The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
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International Atomic
Energy Agency

SMR 1829 - 17

Winter College on Fibre Optics, Fibre Lasers and Sensors

12 - 23 February 2007

Passive Fibre Components

(PART 3)

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“Passive” Fibre Components

Electrically controlled fibers

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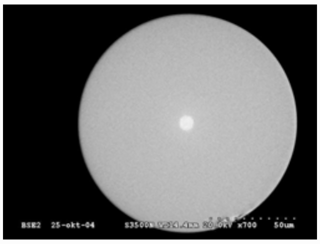
Optical Fibers

Optical fibers are great

- Minimal loss
- Single mode propagation (no difraction)
- High power compatible
- Stable and reliable (e.g., in airplanes)
- Light and CHEAP
- Fun and useful in NLO
- Telecom
- Fiber lasers
- Sensors
- Industry
- Medical

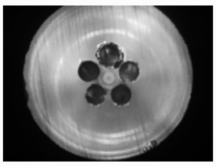
Standard telecom fiber



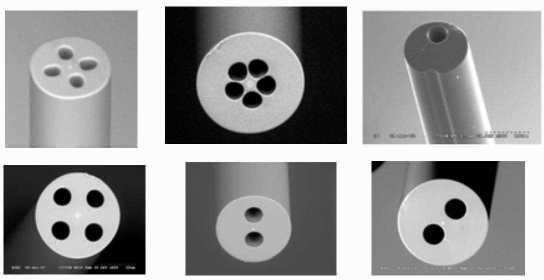
"Immune to electromagnetic interference"

Acreo's fibers with holes

Drill preform



Draw fiber



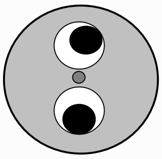
Vision

Electrical control of light in fibers

Electrodes needed
Wire insertion

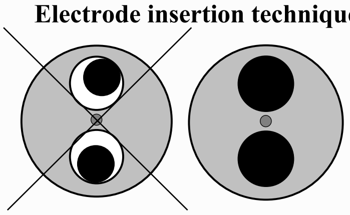
Disadvantages
- Expensive
- Time consuming (manual operation)
- Long lengths (~1 m) difficult
- Position of wire in hole not determined
- Non-uniform field applied
- Low reproducibility of performance
- Impedance not constant

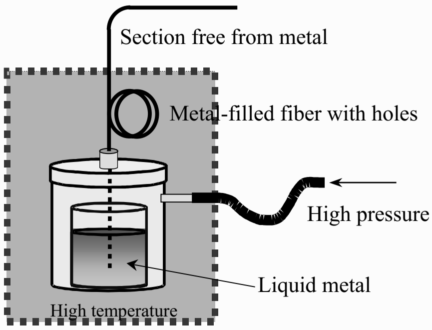
Advantage: keeps PhD student busy



Metal filling

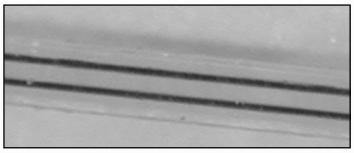
Electrode insertion technique

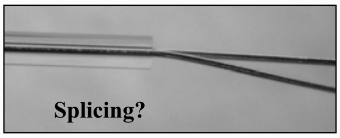




Coating preserved

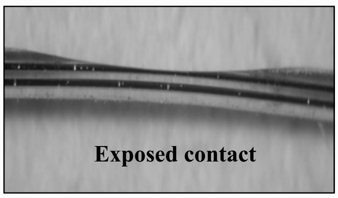
Continuous electrodes

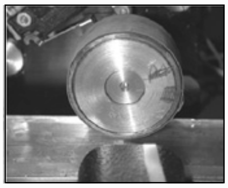




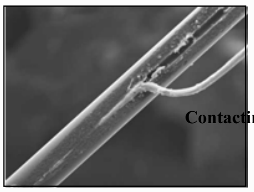
22 m long device fabricated

Side-polishing for contacts

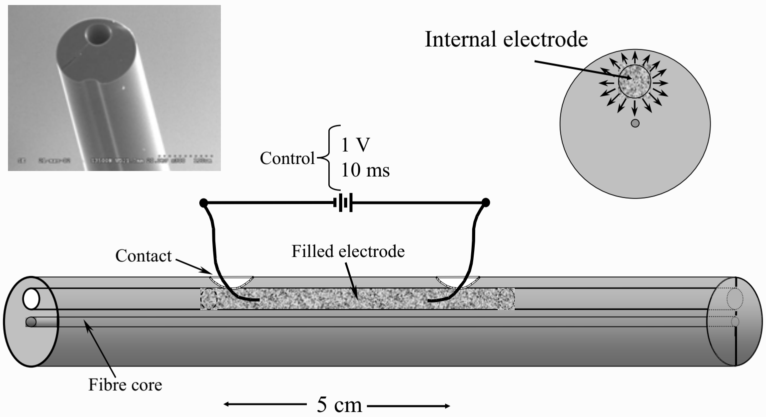




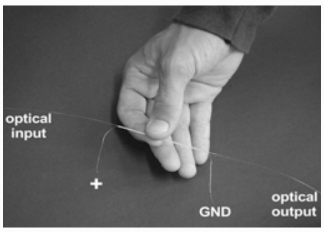
Polishing machine

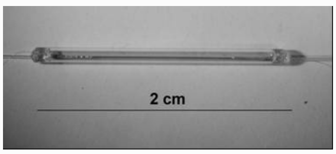


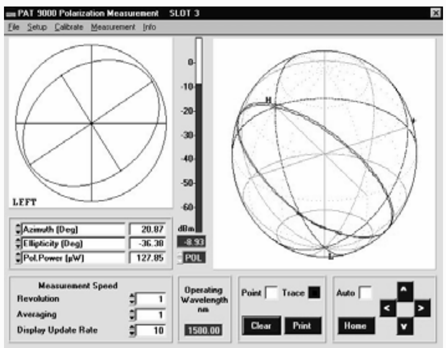
1) Polarization control

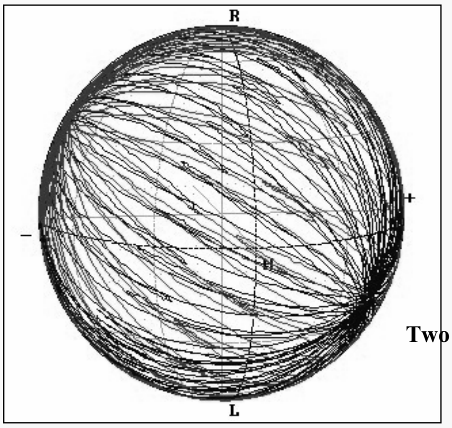


Polarization control

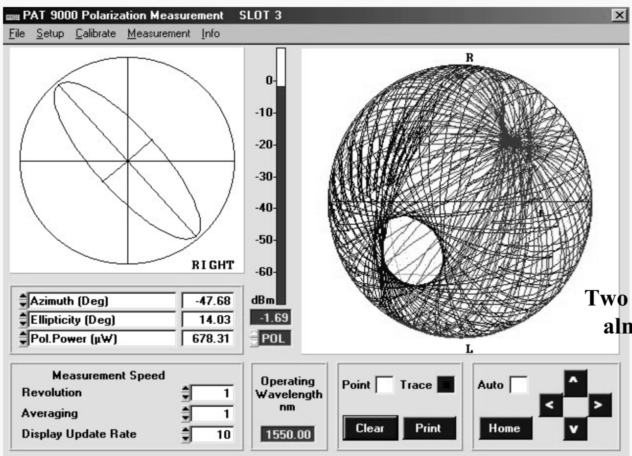






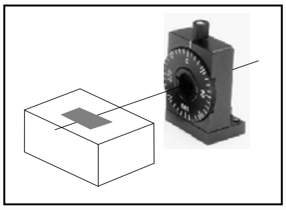


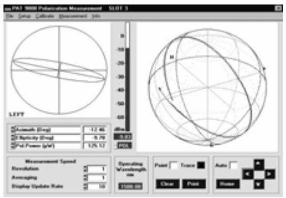
Two devices at 45º



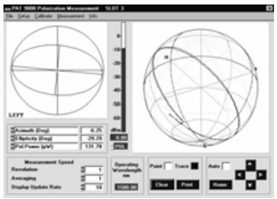
Two devices at almost 45º

Adjusting birefringence axis

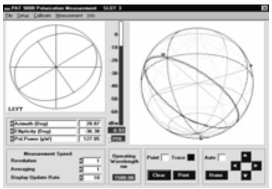




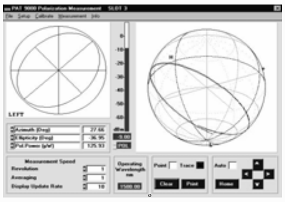
Rotation angle = -60



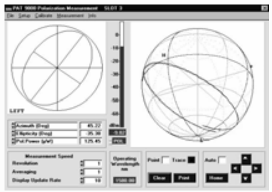
Rotation angle = -20



Rotation angle = 20°

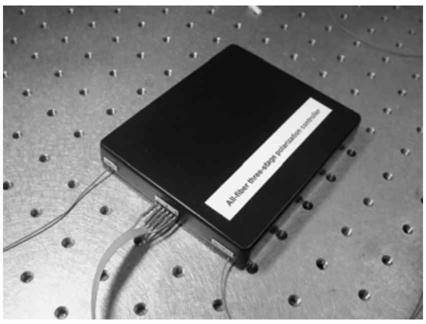


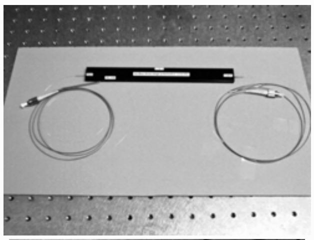
Rotation angle = 30°

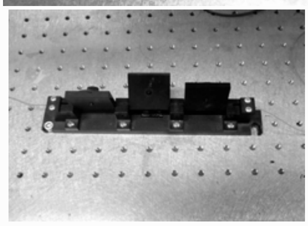


Rotation angle = 40°

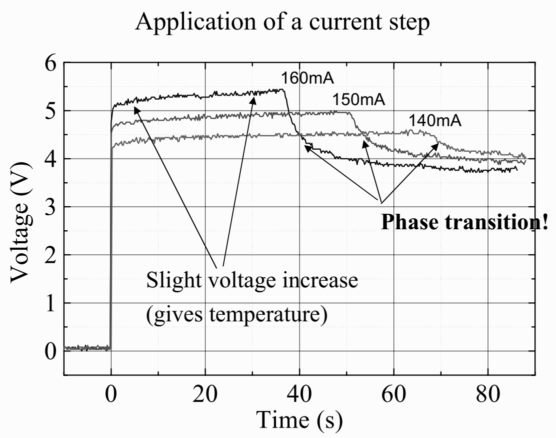
Packaging



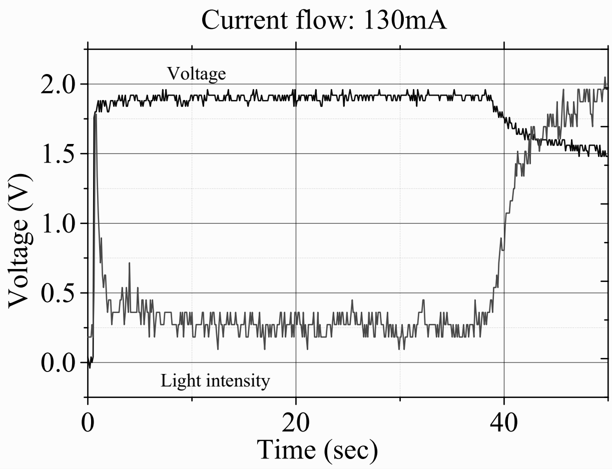




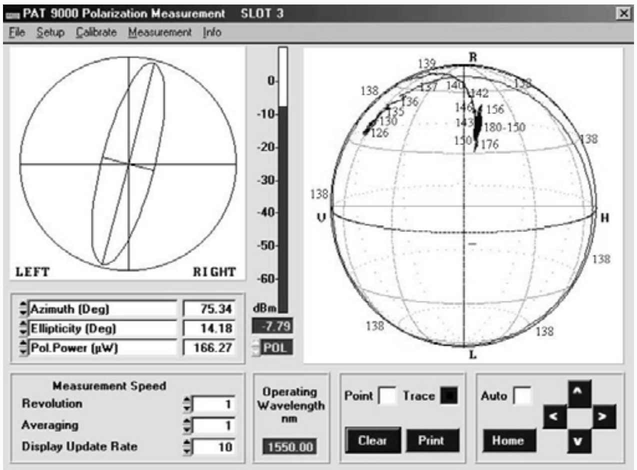
Electrical characteristics



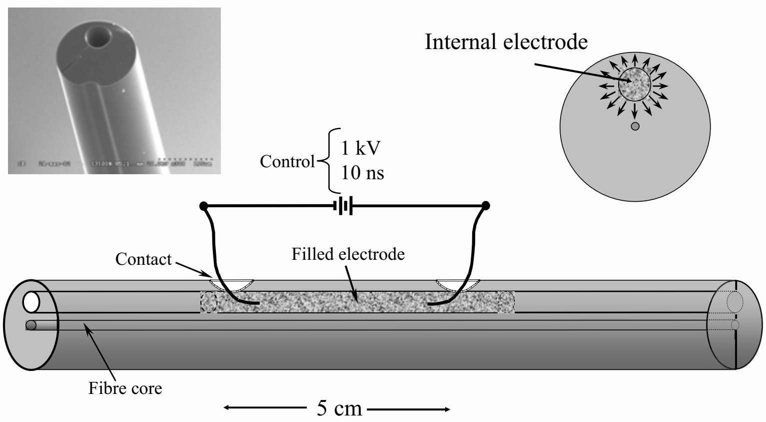
Effect of stress release



Polarization rotation during phase transition



2) Polarization switch



Polarization switch

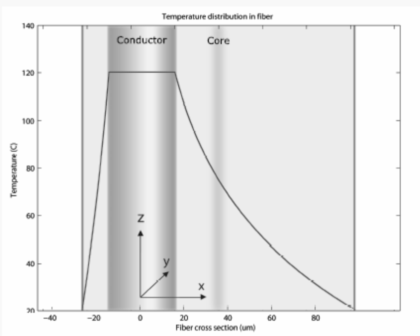
Drive device with kV pulses over ns

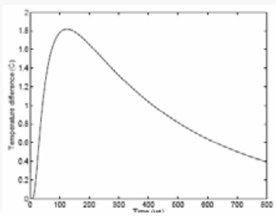
Three main physical processes

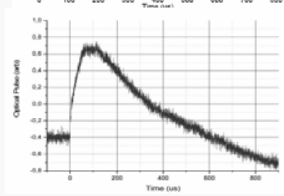
- Thermal (µs)
- Acoustic resonances (~20-60 ns)
- Mechanical expansion (very fast < ns)

Thermal effect

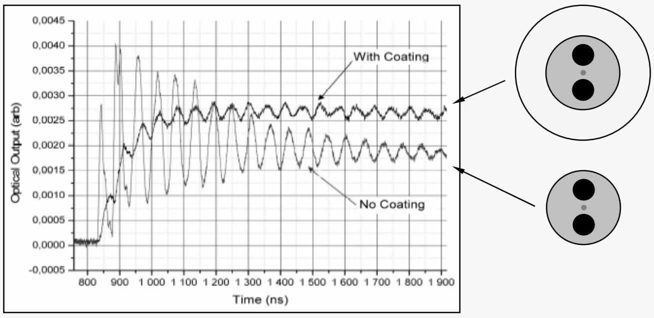
Small temperature gradient across the core (non-isotropic)



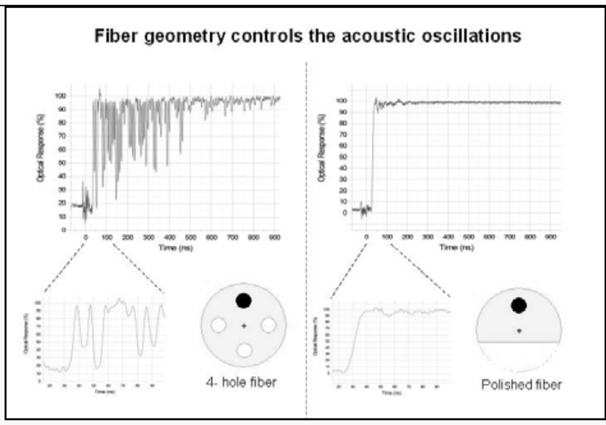




Acoustic effect

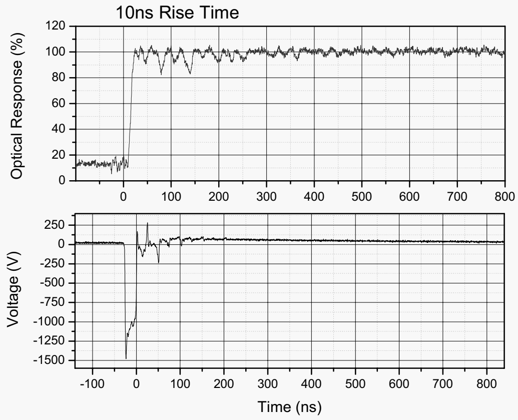


Acoustic effect



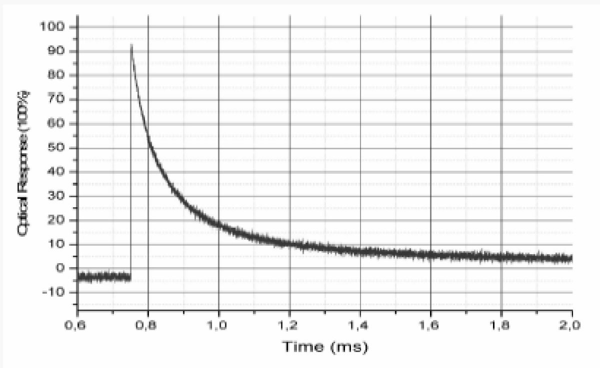
Polarisation switch: response between crossed polarizers

Mechanical effect dominates

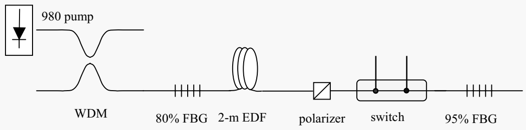


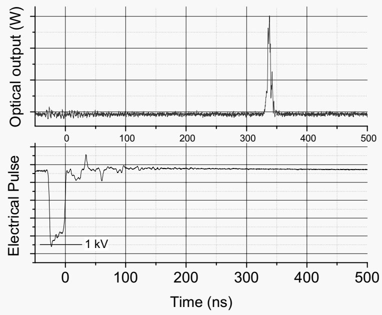
Polarisation switch: response between crossed polarizers

Falltime (e^{-1}) ~200 µs



Q-switching fiber laser, preliminary result





Pulse duration (FWHM): 10 ns

Pump power: 300 mW

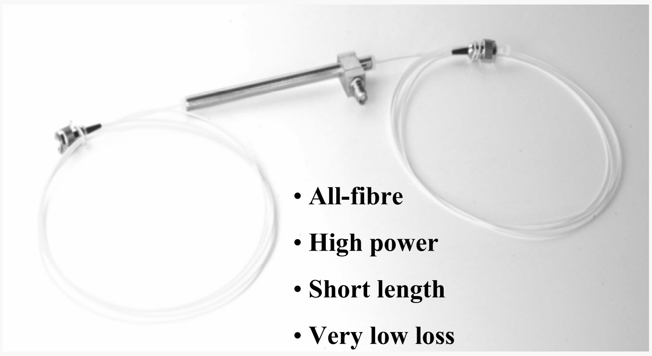
Peak power: 500 W

Pulse energy: 1 uJ

Average output: 1 mW

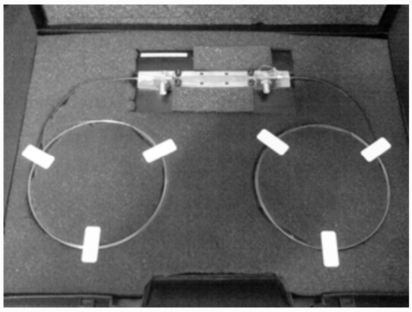
Repetition frequency 200 Hz

Polarization switch



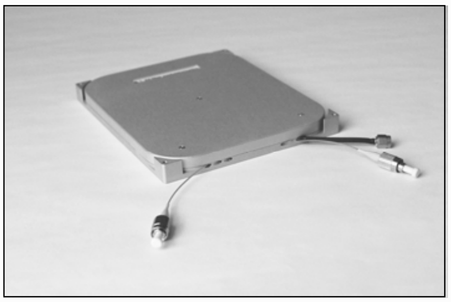
- All-fibre
- High power
- Short length
- Very low loss

Shipping a component



3) Electrooptical fibers

- Cheap
- High power
- Fast non-resonant
- Low loss



Electrooptical fibers

Small amplitude: harmonic motion

$$\mathbf{P = \varepsilon_o \chi^{(1)} E}$$

Large amplitude: motion not harmonic

$$\mathbf{P = P_L + P_{NL}}$$

$$\mathbf{P} = \underbrace{\varepsilon_o \chi^{(1)} \mathbf{E}}_{\text{linear}} + \underbrace{\varepsilon_o \chi^{(2)} \mathbf{E.E} + \varepsilon_o \chi^{(3)} \mathbf{E.E.E}}_{\text{nonlinear}} + \ldots$$

$\chi^{(2)}$: second order nonlinearity

$\chi^{(3)}$: third order nonlinearity

Electrooptical fibers

In glass fibers

$$\mathbf{P} = \varepsilon_o \chi^{(1)} \mathbf{E} + \varepsilon_o \cancel{\chi^{(2)}} \mathbf{E.E} + \varepsilon_o \chi^{(3)} \mathbf{E.E.E} + \ldots$$

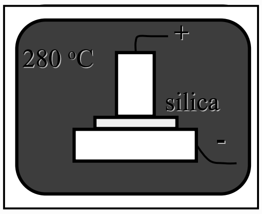
When a strong field is applied

$$\mathbf{P} = \varepsilon_o \chi^{(1)} \mathbf{E} + \varepsilon_o \cancel{\chi^{(2)}} \mathbf{E.E} + \varepsilon_o \underbrace{\chi^{(3)} \mathbf{E_{appl} E_{appl}}}_{\text{Kerr effect}} \mathbf{E} + \ldots$$

When a DC field is recorded (poling)

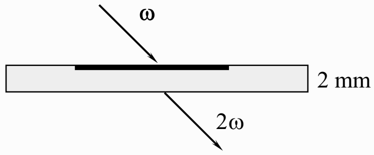
$$\mathbf{P} = \varepsilon_o \chi^{(1)} \mathbf{E} + \varepsilon_o \cancel{\chi^{(2)}} \mathbf{E.E} + \varepsilon_o \underbrace{\chi^{(3)} \mathbf{E_{rec}}}_{\chi^{(2)}_{eff}} \mathbf{E_{appl}} \mathbf{E} + \ldots$$

Thermal poling



Poling fused silica

R. Myers, S. Brueck et al, Opt. Lett. 16, 1732 (1991)

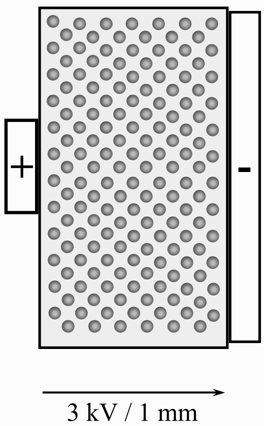


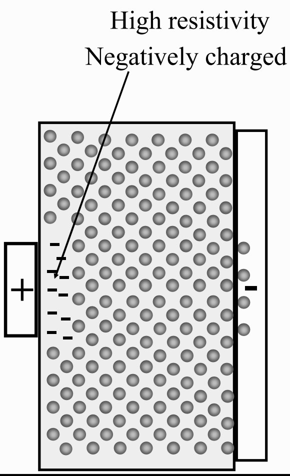
Strong recorded electric field
$\sim 10^8 - 10^9$ V/m !
Top layer < 15 μm

Create an effective $\chi^{(2)}$

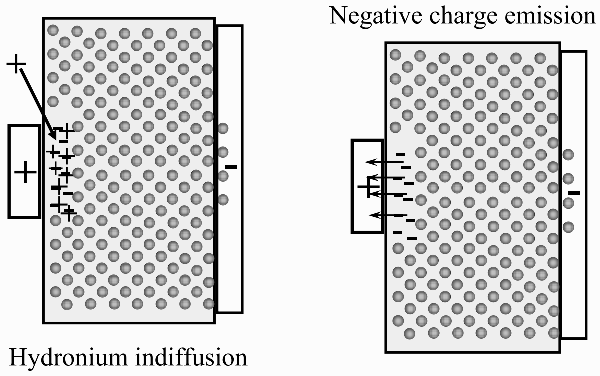
$$\chi^{(3)} E_{dc} . E . E \sim \chi^{(2)}_{eff} E . E$$

Poling mechanisms

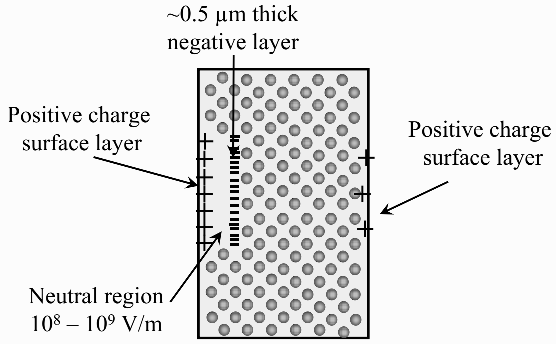




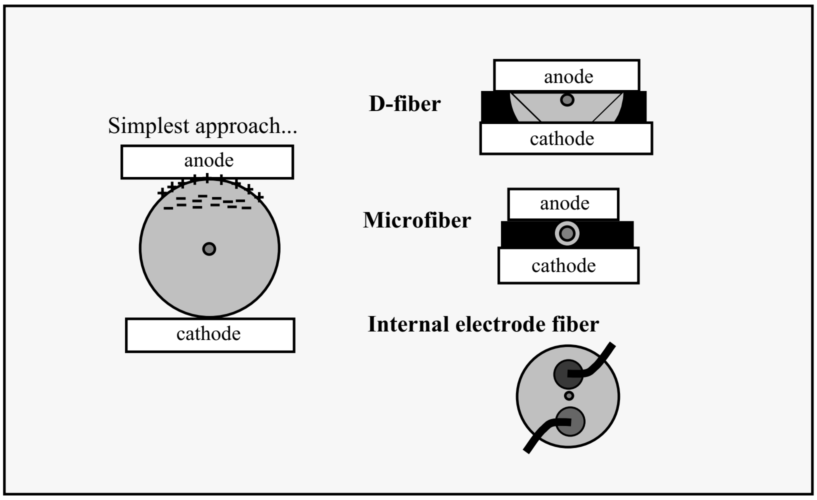
Neutralization effects



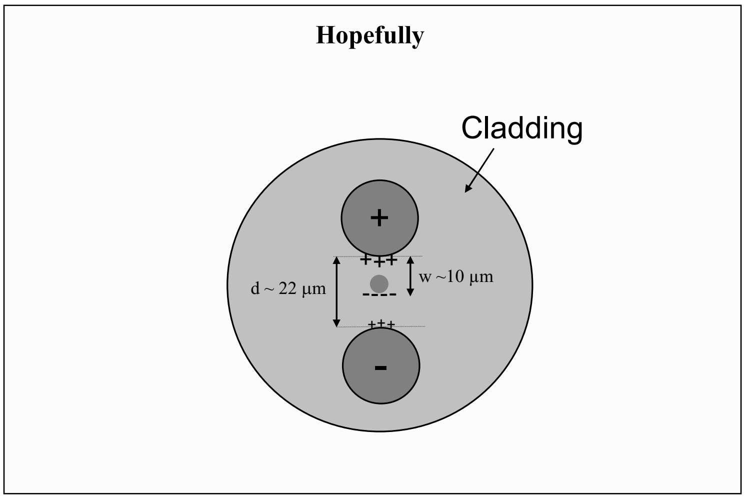
After poling: thin sample



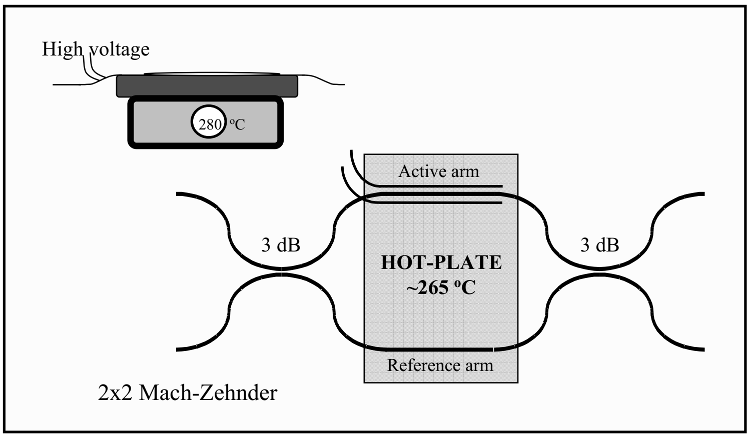
Poling fibers



Spatial distribution of recorded field

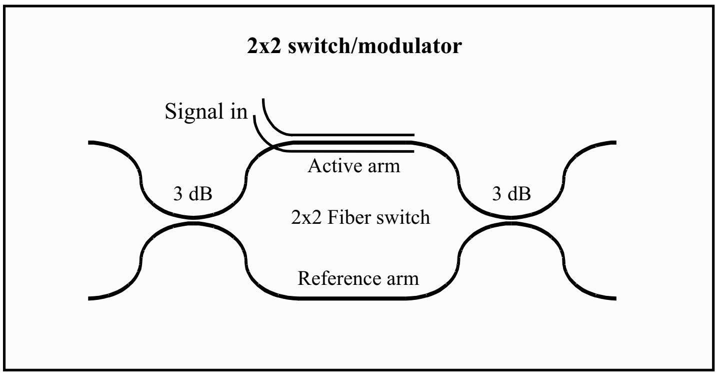


Poling on hot-plate



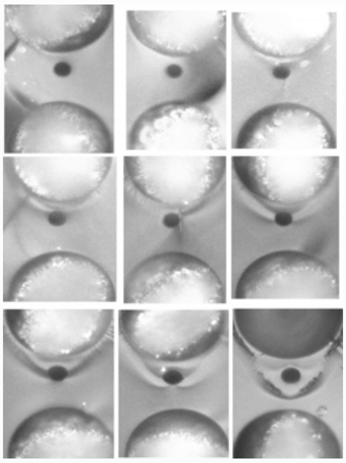
After poling

Phase → Amplitude modulation



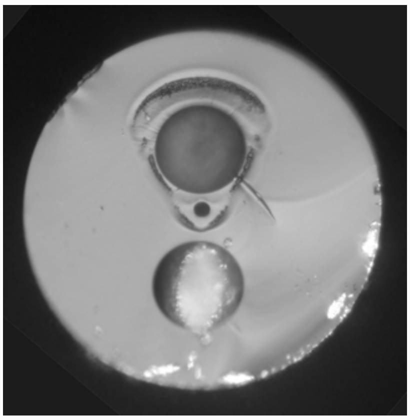
Electrooptical fibers

Evolution of
depletion region
in a poled fibre



Thermal poling

Fibre cross-section after poling and etching



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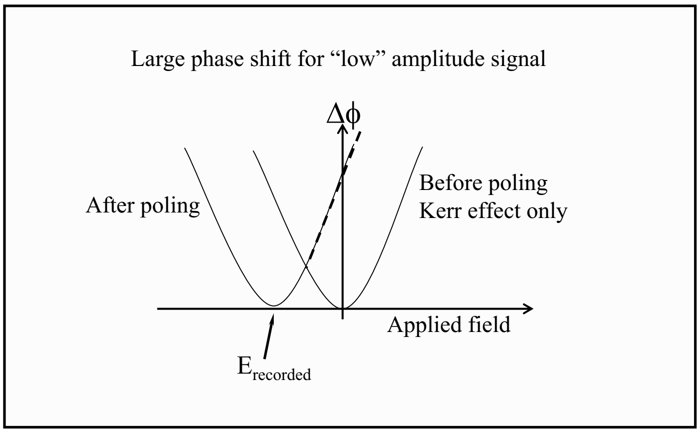
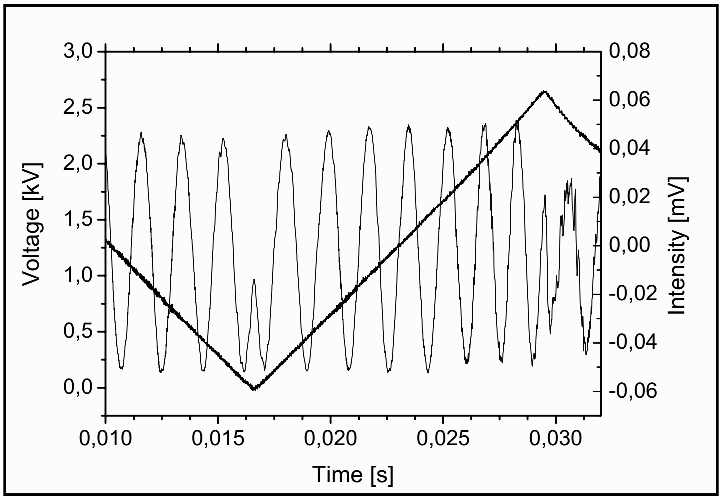
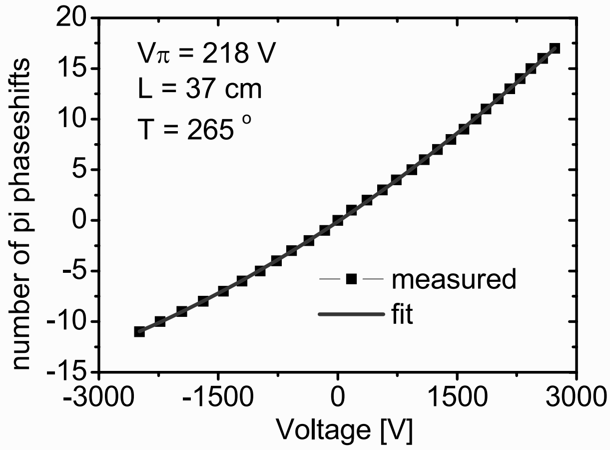
Effect of poling



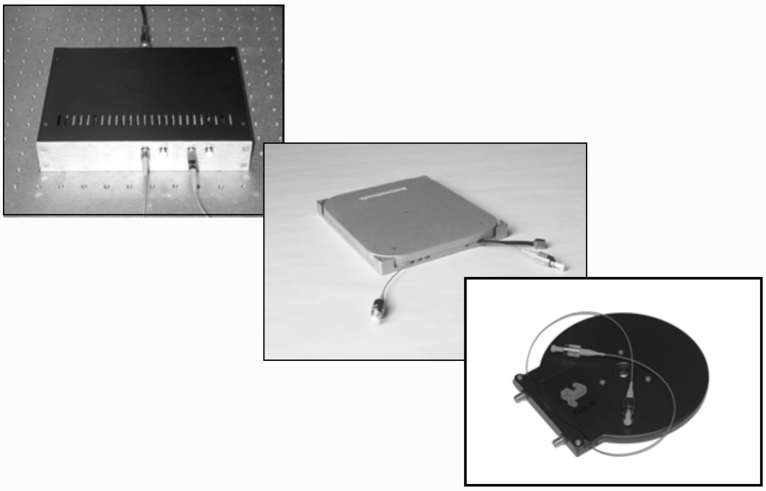
Probing interferometer with voltage ramp



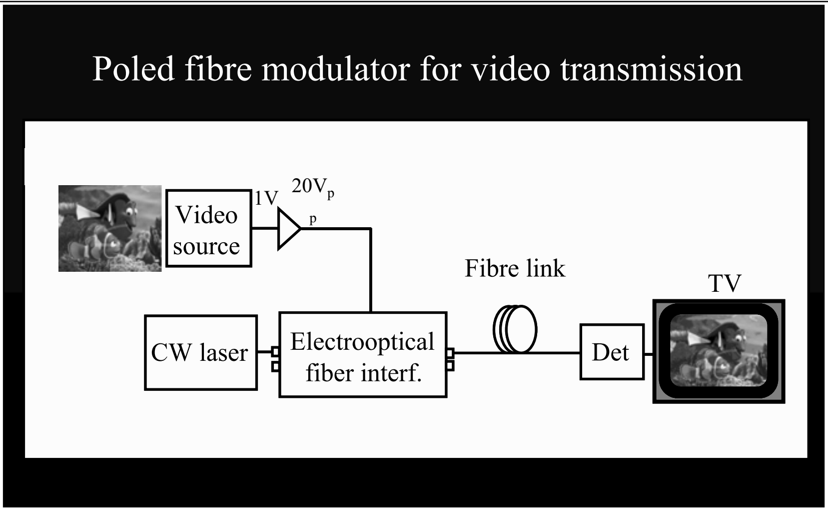
Electrooptical fibers



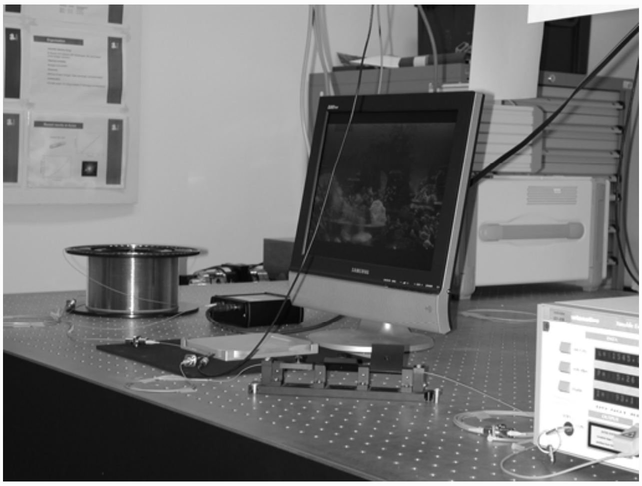
Packaging



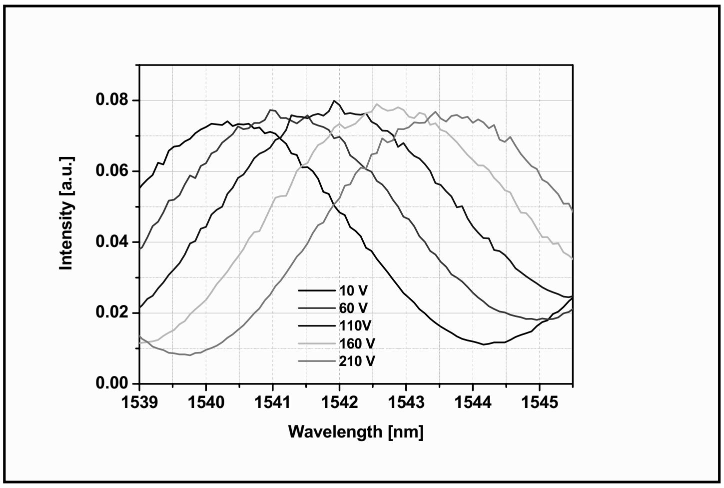
Video transmission



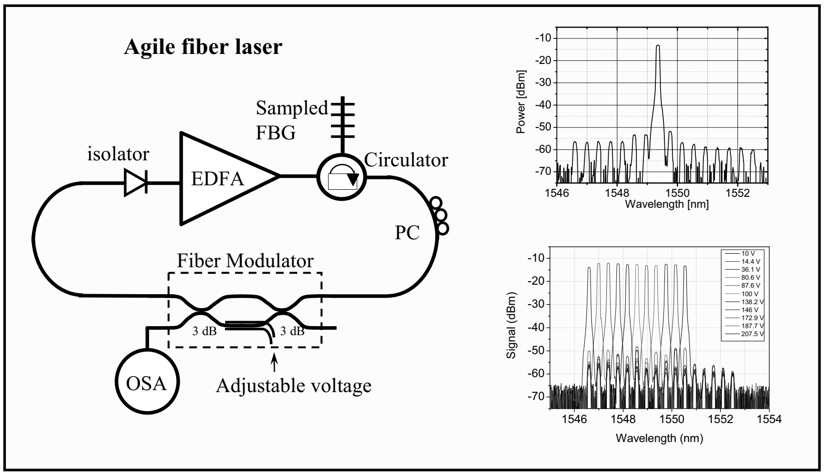
Video transmission



Electrooptic tuning of fiber switch

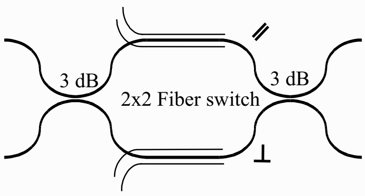


Experimental set-up

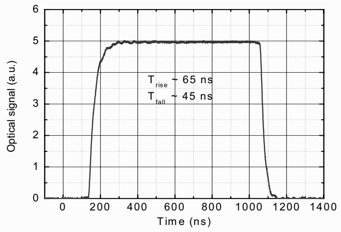


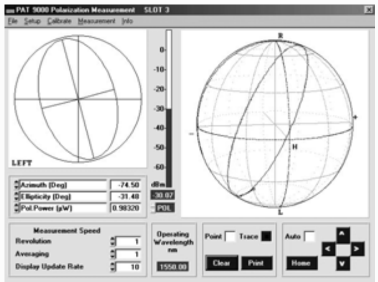
All-fiber polarization control

Polarization rotation if polarization at output is crossed

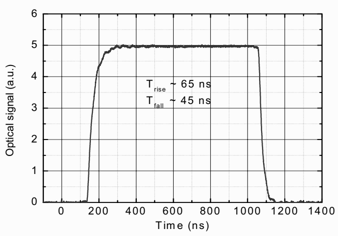


0 V to 77 V applied

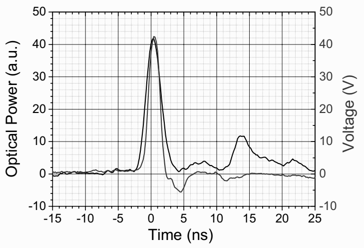




Where we are (technical)



<50 ns polarization rotation



38 V switching voltage at 1.55 µm

<2 dB loss

<2 ns response in travelling wave

“Passive” fiber components

Interesting and challenging physics

Useful !!!

Much space for creativity