Plastic Optical Fibres

for Gigabit Networking
Overview

- POF overview and GI-POF
- Networking applications for GI-POF
- GI-POF product development status
- GI-POF demonstration projects, 2004
Compared with MMF, copper and wireless, POF offers the following advantages:

- Ruggedness, flexibility, easy handling, simplified architecture
- Availability of inexpensive all-plastic connectors
- Reduction in installation cost
- Free from EMI problems
- The preference for consumer electronics
- Stability (non-flammability and excellent chemical resistance)
- Availability of low cost light source (LED, RCLED, VCSEL) from visible to near IR (650, 780, 850, 1300 nm) and high-speed detectors
Advantages of Plastic Optical Fibers (POF)

Ease of Installation

- No expensive termination tooling required
- Simple end preparation (5-10 second dry polish)
- Smaller installed bend radius allowed than silica fiber (non-brittle)
- Large core diameters are NOT important for POF in Gb/s applications

Performance

- High bandwidth over broad wavelength range (lower material dispersion than silica)
- Simple methods for increasing BW using restricted launch (10 Gb/s x 100m)
- Lower modal noise than multimode silica fibers
- Radiation hardness better than silica multimode fiber
Two main materials for POF today:

**PMMA (~ PLEXIGLAS)**
- CH based material
- Attenuation about 130 dB/km
- Operating mostly limited to 650
- Short link (up to 50 m)

**PERFLUORINATED (~ TEFLON AF, CYTOP)**
- CF based materials
- Low attenuation (now down to 20 dB/km)
- Operating at 650, 850 & 1300 nm
- Long link (up to 1 km)
Two main fibre types: SI-POF or GI-POF

**Step Index SI-POF**

- Core
- Cladding

Demonstrated bit rate:
- 500 Mb/s (100m)

**Graded Index GI-POF**

- Core
- Cladding

Demonstrated bit rate:
- 10 Gb/s (100m)
Mélanges intrinsèques d'atténuation simulation

Amorphous PE
C4H8

Amorphous PTFE
C4F8

longueur d'onde (nm)

atténuation (dB/km)
POF vs GOF on attenuation

Loss / dB/km

Wavelength / nm

650 nm  850 nm  1300 nm

LOW ˚NA PMMA
GI-CYTOP
HCS MMF
GI-CYTOP theory
MMF
SMF

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POF Applications

Automotive
- SI PMMA

Focus on mechanical properties

Industrial applications
- SI PMMA ++

Focus on combination of bandwidth and mechanical properties

Aerospace
- GI PMMA

10/100MBps

> 1 GBps

Interconnection
- GI CYTOP

Central office

Fibre to the Home

Home Networking
- GI CYTOP

Local Area Network

GI CYTOP
- POF combines benefits of both copper and glass

![Performance Comparison Graph]

- Data Rate
- Distance
- BMI
- Packing Density
- Low Weight
- Pulling Force
- Temperature Range
- Lifetime
- Flexibility (Bending Radius)
- Vibration
- Compatibility
- Short Installation Time
- Special tools
- Robustness
- Handling

Legend:
- Glass Fibre
- POF
- Cat.6 Copper UTP

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Wavelength Support

- 3 windows
- Broad range of wavelength supported:
  650nm 850nm 1300nm
- Flat curve allows deviation from center wavelength

![Graph showing fiber attenuation (dB/km) vs. wavelength (nm).](image)
High bandwidth POF types

- Bandwidth above 1 Gbps
- CYTOP Polymer only
- GI-POF only

Advantages

- Support for all applications (High Speed and Low Speed)
- Support for all wavelength (510, 650, 850, 1300nm)
- Support for existing light sources (used for Silica fibre)
- Known cable construction from GOF cable
Fibre Products

- **Type 1:**
  - **120µm core, 500µm outer diameter**
  - Diameter supports "Ease of Installation" and enables on-site termination
  - High Speed, 1Gbps
  - Applications: **LAN, Industrial, Telecom, (near-term)**
**Fibre Products**

- **Type 2:**
  - 62.5 µm core, 250µm outer diameter
  - Diameter allows higher bandwidth and ribbon cable structure
  - Ultra High Speed, 10Gbps
  - Applications: **Interconnect, LAN, (long-term)**

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**Diagram:**
- PMMA Layer
- CYTOP
- Core
- Cladding
- Reinforcement
- 62.5 µm core diameter
- Width (w) 2100 µm
- Thickness (h) 310 µm

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### Draft specifies 4 new types of perfluorinated GI-POF

<table>
<thead>
<tr>
<th>Principal applications</th>
<th>A4e</th>
<th>A4f</th>
<th>A4g</th>
<th>A4h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer diameter (µm)</td>
<td>750 ± 20</td>
<td>490 ± 10</td>
<td>490 ± 10</td>
<td>250 ± 5</td>
</tr>
<tr>
<td>Core diameter (µm)</td>
<td>500 ± 20</td>
<td>200 ± 10</td>
<td>120 ± 10</td>
<td>62.5 ± 5</td>
</tr>
<tr>
<td>Attenuation at 650 nm (dB/km)</td>
<td>≤100 dB/km</td>
<td>≤100 dB/km</td>
<td>≤100 dB/km</td>
<td>n/a</td>
</tr>
<tr>
<td>Attenuation at 850/1300 nm (dB/km)</td>
<td>≤40 dB/km</td>
<td>≤40 dB/km</td>
<td>≤40 dB/km</td>
<td>≤40 dB/km</td>
</tr>
<tr>
<td>Minimum modal bandwidth at 650 nm (MHz-km)</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>n/a</td>
</tr>
<tr>
<td>Minimum modal bandwidth at 850/1300 nm (MHz-km)</td>
<td>150-300</td>
<td>150-400</td>
<td>150-500</td>
<td>150-500</td>
</tr>
</tbody>
</table>

**Fibre standards**

<table>
<thead>
<tr>
<th>IEC 60793-2-40</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC SC86A/WG1</td>
</tr>
</tbody>
</table>
• Standards
  ◦ POF included in Draft for ISO/IEC 24702 Industrial Cabling
    ■ New Fibre Classes OF100 and OF200

```
Table 3 – Channel attenuation of optical fibre cabling channels

<table>
<thead>
<tr>
<th>Class</th>
<th>Maximum channel attenuation (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>510 nm</td>
</tr>
<tr>
<td>OF-25</td>
<td>ffs</td>
</tr>
<tr>
<td>OF-50</td>
<td>ffs</td>
</tr>
<tr>
<td>OF100</td>
<td>ffs</td>
</tr>
<tr>
<td>OF-200</td>
<td>ffs</td>
</tr>
</tbody>
</table>

OF 300  | 1310   | 1550   |
OF 500  |        |        |
OF 2000 |        |        |
OF 5000 | 4.0    | 4.0    |
OF 10000| 6.0    | 6.0    |
```
Nexans Activities

- Nexans Activities are concentrated in NRC Lyon (Central Nexans Research Centre, France)

- Nexans participates in three EU Projects
  - Motifes
  - Home Planet
  - Interconnect by Optics

- To develop interoperable GI-POF products, cooperation among participants to develop connectivity and transceiver components for GI POF
Task:
- Basic R&D (Materials + Properties)
- Development of Preform Production
- Research: Comparison of different production technologies

Status 2004:
- POF drawing facilities operating; fibres reach target properties
  - Type 1 120/500µm
  - Type 2 62.5/250µm
- Sample quantities available
- Work ongoing for process control and optimisation
Achievements

✓ Good optical performance
  ✓ 10 times better attenuation than SI POF
  ✓ Support of multiple wavelength 650 / 850 / 1300nm
  ✓ Good Index profile; Independence of launching conditions
  ✓ High bandwidth (equal to GOF 62,5/125)
  ✓ Less modal noise than GOF (better quality for video signal)
  ✓ Works with available equipment, 850µm cards

✓ Good mechanical properties of plastic material
  ✓ Good ageing and thermal resistance for in-door applications
  ✓ Low bending radius
  ✓ Ease of installation
Challenges

- Technical Challenges:
  - Finish distance testing for Gigabit Ethernet
  - Develop connectors that make use of plastic material
  - Develop low cost production processes for base material
  - Develop low cost transceivers that make use of simplified alignment
## Nexans

### GI POF compared to Gigabit Ethernet Standard

<table>
<thead>
<tr>
<th>Standard</th>
<th>Fibre</th>
<th>Bandwidth (MHz/km)</th>
<th>Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000BASE–SX (850 nm) OM1</td>
<td>MMF 62.5 / 125 MMF 50 / 125 <strong>GI POF</strong>*</td>
<td>160 400 510/812***</td>
<td>220 500 300</td>
</tr>
<tr>
<td>1000BASE–SX (850 nm) OM2</td>
<td>MMF 62.5 / 125 MMF 50 / 125 <strong>GI POF</strong>*</td>
<td>200 500 510/812***</td>
<td>275 550 300</td>
</tr>
<tr>
<td>1000BASE–LX (1300 nm)</td>
<td>MMF 62.5 / 125 MMF 50 / 125 <strong>GI POF</strong>*</td>
<td>500 400 - 500</td>
<td>550 550</td>
</tr>
<tr>
<td>1000BASE–LX (1300 nm)</td>
<td>SMF 9 /125</td>
<td>N/A</td>
<td>5000</td>
</tr>
</tbody>
</table>

*Due to non linear behaviour the real bandwidth of GI-POF over 1 km would be 812MHz (in case attenuation will lower in future)*
POF Gigabit Ethernet Testing

- Test Setup and Results
  - 400 meters of POF
  - IXIA 1600T Chassis containing LM1000GBIC load modules with 1000BASE-SX GBICs
  - Transmitted over three-trillion 64-byte Gigabit Ethernet packets with 96 ns inner-packet gap with no errors. Translates to a FER of $3.30 \times 10^{-13}$. 
Bandwidth Performance

* measured bandwidth on 300m of Nexans GIPOF 120/490 under different launching conditions / offsets
Measurement Results

10.7 Gbit/s Transmission over GIPOF at 850 nm VCSEL (Supplier A)

> 100 m GIPOF; RX: PIN + TIA; optimised offset launch

> BER < 10^{-10} achieved

Successful test: 10 Gbps over 100m
Fibre used: 120/230 /490μm GIPOF
Optical fibre production

- Historical methods
- Current techniques
- Future development
Drawing from a preform

Procedure:
- preform is heated until a fiber can be drawn.

Fiber type:
- Step Index POF or Graded Index POF

Comments:
- used for glass fiber manufacturing
- well suited for the production of GI POF
Procedure:

- monomer distillation
- addition of initiator and polymerization regulator.
- the extrusion of through a nozzle with nitrogen
  - cladding immediately applied.

Fiber type: Step Index POF

Comments: not widely used.
Continuous Extrusion of core and cladding

Procedure:
• pre-polymerized (80%) monomer
• mixture pumped towards the extruder
• second extruder for the cladding

Fiber type: Step Index POF

Comments:
• Process suitable for continuously manufacturing POF on a large scale
• very low contamination during the process.
• standard process for SI-PMMA manufacturing.
Melt spinning process

Procedure:

• polymer melted and pressed through a die.

• Cladding applied after fiber formation.

Fiber type:

Step Index POF or Graded Index POF

Comments:

• Possibility to manufacture several fibers simultaneously

• Extremely high drawing speed.

• Technique very expensive to set up.
Direct UV cross-linking of resins

Procedure:
• Cladding and core resins pumped towards a reactor
• Liquid resins flowing through a nozzle
• UV curing in line.

Fiber type:
Step Index POF or Graded Index POF

Comments:
• Continuous process
Cable Structures for Gigabit POF

Standards:
- IEC 60794-2-42 (in preparation)

BENEFITS
- Long Lifetime
- No additional buffer to strip
- Enables fast termination
- Drives down total networking cost

- **SC/ZC Design for Fibre Patch cords**
  - 1/2 fibres 490µm
  - Bending radius* = 20mm

- **MC Design for Breakout cabling**
  - 2-4 fibres
  - Aramid strength member

- **UT Design for Backbone cabling**
  - Up to 12/24 Coloured fibres 490µm
  - Dry tube solution
“Easy to install“ Connector for Gigabit POF

● **FERRULE:**
  ◦ New ferrule adapted for Gigabit-POF
  ◦ Supports 2 fibre types: 120/490 and 62,5/245µm
  ◦ Mechanical fixation of the fibre (patent pending)
  ◦ Reusable (no crimp)

● **CONNECTORS**
  ◦ Usable for SC, ST, LC, MTRJ connectors
  ◦ Compatible to standard components
  ◦ Preassembled connector
  ◦ Avoids glue and heat
  ◦ Polishing not mandatory

● **BENEFITS:**
  ◦ Short installation time
  ◦ Simple termination like copper
62.5 µm 1X8 ribbon POF

Thickness (h) 310 µm

Width (w) 2100 µm

Ribbon BW : 8 x 5 GHz @ 100 m
- 40 GHz over 100 m @ 850 nm

Ribbon Bitrate : 8 x 10 Gbps @ 100 m
- 80 Gbps over 100 m @ 850 nm
**European POF Activities**

**IO** (Interconnect by Optics within Electronics Systems)

Objective: Develop high-density high-speed interconnect systems

- Nexans: plastic fibre, cable
- Alcatel: high-level IP router design
- IMEC: modeling, integration, demonstration
- FCI: connectivity
- RCI: microwiring fibre deposition
- PPC: sandwiched diffused glass waveguide

**Home Planet**

Objective: Build a Home Plastic Optical Fibre Network

- Nexans: plastic fibre, cable, connectivity
- NMRC: O/E research, modeling
- FireComms: O/E RCLED, VCSEL, Transceivers
- Grundig: AV demonstration, 1394 & HaVi stacks

**MOTIFES**

Objective: Elaborate Multimedia POF Technologies for In-Flight Entertainment

- University of Surrey: 650 nm VCSEL design
- NMRC: 650 nm VCSEL fabrication
- Nexans: High temperature POF transceiver development
- Thales: 1394-to-PCI board assembly
- FireComms:
IO (interconnects by Optics) is a European project, co-funded by the EC, in the framework of the Information Society Technology (IST) program. Contract number is IST-2000-28358.

**Parallel optical interconnections**

The project runs from September 1, 2001, to August 31, 2004.

www.intec.rug.ac.be/IO
Assess trade-offs between parallel and serial I/O modes

Develop high-density high-speed interconnect systems
- between Integrated Circuits (on-board and in-board)
- between Printed Circuit Boards and Backplanes (on-Backplane and in-Backplane)

Based on
- 2D (up to 256) plastic fiber arrays (stacked ribbons of high temperature small diameter POF fibers,
- glass sheet waveguides, operating at 1,25 Gbps/channel

Consortium: Nexans (plastic fiber, cable), Alcatel Bell (high-level IP router design), IMEC- R.U.Gent (modeling, integration, demonstration), FCI (connectivity), RCI (microwiring fiber deposition). PPC (sandwiched diffused glass waveguide), Caswell, Opto Speed, Helix
Wiring of POF on flex foils:
Elaborate end-to-end European technological capability in the Japan-dominated arena of consumer electronics

Build a Home Network based on the
- IEEE1394 interface standard (i-Link, Firewire)
- HaVi stack (supporting Digital Video broadcasting std)
- PMMA small numerical aperture fiber
- 650 nm RCLEDs and VCSELs

Testbed to operate at 200 & 400Mbps (50m)

Demonstrate 800Mbps and 1600Mbps technology feasibility

Consortium: Nexans (plastic fibre, cable, connectivity)
NMRC (O/E research, modeling)
FireComms (O/E RCLED, VCSEL, Transceivers)
Grundig (AV demonstration, 1394 & HaVi stacks)
IQE (wafer growth)
Aerospace MOTIFES

Multimedia Optical-Plastic Technologies for In-Flight Entertainment Systems

(MOTIFES)

CONSORTIUM OVERVIEW

<table>
<thead>
<tr>
<th>Participant</th>
<th>Business activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Microelectronics Res.Centre (NMRC) Ireland</td>
<td>650 nm VCSEL fabrication/environmental test</td>
</tr>
<tr>
<td>Department of Physics, University of Surrey, UK (UNIS)</td>
<td>650 nm VCSEL design/ wafer characterisation</td>
</tr>
<tr>
<td>Nexans Filotex, France</td>
<td>GI-POF development/environmental tests</td>
</tr>
<tr>
<td>Thomson-CSF/LCR, France</td>
<td>transceiver development/ 850 nm VCSEL fabrication</td>
</tr>
<tr>
<td>FireComms Ltd, Ireland</td>
<td>1394-to-PCI board assembly</td>
</tr>
</tbody>
</table>
Conclusions

- POF capacity for improving usefulness of multimode optical fiber has been demonstrated
  - Simplified termination
  - Superior resistance to mechanical stress
  - Improved bandwidth
- Combined advantages of MMOF and Copper
- Practical and relevant POF components development is underway
  - Supports 850nm
  - Supports gigabit networking
  - Wider distance scalability