Manufacture of Perfluorinated Plastic Optical Fibers

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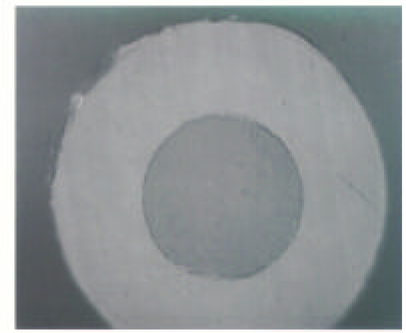
Attractions of Plastic Optical Fibers (POF)



Razor blade cut
3 second dry polish

Ease of Installation

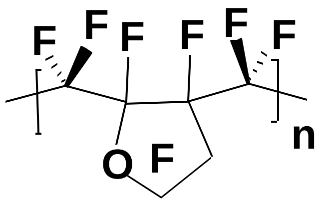
- No expensive termination tooling required
- Simple end preparation (5-10 second dry polish)
- Smaller installed bend radius allowed than silica fiber (non-brittle)
- Large core diameters are NOT important for POF in Gb/s applications

Performance

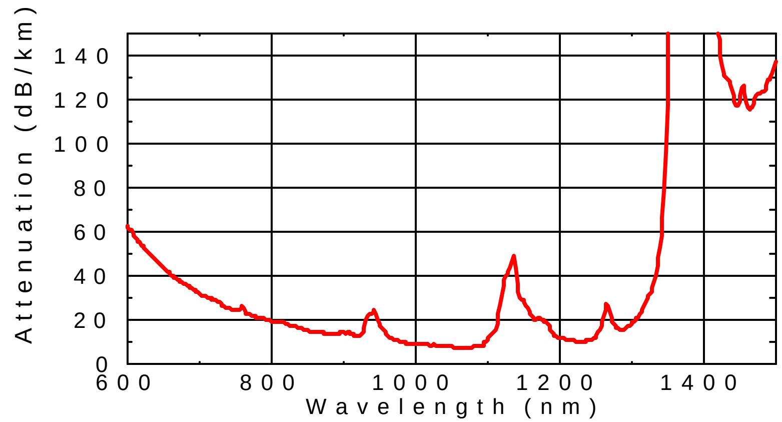
- High bandwidth over broad wavelength range (lower material dispersion than silica)
- Simple methods for increasing BW using restricted launch (10 Gb/s x 100m)
- Lower modal noise than multimode silica fibers
- Radiation hardness better than silica multimode fiber

Perfluorinated GI-POF: The Great Leap Forward

Perfluorinated polymers greatly reduce attenuation, increase wavelength choice



poly(perfluorobutenylvinyl ether)
(CYTOP, Asahi Glass Co.)



10-fold lower attenuation than PMMA-based POF
IR transparency as well as visible transparency

Perfluorinated GI-POF has much higher usable bandwidth than any other POF

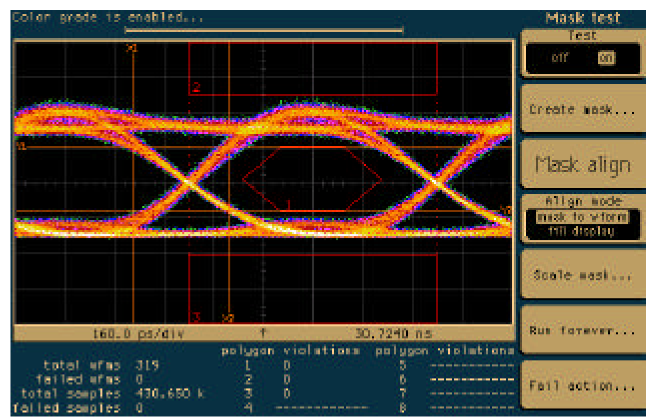
Overfilled BW typically > 300-400 MHz-km

Up to 1 GHz-km with underfilled launch

Uses inexpensive existing high speed lasers

Immediately compatible with gigabit detectors

By contrast, 500 mm PMMA GI-POF needs significant development of both sources and detector coupling technologies



300 m x 1.25 Gb/s with TXR intended for multimode silica

Preform Production of PMMA GI-POF

-For PMMA graded-index preforms, interfacial gel process is very desirable. (Y. Koike, 1

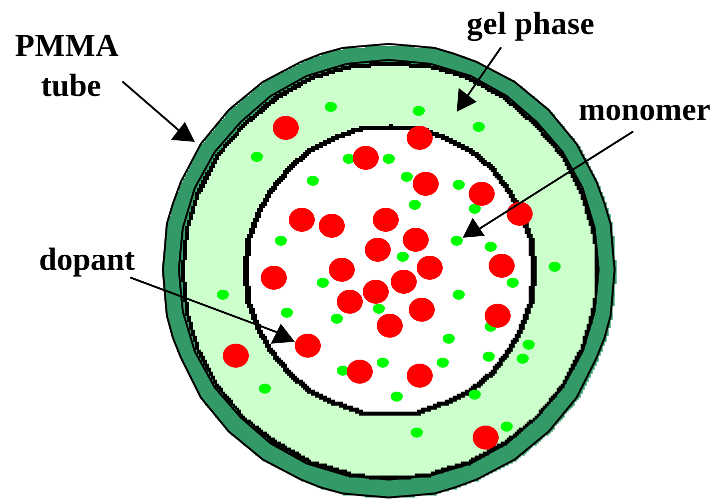
-Start with uniform mixture of MMA monomer and dopant molecules

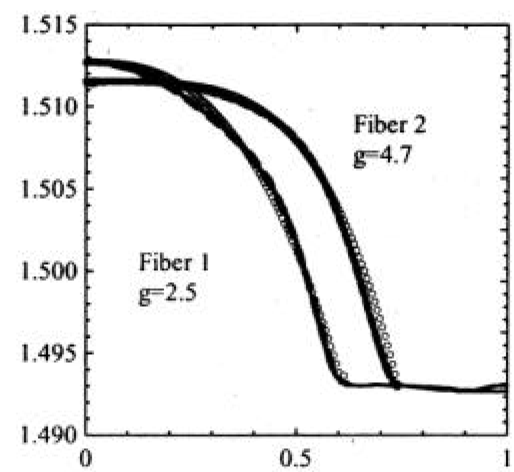
-Index profile formed by preferential exclusion of dopant molecules from gel phase as gelation front propagates inward

-Profile controlled by adjusting polymerization rate, temperature, etc.

-Approximate power-law profiles with g = 2-5

-Demonstrated near-intrinsic attenuation, 500 Mhz-km bandwidth at 650 nm





Interfacial gel was first effective graded-index POF technology

Recently commercialized by Fuji Film

Process has not been demonstrated with perfluorinated materials

Production of Perfluorinated GI-POF Preforms

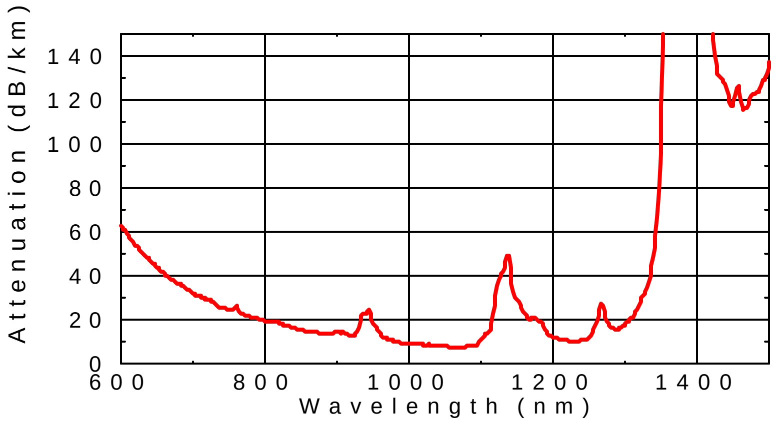
-Pioneered by Asahi Glass Co in late 1990's

-CYTOP polymer, small-molecule dopant

-Lowest-attenuation process for making POF (15 dB/km)

-300 MHz-km bandwidth specification

-Commercial production volumes (megameters/yr)

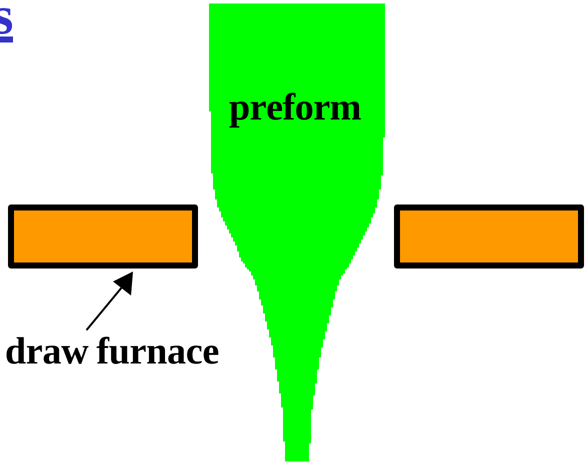


Typical Installation
Ginza Tower

Drawing of Polymer Preforms

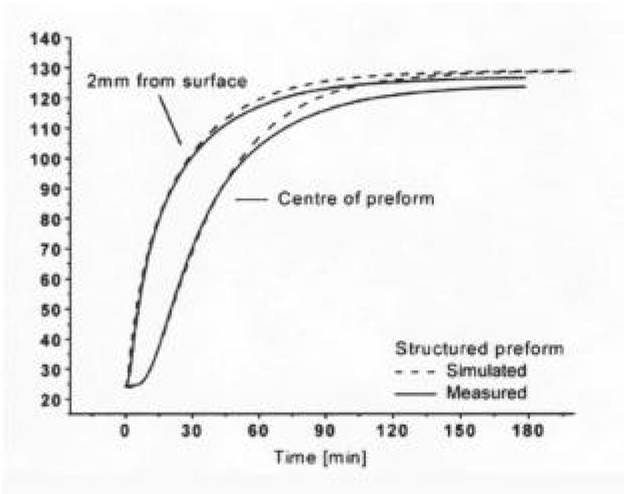
Silica preform processes are scalable to large volumes

- Draw temperature ~2000° C
- Fast, uniform radiative heating
- Negligible material absorption a furnace wavelengths
- Tens of meters/second line speeds



Polymer preform processes are NOT scalable

- Draw temperature ~200° C
- Mixture of convective, radiative heating, low heat flux
- Significant material absorption a furnace wavelengths
- Heat transfer and thermal uniformity set limits
- Tenths of meters/second line speeds

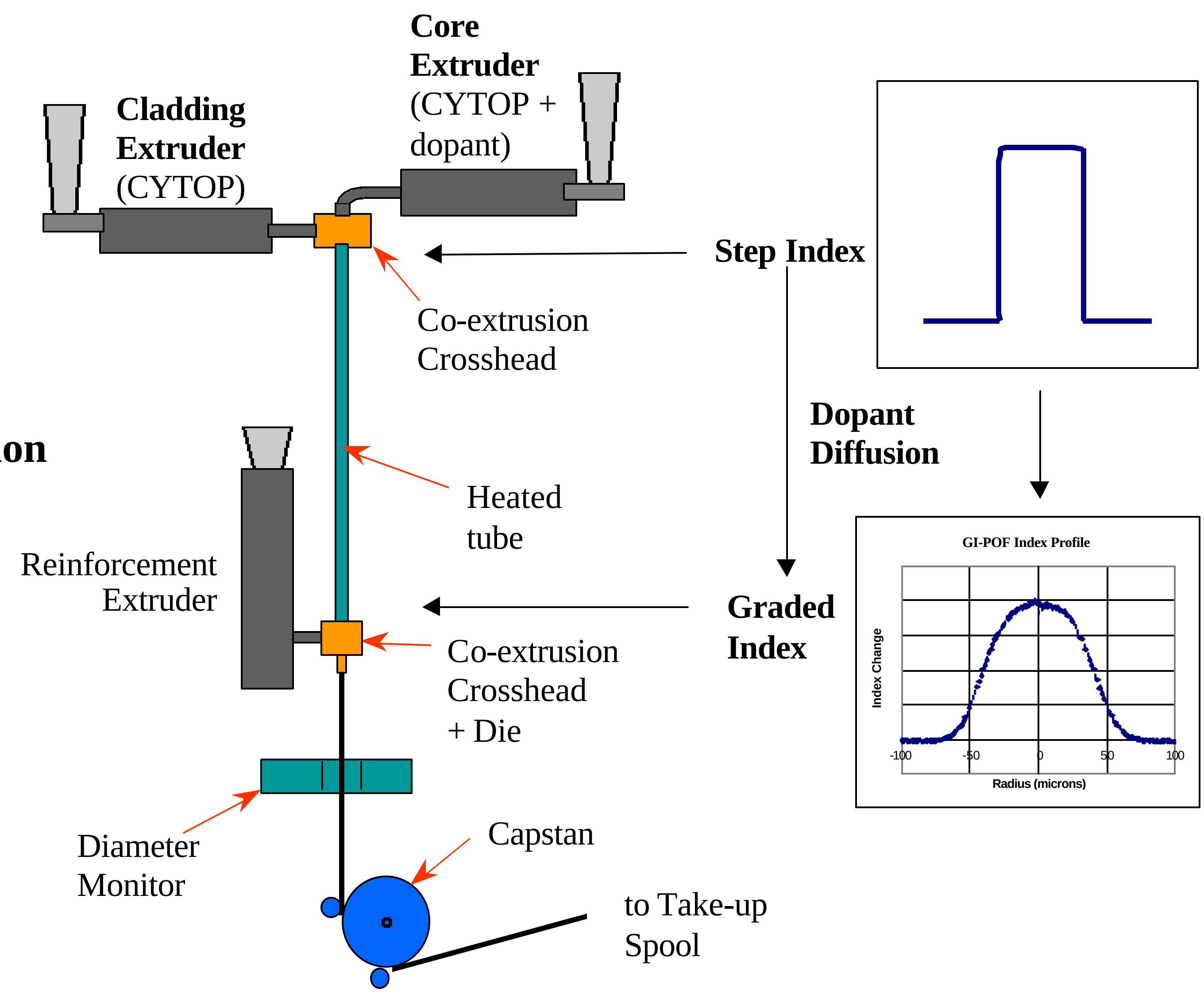


5 cm PMMA Preform

To achieve true mass production of POF, this problem must be avoided

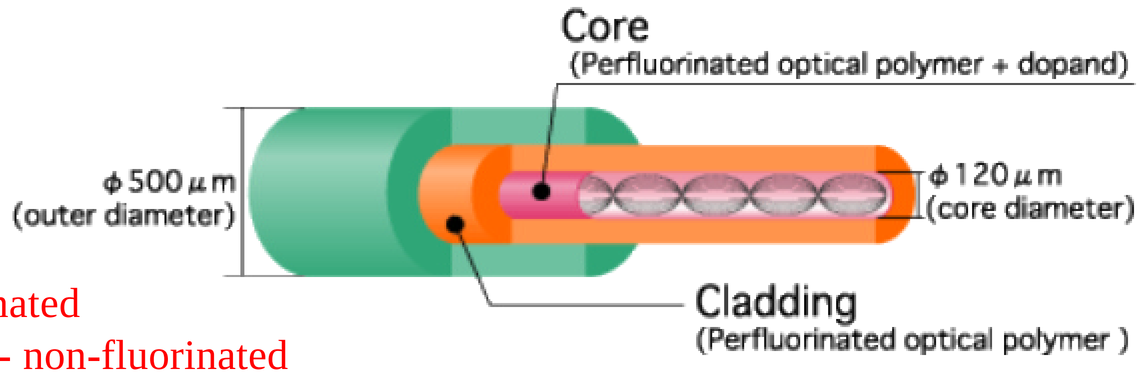
Graded-index POF Extrusion

- High Line Speed
- Continuous Production
- Much Lower Cost
- Flexible



Technical Challenges of Extruding GI-POF

Structural Complexity



Perfluorinated POF needs
3 or more layers composed
of very different materials.

Core and cladding layers -- perfluorinated
Reinforcement (overcladding) layer -- non-fluorinated

Multilayer, heterogeneous fibers are simple in principle, but difficult in practice

- Compatible processing temperatures
- Good interfacial adhesion
- Comparable thermal expansion for low microbending loss
- Control of diameter and other geometric properties for all layers
- Tight tolerances for gigabit applications (e.g. +/-5 μm OD variation)

Ultrahigh Purity

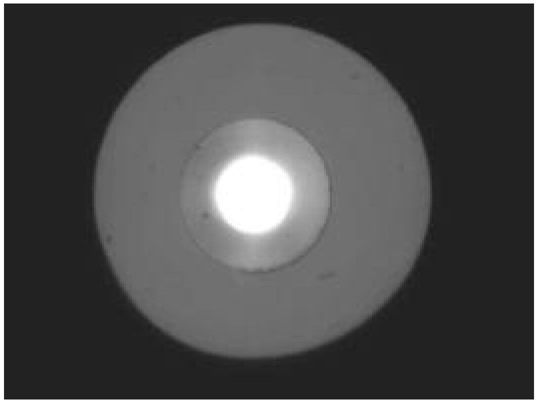
In a fiber with 100 μm core diameter, a 5 μm particle will scatter ~0.25 % of incident optical power
For attenuation within 10 dB/km of intrinsic, there must be less than 1 such particle per meter
This corresponds to about **8 parts per billion** by volume (less for smaller particles)

So, the material must be dried from solution, transferred into the extruder, and processed without adding more than a few ppb of contaminants. Since in-situ polymerization is not feasible, all of this must be done after polymerization.

Surprisingly, this is both possible and manufacturable

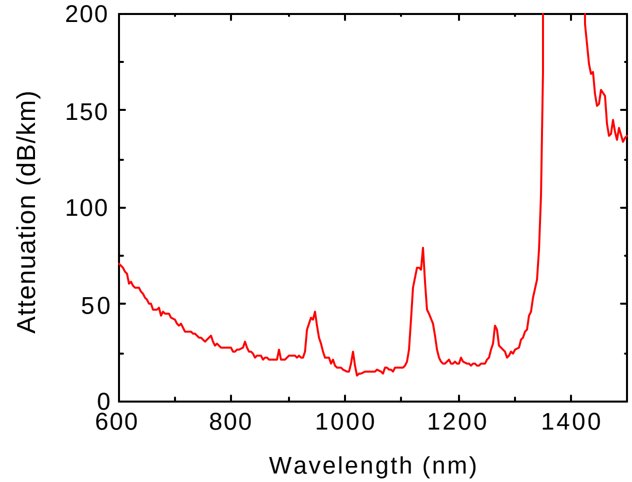
Properties of Extruded Perfluorinated GI-POF

Geometry



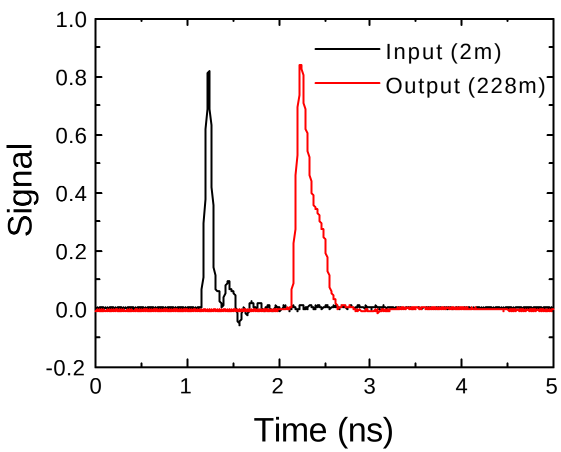
Geometry controlled by flow ratios
Easy, rapid shift between fiber types
OD variation < +/- 3 mm (500 mm OD)

Attenuation



Attenuation typically 25-35 dB/km at 850 nm

Bandwidth



Typical bandwidth > 400 MHz-km

Reliability

Fundamental material and process advantages

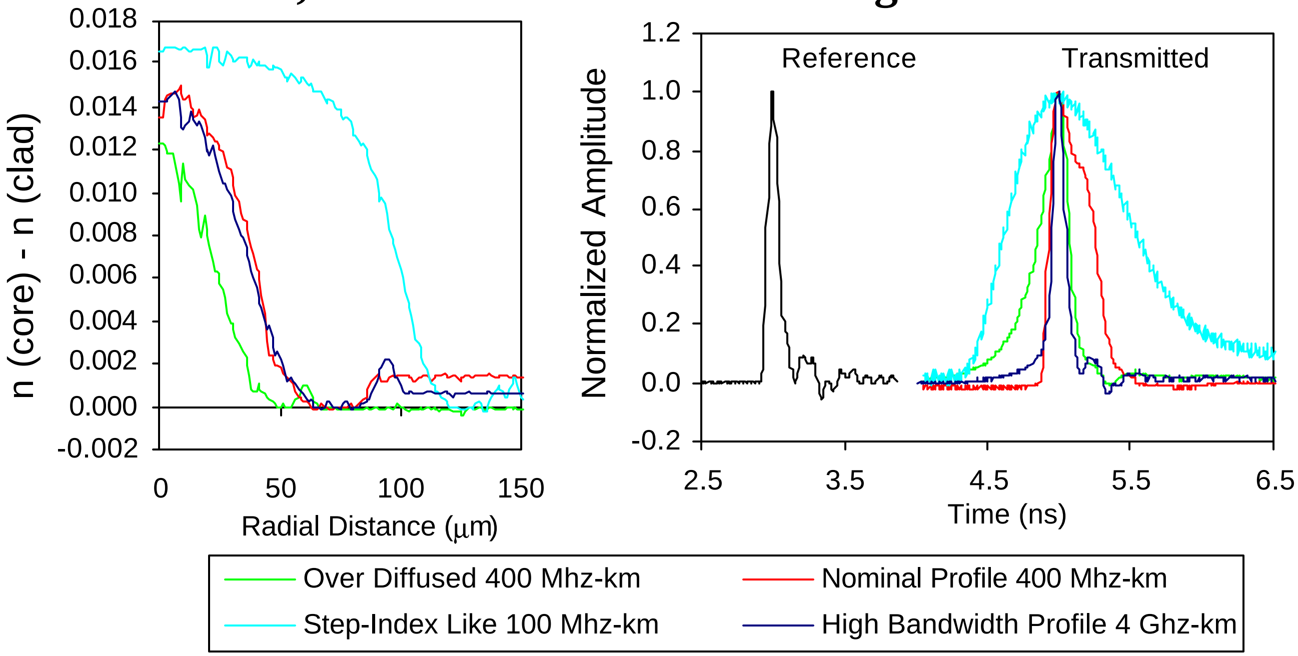
Low residual stress -- good dimensional stability

Low water absorption by all materials

No change on exposure to 75^{o}C 85% RH (30 days)

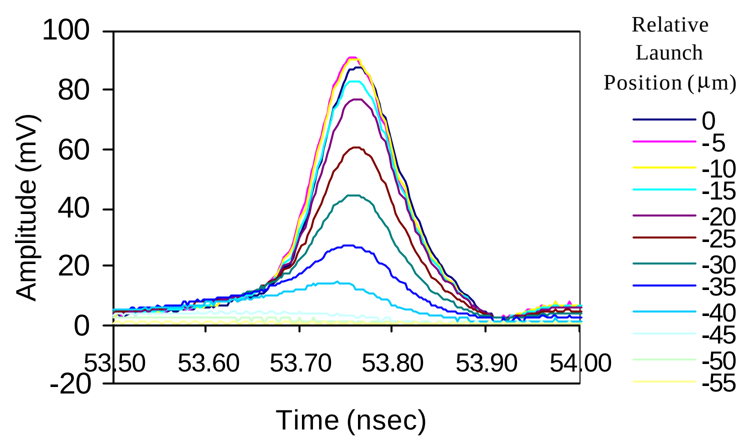
Extrusion of Ultrahigh Bandwidth GI-POF

Under some conditions, overfilled bandwidths as high as 4 GHz-km can be attained



Differential Mode Delay measurements verify low intermodal dispersion

First demonstration of POF with bandwidth matching best MM silica products



Standards for Perfluorinated GI-POF

Currently, IEC 60793-2-40 defines 4 families of step-index POF (A4a, A4b, A4c, A4d)

- **All PMMA-based, with 400 dB/km attenuation specification at 650 nm**
- **Bandwidth specifications range from 1-10 MHz-km**
- **No specs for bend loss, environmental performance or chromatic dispersion**

Draft standard introduced as modification of IEC 60793-2-40

- **Proposal co-developed and co-sponsored by Nexans, Asahi Glass and OFS**
- **Recognize possibility of multiple wavelengths in transmission requirements**
- **Introduce 4 GI-POF families: 1 PMMA based, and 3 perfluorinated families**
- **Perfluorinated GI-POF families include specs for bend loss, chromatic dispersion and environmental performance**

Proposed new A4 fiber families

Multiple families of graded-index POF proposed to cover diverse applications

	PMMA	Perfluorinated		
	A4e	A4f	A4g	A4h
Principal applications	consumer electronics	industrial, mobile	SOHO LAN	high speed, multi-Gb/s
Outer diameter (µm)	750 ± 45	490 ± 10	490 ± 10	250 ± 5
Core diameter (µm)	500 ± 30	200 ± 10	120 ± 10	62.5 ± 5
Attenuation at 650 nm (dB/km)	<180 dB/km	<100 dB/km	<100 dB/km	n/a
Attenuation at 850/1300 nm (dB/km)	n/a	<40 dB/km	<33 dB/km	<33 dB/km
Minimum modal bandwidth at 650 nm (MHz-km)	20	80	80	n/a
Minimum modal bandwidth at 850/1300 nm (MHz-km)	n/a	150-400	188-500	188-500

A standard will likely be adopted in early 2005

Nexans

ASAHI GLASS COMPANY

ofs

Leading Optical Innovations

Conclusions

Three commercial Graded-Index POF processes now in existence

The extrusion process greatly reduces the cost of GI-POF manufacture, and can routinely produce fiber with attenuation < 25 dB/km, and bandwidth > 400 MHz-km. This development finally opens the door to large-scale application of GI-POF.

For the first time, POF demonstrated with bandwidth comparable to best multimode silica products

Standards for perfluorinated GI-POF are moving ahead rapidly