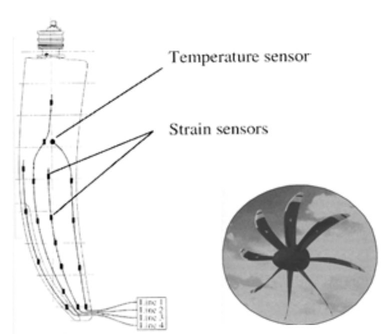



$\lambda_b=2nD$

- Multimode fibre with broad input spectrum
- Strain or heating changes *n* so reflected wavelength changes
- Suitable for distributed sensing

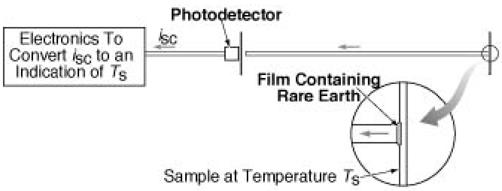


## Phase modulated sensors – distributed sensors



# Temperature Sensors

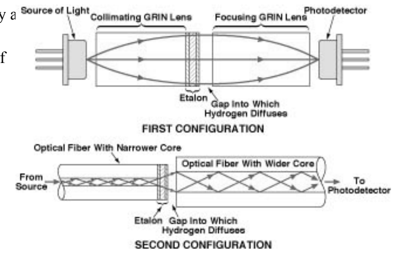
- Reflected phosphorescent signal depends on Temperature
- Can use BBR, but need sapphire waveguides since silica/glass absorbs IR




# Phase modulated sensors

Fabry-Perot etalons:

– Two reflecting surfaces separated by a few wavelengths
– Air gap forms part of etalon
– Gap fills with hydrogen, changing refractive index of etalon and changing allowed transmitted frequencies.






# Digital switches and counters

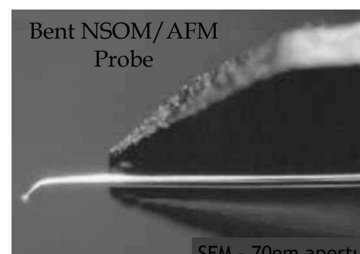
- Measure number of air particles in air or water gap by drop in intensity
  - Environmental monitoring
- Detect thin film thickness in manufacturing
  - Quality control
- Counting things
  - Production line, traffic.



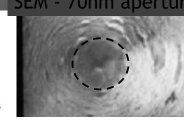
## NSOM/AFM Combined

•Optical resolution determined by diffraction limit (~$\lambda$)

•Illuminating a sample with the "near-field" of a small light source.
• Can construct optical images with resolution well beyond usual "diffraction limit", (typically ~50 nm.)




SEM - 70nm aperture





## NSOM Setup

Ideal for thin films or coatings which are several hundred nm thick on transparent substrates (e.g., a round, glass cover slip).