



High Bit Rate Optical Data Bus Technologies for Advanced Wireless Handheld Devices

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Forms of Energy Used in Data Links

- Electric current (Twisted Pair or Coax)
- Audible sounds (Dial-up)
- Infrared (Fiber Optics)
- Radio frequency (RF)
- Omni-directional electromagnetic waves
- Directional electromagnetic waves
 - Point-to-point satellite channel
 - Limited broadcast (spot beam)
 - Microwave
 - Laser beam



Electrical vs. Optical Interconnects

	Electrical Interconnects	Optical Interconnects
Energy Form	Electrical Current (AC, travels further than DC)	Light
Transmission Medium	Copper Wire (Twisted Pair [TWP], Coax)	Silica Fiber (SF), POF, Planar Polymer
Typical Modulation	Phase Shift Modulation	Amplitude Modulation
Encoding	Negative/Positive Voltage encodes signal	High/Low Voltage encodes signal
Multiplexing	TDM, FDM	TDM, WDM
Dimensions	TWP: 7.4mm, Coax: 1.9/6.4/7.4mm inner/outer/jacket	SF: 8/125/245/2000µm core/clad/jacket/sheath
Capacity (Max Bandwidth)	TWP: 10/100Mbps 3km/100m, Coax: 300Mbps 100km	25-100 Tbps (varies with fiber type)
Max Distance Before Amplification	5 km between repeaters	40 km (Std), Continuous in-fiber (Raman)
Max Distance Before Regeneration	5 km between repeaters	500 km (Std), 3000 km (Raman)
Efficiency	Low	High
Security	Low (can be tapped inductively)	High (cannot be tapped non-disruptively)
Immunity to Noise	Low	High
Cost	High	Low
Signal Transmission Speed	High (2/3 speed of light in vacuum)	High (2/3 speed of light in vacuum)
Signal Processing Speed	Low	High (All-Optical)
Weight	High (1000 1-km TWP: 8000 kg)	Low (2 1-km fibers: 100 kg)
Flexibility	Low	High
Bending Radius	Large	Small
Ability to Withstand Pulling	Low	High
Upgradability	Requires Digging	Does Not Require Digging (Multiplexing)
Energy Dissipation	Electrical energy dissipates with distance	Optical energy is absorbed with distance
Signal Quality	Wire R, C, L, & Mag. or Elec. interference distort signals	Fiber dispersion smears signals
Network Centricity	Voice-centric	Data-centric
Distance	Short	Long
Wiring / Splicing	Easy	Relatively difficult
Field Data	All distances	Mainly long distances

Green: Superior
Blue: Inferior

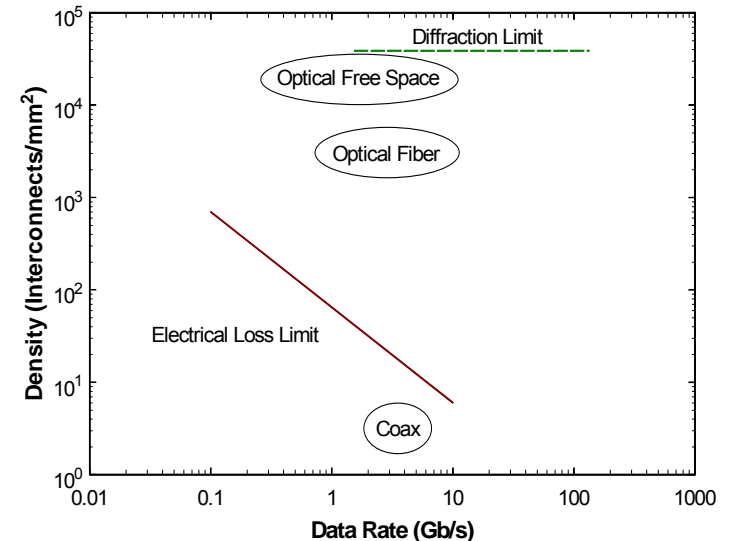
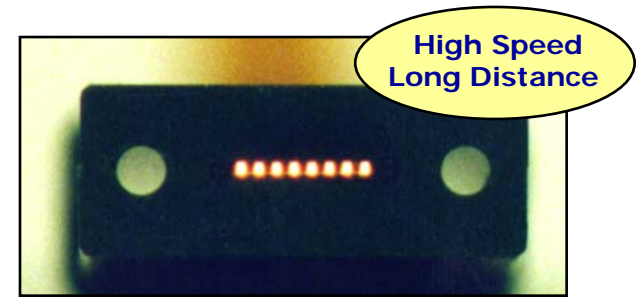
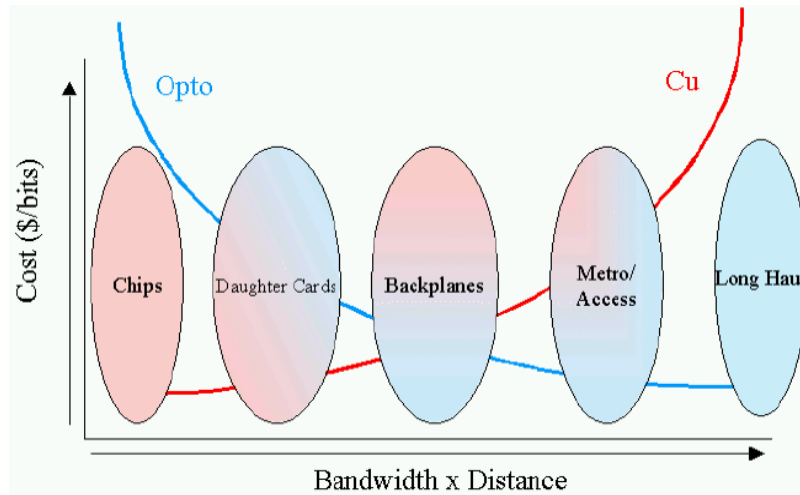


Optical Interconnects

Key Advantages over Electrical Interconnects

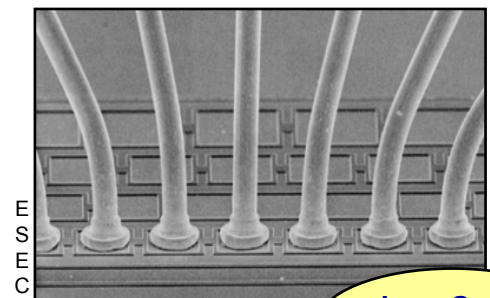
- Immunity to EMI
- High bandwidth
- Low signal attenuation
- Long reach
- Easy thermal management
- Negligible dispersion
- Future scalability beyond 1Tbps
- Low media cost
- Small size and light weight
- Easy cable management
- Robustness
- Low latency
- Low power consumption
- High port density

Optical Interconnects vs. Copper



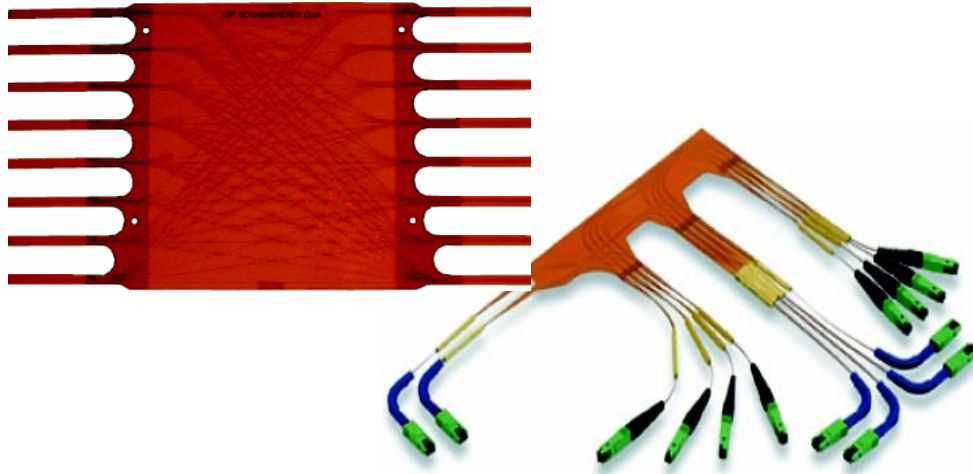
Transition from electrical to optical interconnects:

- Increases bandwidth-length product
- Increases interconnect density
- Decreases cost per bit for board-to-board & beyond



Optical Interconnects

Glass Fiber vs. Polymer Interconnects



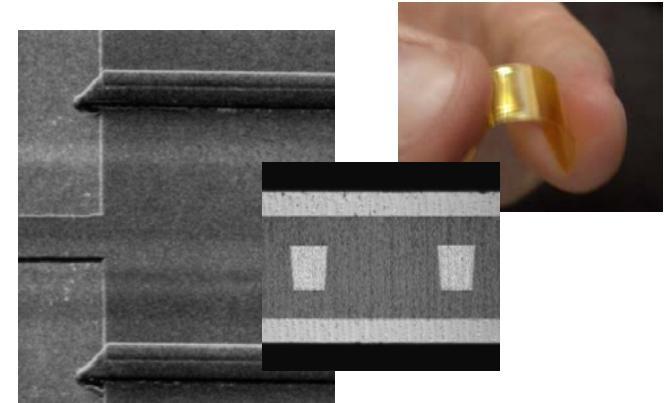
Glass Fiber Interconnects

Pros:

- Widely available technology
- Optical loss (0.00002-0.0005 dB/cm)
- 50 m @ 20 Gbps

Cons:

- Costly
- Labor intensive
- Bulky
- Point-to-point only (no passives)



Planar Polymer Interconnects

Pros:

- Dense, compact integration
- Cost efficient (\$1/Gbps 10-50m)
- 10 m @ 20 Gbps
- Passive structures possible
- High flexibility
- Mechanical resiliency
- Embedded in/on board, compatible with lamination pressure & 260°C Pb-free wave soldering

Cons:

- Optical loss (0.0005-0.05 dB/cm)
- Availability of best polymers
- Stability of some polymers



Organics as Optical Interconnects

PCB & CMOS Compatibility:

- Conform to topography
- Planarization easy
- Can be fabricated in/on boards, and on finished CMOS chips
- Minimal temperature excursion (process temperature < 100°C)
- Low temperature dissipation for dynamic functions

Manufacturability:

- Rapid processes (stamping, etc.)
- Low cost
- Ready now
- Compatible with high temperatures (up to 400°C)

Adaptability:

- All elemental functions achievable
- Widely tunable refractive index contrast
- Post-fab trimming/rework possible
- 3D routing possible (2-photon polymerization, etc.)



Organics in Packaging

Organic Coatings:

- Broadly used for chip passivation, planarization, anti-reflection coatings, etc.

Organic Adhesives:

- Broadly used for pigtailling of optical chips, die attach, surface mount, flip-chip underfills, etc.

Organic Sealants:

- Provide low cost semi-hermetic sealing of packages (at lid, ferrule, etc.) for moderate-length lifetimes (5-10 years)

Organic Encapsulants:

- Ultra-low cost packaging using glob-top coating, "dam and fill" encapsulants, etc.

Plastic Packages:

- Very low cost packages/cases/enclosures/boxes for non-hermetic components



Polymer Optical Interconnects

OEMs Active in the Field

- Agilent
- Fujitsu
- IBM
- Intel
- LG
- Motorola
- Samsung
- Sun Microsystems
- etc.



Optical Polymers

Global Material Production Effort

Manufacturer	Polymer Type [Trade Name]	Patterning Techniques	Propagation Loss, Single- Mode Waveguide, dB/cm [wavelength, nm]	Other Properties [wavelength, nm]
Amoco	Fluorinated polyimide [Ultradel™]	Photoexposure / wet etch	0.4 [1300] 1.0 [1550]	Birefringence: 0.025 Crosslinked, Thermally stable
Dow Chemical	Benzocyclobutene [Cyclotene™]	RIE	0.8 [1300] 1.5 [1550]	T _g : > 350°C
	Perfluorocyclobutene [XU 35121]	Photoexposure / wet etch	0.25 [1300] 0.25 [1550]	T _g : 400°C
DuPont (formerly Corning, Honeywell, AlliedSignal)	Acrylate	Photoexposure / wet etch, RIE, laser ablation	0.02 [840] 0.3 [1300] 0.8 [1550]	Birefringence: 0.0002 [1550] Crosslinked, T _g : 25°C Environmentally stable
	Halogenated acrylate	Photoexposure / wet etch, RIE, laser ablation	<0.01 [840] 0.06 [1300] 0.2 [1550]	Birefringence: <0.000001 [1550] Crosslinked, T _g : -50°C Environmentally stable
DuPont (formerly Telephonics)	Halogenated acrylate [OASIC™]	Photoexposure / wet etch, RIE, laser ablation	<0.01 [840] 0.03 [1300] 0.1 [1550]	Environmentally stable No loss of transparency after 5000 hours @225°C [1550]
DuPont	Acrylate [Polyguide™]	Diffusion	0.18 [800] 0.2 [1300] 0.6 [1550]	Laminated sheets Excimer laser machinable Passive fiber pigtailling
DuPont	Copolymer: tetrafluoroethylene & 4,5-difluoro-2,2- bis(trifluoromethyl)-1,3-dioxole [Teflon® AF]	Dry etch	<0.001 [800] <0.001 [1300] 0.001 [1550]	Temperature/humidity resistance Chemical resistance Low thermal conductivity High creep resistance
Gemfire	[Gemfire]	Photoexposure / wet etch	1.0 [1550]	Birefringence: 0.0002 [1550] Crosslinked
General Electric	Polyetherimide [Ultem™]	RIE, laser ablation	0.24 [830]	Thermally stable
Hitachi	Fluorinated polyimide	Photoexposure / wet etch	TE: 0.5, TM: 0.6 [1300]	Birefringence: 0.009 [1300] PDL: 0.1 dB/cm [1300] T _g : 310°C, Thermally stable
Hoechst Celanese	PMMA copolymer [P2ANS]	Photobleaching	1.0 [1300]	NLO polymer
Ipitek	Poly(methylmethacrylate) with CLD-1 chromophore [PMMA-CLD-1]	RIE	5.0 [1300]	NLO polymer r ₃₃ = 60 pm/V [1300] Pigtail loss = 3.5 dB / facet
JDS Uniphase (formerly Akzo Nobel)	Polycarbonate [BeamBox™]	RIE	0.6 [1550]	Thermally stable
K-JIST	Fluorinated poly(arylene ether sulfide) [FPAESI]	RIE	TE: 0.42, TM: 0.4 [1550]	PDL: 0.02 dB/cm [1550] Birefringence: 0.0003 [1550] Crosslinked, Thermally stable
Lumera	Polyurethane with FTC chromophore [PU-FTC]	RIE	2.0 [1300]	NLO polymer r ₃₃ = 25 pm/V [1310] Pigtail loss = 5 dB / facet
NTT	Halogenated acrylate	RIE	0.02 [830] 0.07 [1310] 1.7 [1550]	Birefringence: 0.000006 [1310] T _g : 110°C
	Deuterated polysiloxane	RIE	0.17 [1310] 0.43 [1550]	Environmentally stable
	Fluorinated polyimide	RIE	TE: 0.3, TM: 0.7 [1310]	PDL: 0.4 dB/cm [1310] Environmentally stable
PacificWave	Polycarbonate with CLD-1 chromophore [PC-CLD-1]	RIE	1.8 [1550]	NLO polymer r ₃₃ = 70 pm/V [1310] Pigtail loss = 1.5 dB / facet
Redfern	Inorganic polymer glass [IPG™]	RIE		Environmentally stable



Optical Polymer Requirements

The Top 50 List

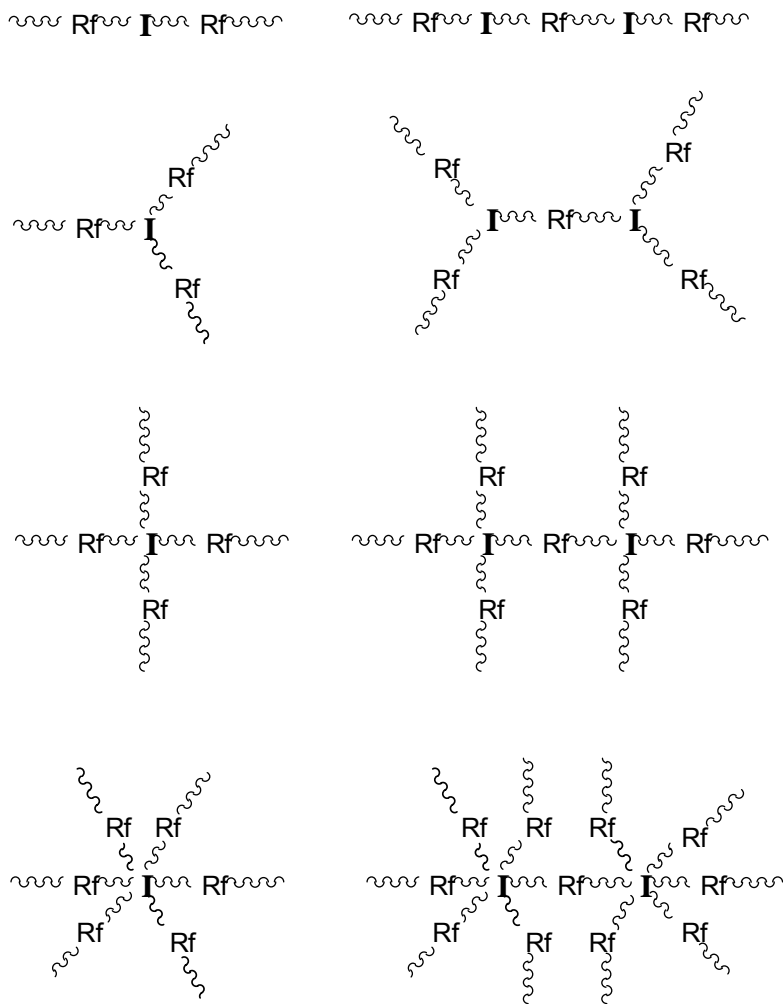
1. Low absorption loss
2. Low wavelength dependent loss (WDL)
3. Low polarization dependent loss (PDL)
4. Low polarization mode dispersion (PMD)
5. Low chromatic dispersion (CD)
6. Low birefringence
7. Low stress
8. Low fiber pigtail loss
9. Closeness to refractive index of silica fiber
10. Stability of refractive index
11. Variable refractive index difference (Δn)
12. Variable refractive index profile
13. Low refractive index dispersion ($dn/d\lambda$)
14. Large T/O coefficient (dn/dT)
15. Linearity of refractive index with temperature
16. Optimal thermal conductivity
17. Thermal stability
18. No phase transition in operating range
19. Stability with humidity
20. Hydrophobicity
21. Stability with optical power
22. Adhesion (to substrates, self, electrodes)
23. Compatibility with electrode patterning
24. Low reactivity to acids, bases, solvents
25. Stability with oxygen
26. Isotropy
27. Homogeneity
28. Low level of impurities
29. Optimal molecular weight distribution
30. Optimal viscosity
31. Low volatility
32. Optimal photosensitivity
33. Optimal cure speed
34. Full curability
35. Thermoset material
36. High crosslink density
37. Low shrinkage
38. Optimal free volume
39. Contrast in patterning
40. Optimal surface energy
41. Processability for high film quality
42. Process latitude in patterning
43. Patternability with low scattering loss
44. Machinability (cleaving, dicing, polishing)
45. Mechanical robustness
46. Flexibility
47. Stability of mechanical integrity
48. Volume manufacturability
49. Manufacturability with repeatable properties
50. Long shelf life

**Not an easy task –
After 25 years of molecular nanoengineering,
DuPont optical polymers meet all 50 requirements**



Hyper-branched Fluoropolymers

Nanoengineered for Communication Applications



Properties:

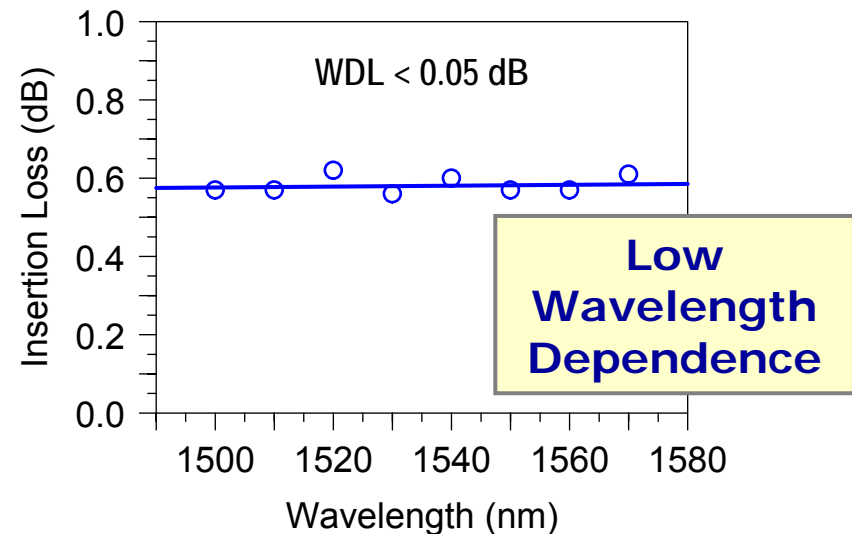
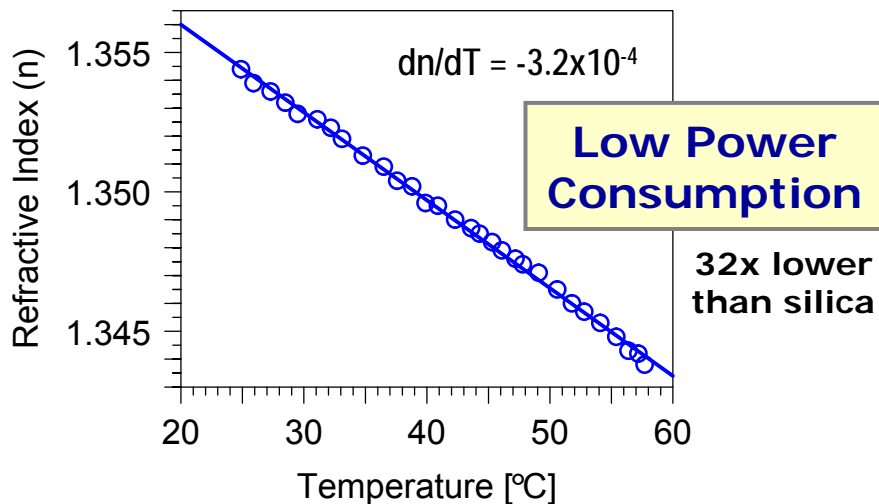
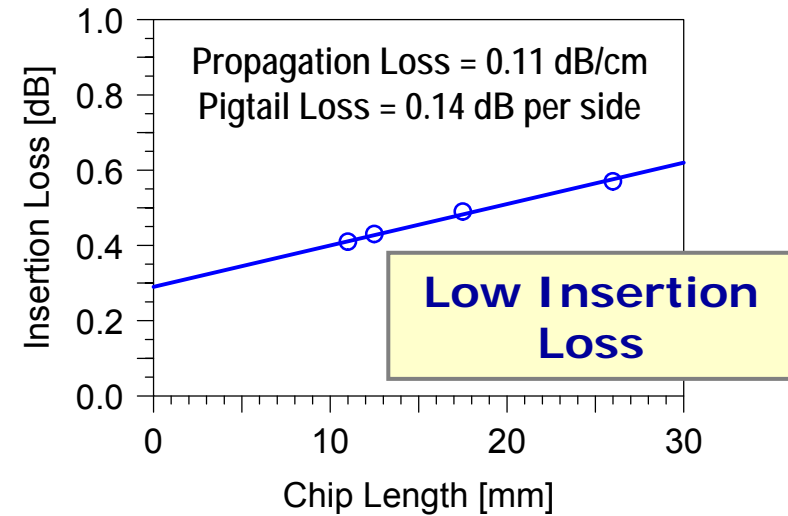
- **Low Absorption at 800-1600 nm**
 - Halogenation
- **High Stability**
 - Molecular design
- **Low Birefringence and PDL**
 - Isotropic & homogeneous
- **Low Shrinkage**
 - High MW
- **Fast Curing**
 - One end pre-fixed
- **High Crosslink Density**
 - One end pre-fixed
- **Low Volatility**
 - High MW
- **Controlled Viscosity**
 - MW & molecular structure
- **High dn/dT for Thermo-optics**
 - High free volume & low T_g



DuPont Polymer PLCs

Key Properties at 1550 nm

Cycle Time	Minutes/wafer
Propagation Loss	0.11 dB/cm (sm wg)
Polarization Effects	Birefringence = 10^{-6} PMD = 0.01 ps (1 cm sm wg) PDL = 0.01 dB (1 cm sm wg)
T/O Coefficient	$dn/dT = -3.2 \times 10^{-4}$
Index Contrast	$\Delta n = 0-30\%$
Reliability	Proven
Functions	Static & Dynamic in Polymer Active by Hybrid Integration





Optical Loss in Waveguides

The 5 types of loss & how to minimize them

- **Absorption loss**, minimized by:

- Halogenation

- **Scattering loss**, minimized by:

- Homogeneous medium

- Minimal roughness

- Low intrinsic stresses

- Graded index

- Large mode field diameter

- **Radiation loss**, minimized by:

- Large radii of curvature

- Adiabatic modal transitions

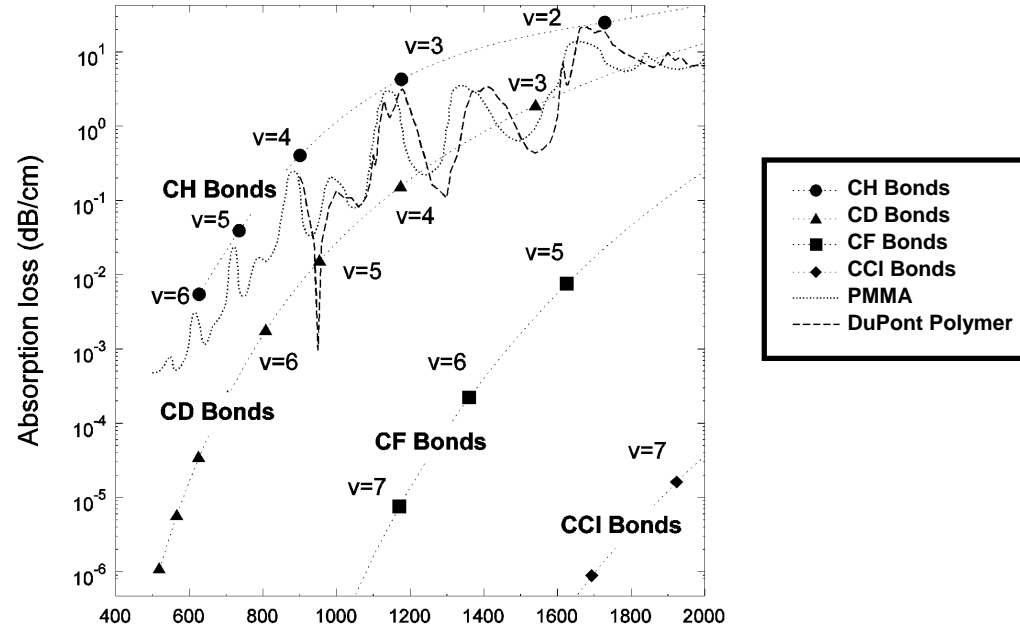
- **Mode overlap loss** (with fiber), minimized by:

- Mode matching

- Optimized alignment

- **Fresnel reflection loss**, minimized by:

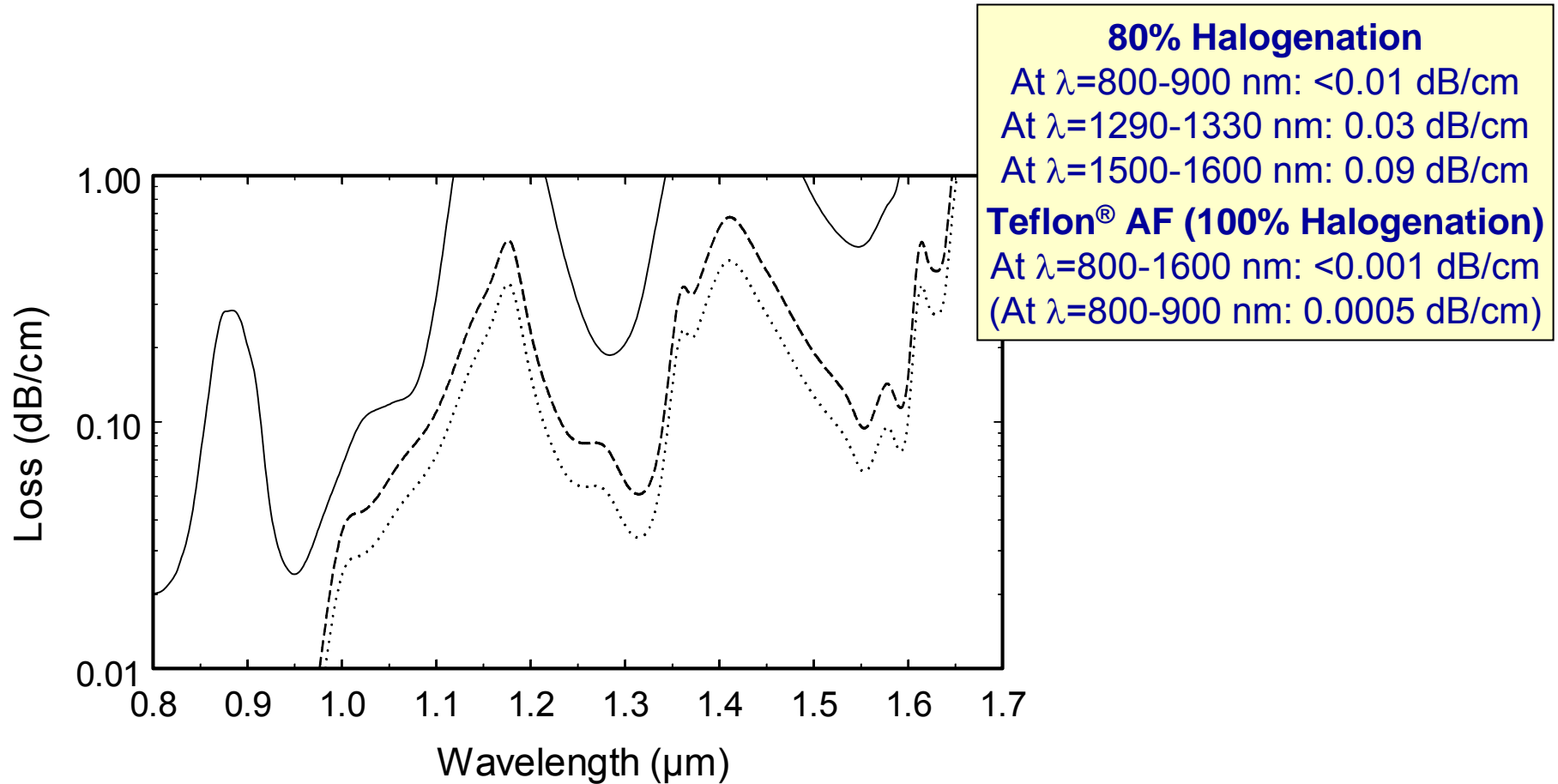
- Index difference minimization at interfaces





DuPont Polymers

Absorption Loss Spectra



80% Halogenation

At $\lambda=800-900$ nm: <0.01 dB/cm

At $\lambda=1290-1330$ nm: 0.03 dB/cm

At $\lambda=1500-1600$ nm: 0.09 dB/cm

Teflon[®] AF (100% Halogenation)

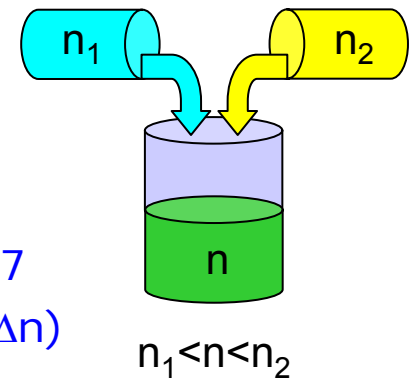
At $\lambda=800-1600$ nm: <0.001 dB/cm

(At $\lambda=800-900$ nm: 0.0005 dB/cm)



Refractive Index Contrast

Numerical Aperture Control



- Optical polymer refractive indices span the range from 1.3 to 1.7
- Refractive index contrast is the core/cladding index difference (Δn)
- Refractive index contrast is controlled by material composition
- Refractive index contrast continuously tunable between 0 and 30%

Δn	Standard	Medium	Med. High	High	Very High	Ultra High	Highest
Δn value	0.0075	0.01125	0.015	0.0225	0.045	0.15	0.45
$\Delta n/n$	0.5%	0.75%	1%	1.5%	3%	10%	30%
Core Size*	7x7 μm^2	6x6 μm^2	4.5x4.5 μm^2	3x3 μm^2	2x2 μm^2	1x1 μm^2	0.5x0.5 μm^2
Coupling Loss**	0.0077 dB	0.23 dB	0.56 dB	1.6 dB	4.2 dB	8.0 dB	9.6 dB
Bend Radius***	15 mm	6 mm	4 mm	2 mm	0.5 mm	0.1 mm	0.01 mm
Chip Size****							

* Largest core size for square-cross-section single-mode buried channel waveguide

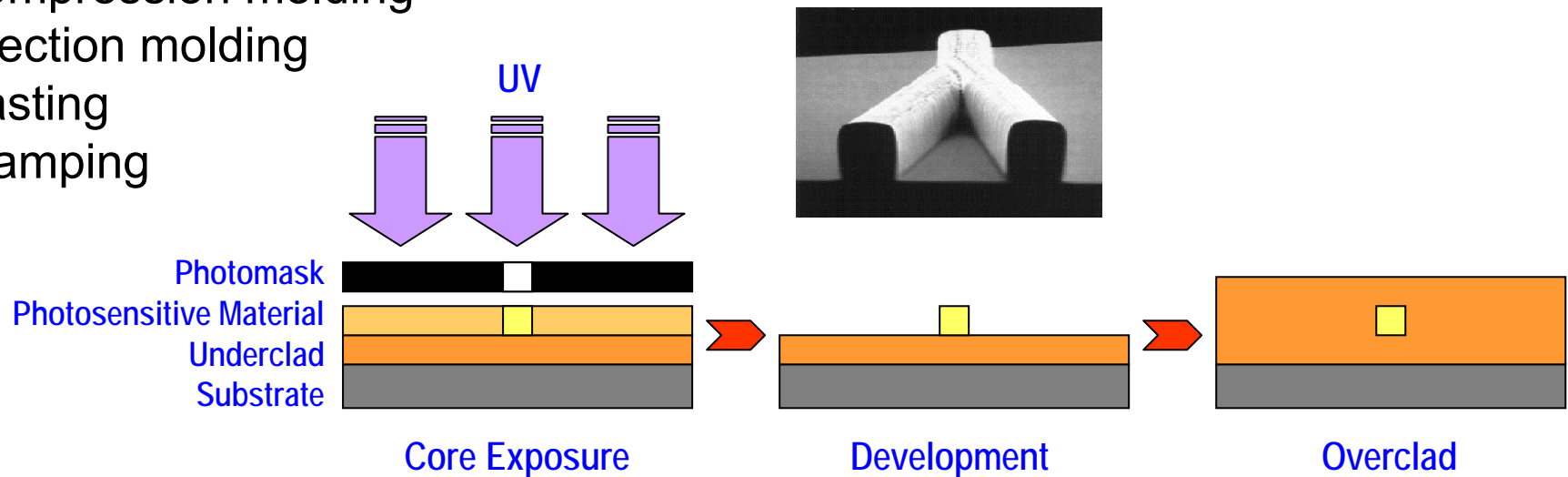
** Lowest possible coupling loss to Corning SMF28 fiber for both sides of chip

*** Smallest radius of curvature for negligible bend radiation loss

**** Relative dimensions

Polymer Optical Circuit Fabrication

- Form monomer film, expose, develop
- Form oligomer/solvent film, bake, expose, develop
- Reactive ion etching
- Hot embossing
- Soft embossing
- Compression molding
- Injection molding
- Casting
- Stamping



- Films formed by spin coating, spray coating, slot coating, doctor blading (tape casting), or dipping
- UV exposure performed with mask and UV lamp or by laser direct writing
- Material can be negative tone or positive tone



Polymer Optical Interconnects

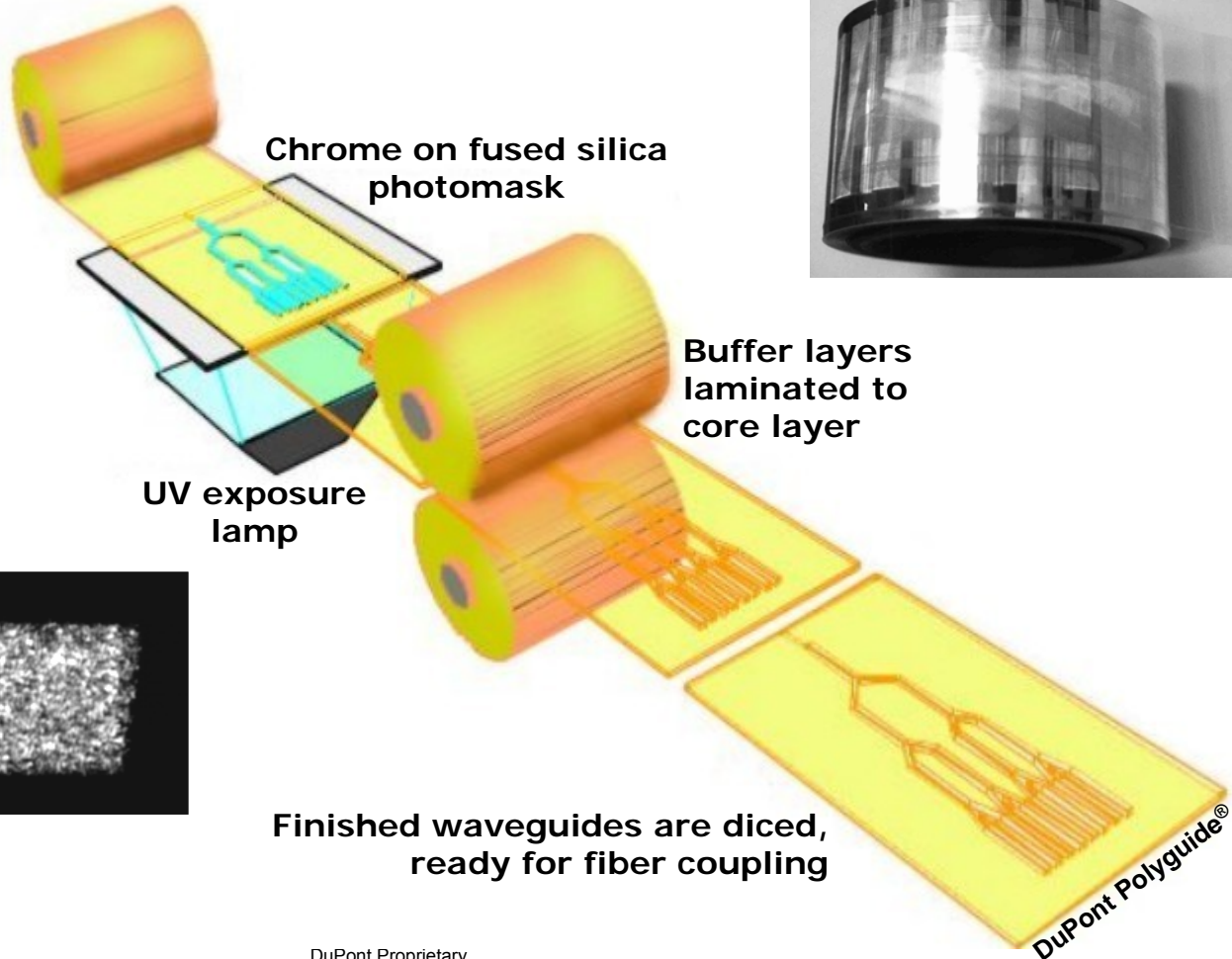
Fabrication Approaches

Reel-to-reel Processing is used for rapid cost-effective mass production of long, flexible, planar photonic circuits

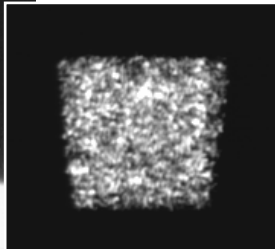
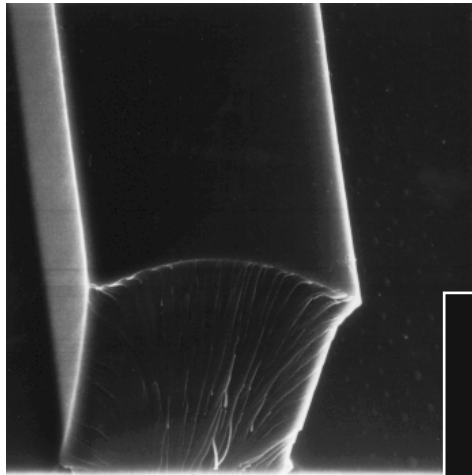
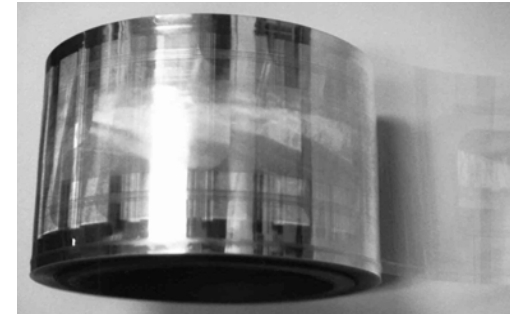
Laser direct writing of waveguides on chips, multi-chip modules (MCM's), boards, and backplanes allows to interconnect transmit/receive elements regardless of surface topography

UV Exposure & Lamination

Unexposed waveguide
Material on 1000' roll



Stamping

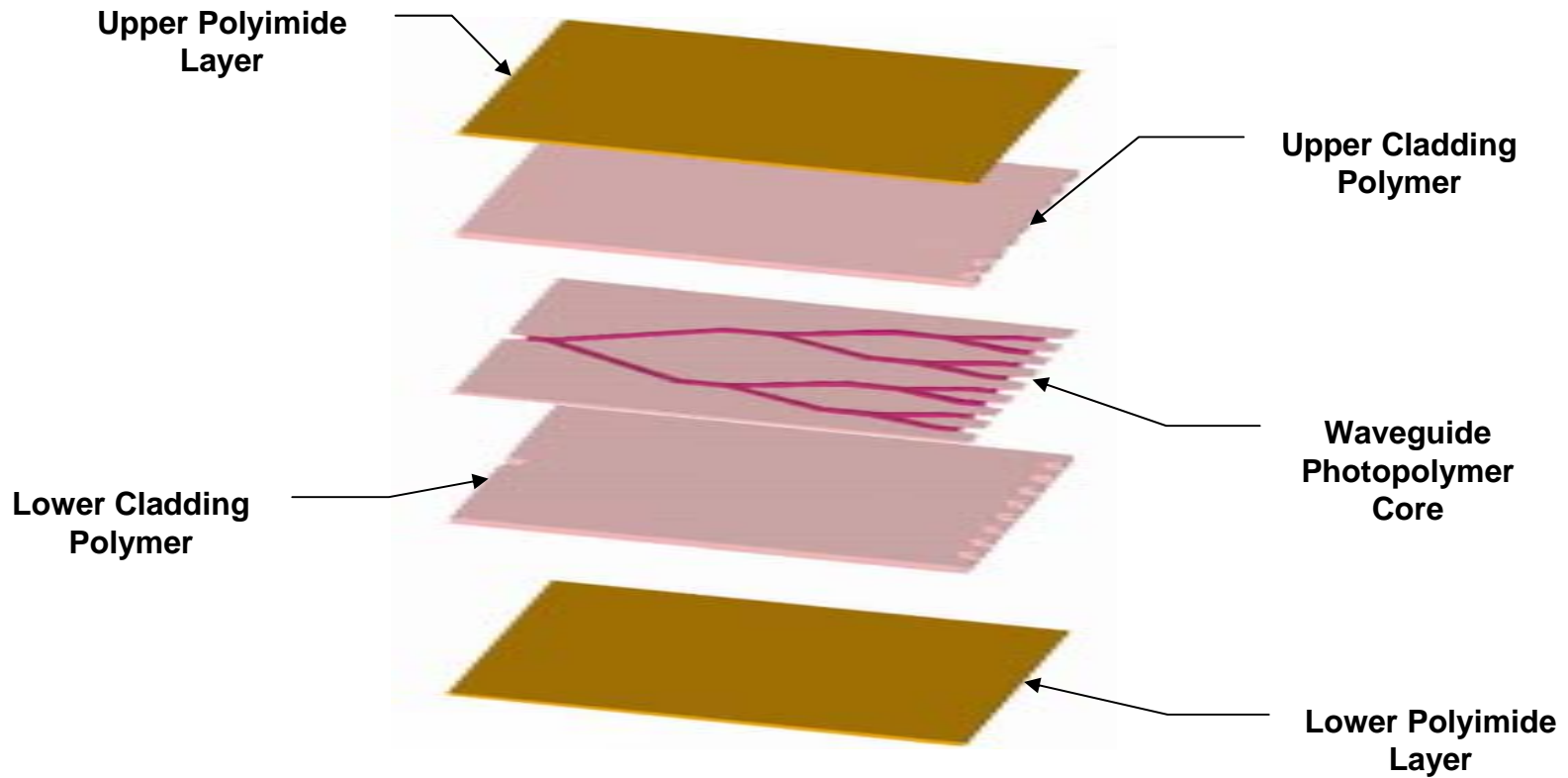


000017 20KV X600 ***** 50um



Polymer Optical Interconnects

DuPont Optoflex Stack





Polymer Optical Interconnects

Dimensions & Refractive Indices

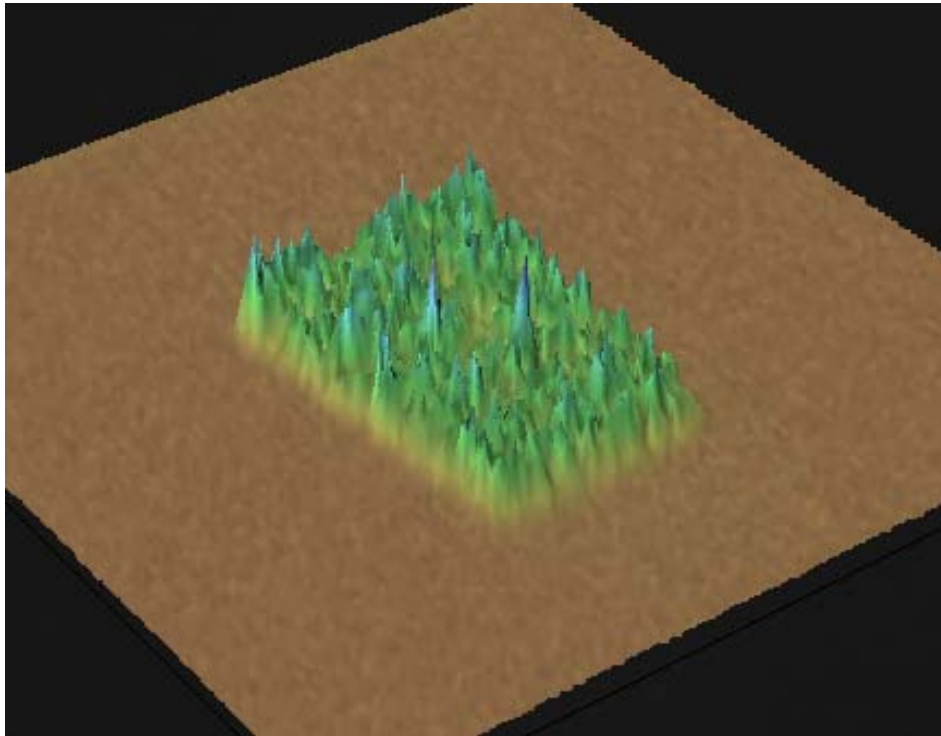
- Typical core dimensions:
 - Width at top: 45 μm
 - Width at bottom: 55 μm
 - Height: 55 μm
- Typical indices of refraction at 850 nm:
 - $n_{\text{clad}} = 1.48-1.52$
 - $n_{\text{core}} = 1.52-1.56$
- Typical index of refraction difference between core and clad: $\Delta n = 0.008-0.08$
- Typical $\Delta n/n = 0.5-5\%$



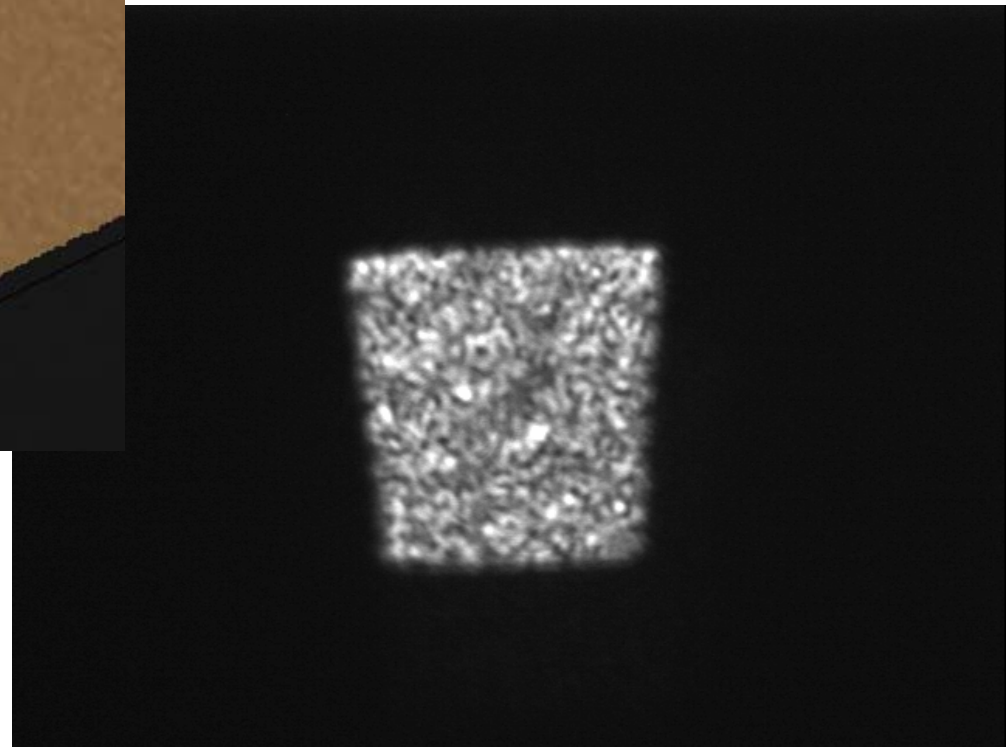


Polymer Optical Interconnects

Near-Field Output Intensity Pattern



Polymer waveguide excited by multimode fiber



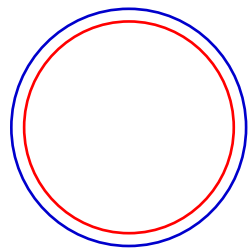
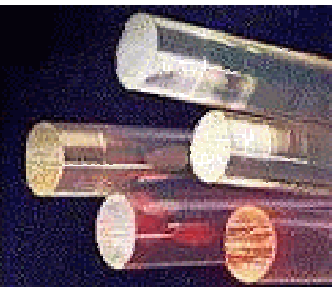


Plastic Optical Fiber

Comparison with Glass Optical Fiber

Plastic Optical Fiber

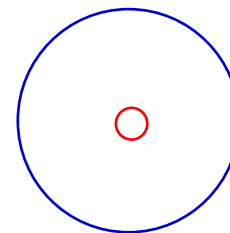
- Large Core: Up to 1mm
- Large Connectorization Tolerance
- Polishing-Free
- Flexible & durable
- High NA



POF
Polymer Core
Polymer Clad

Glass Optical Fiber

- Small Core: Up to 62.5 μ m
- Small Connectorization Tolerance
- Polishing
- Brittle & Fragile
- Low NA



GOF
Silica Core
Silica Clad





Plastic Optical Fiber

Advantages over Copper Based Interconnects

- High bandwidth
- High flexibility
- High durability
- Easy handling and processing
- Light weight
- EMI immunity
- Low cost components
- Low attenuation

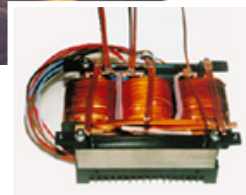
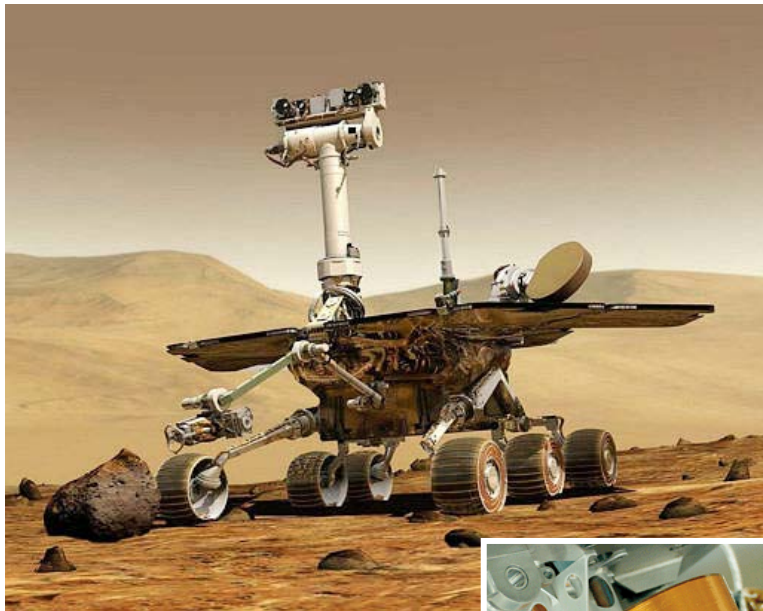


Reliability of Organic Materials

Can Organics Be Reliable in Demanding Environments?

DuPont organic materials are used in computers, cell phones, display panels, PDAs, video camcorders, and digital cameras, making these products smaller and more durable, while allowing them to do more, faster, better, and at lower cost.

In addition, they are used in:

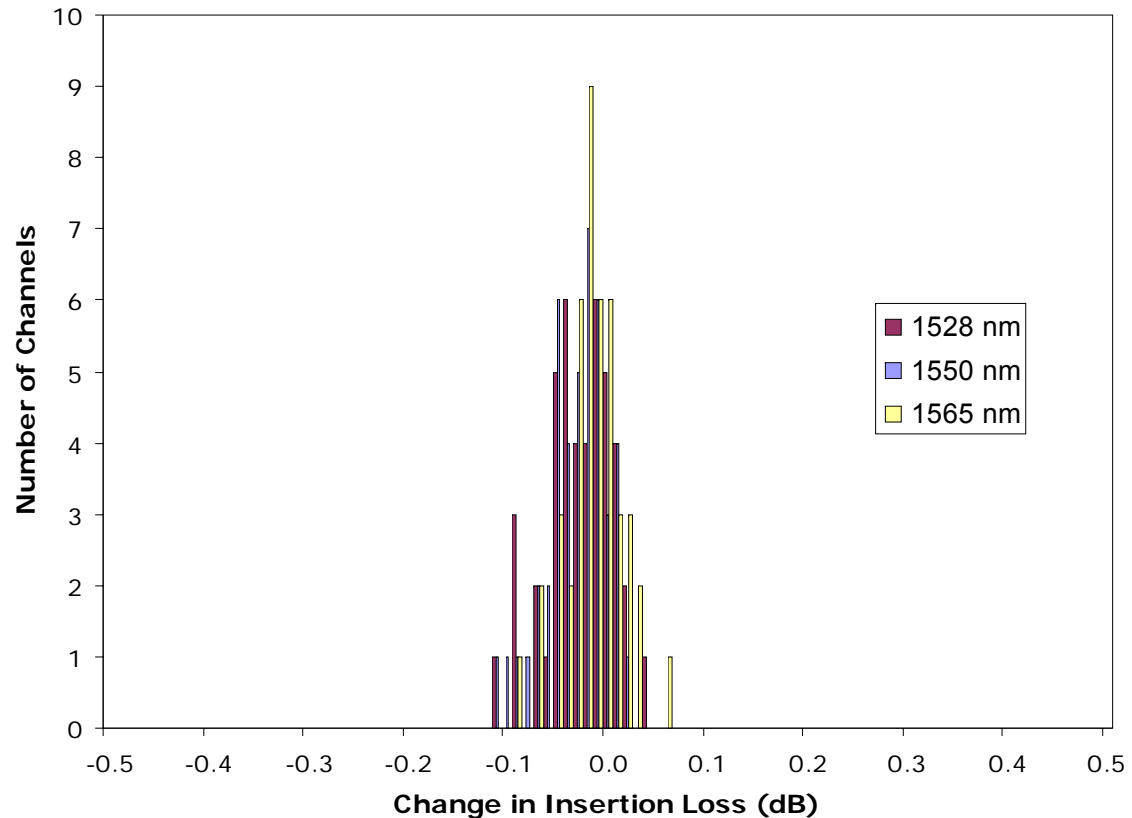


The miracles of science®



Telcordia Qualification

Telcordia Tests GR-1209-CORE/GR-1221-CORE
High Temperature Storage (85°C, 2000 hours)
Lifetest (70°C, 2000 hours, <i>in-situ</i> operation & test)
Temperature-Humidity Aging (85°C/85%RH, 336 hours)
Temperature Cycling (-40°C to 85°C, 100 cycles)
Thermal Shock (0°C to 100°C, 15 cycles)
Vibration (20-2000 Hz, 3 axes, 4 cycles/axis)
Mechanical Shock (500 G, 6 directions, 5 times/direction)
Cable Retention (3.4 lb load, 1 minute)
Fiber Side Pull (0.5 lb load, 90° angle)



DuPont's polymer-based photonic components passed Telcordia 1209/1221 qualification with a large margin

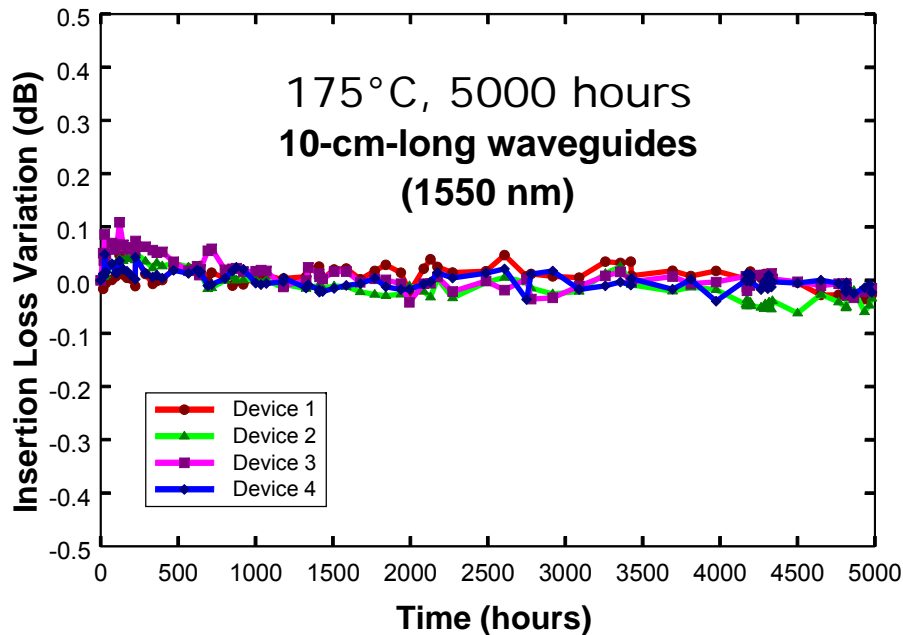
Narrow data distribution around 0 dB IL change
Changes on order of measurement error



Reliability of Polymers and Devices

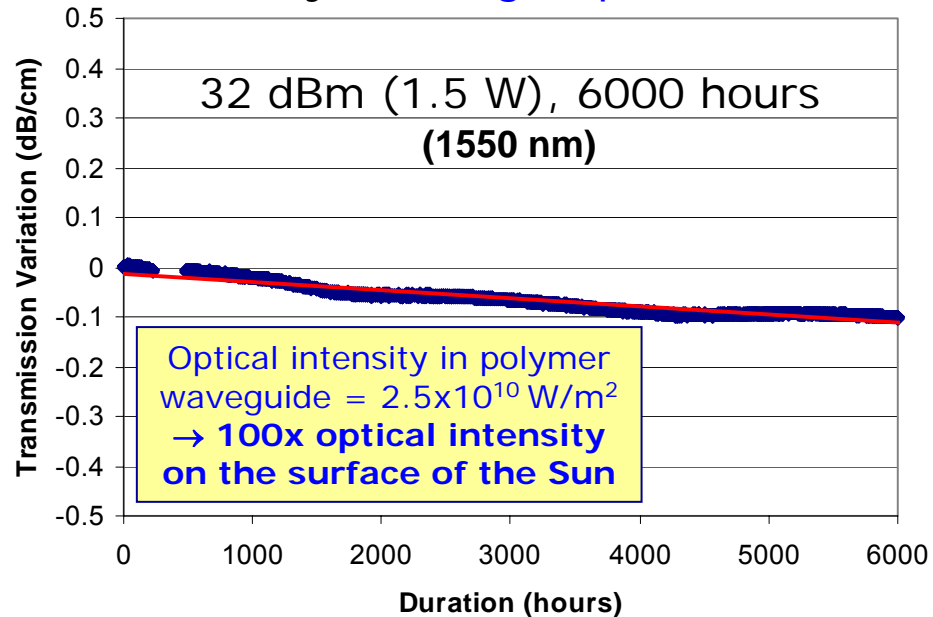
Highly Accelerated Stress Tests (HAST)

Stability with High Temperature



Lifetime > 20 years at maximum operating temperature of 150°C

Stability with High Optical Power



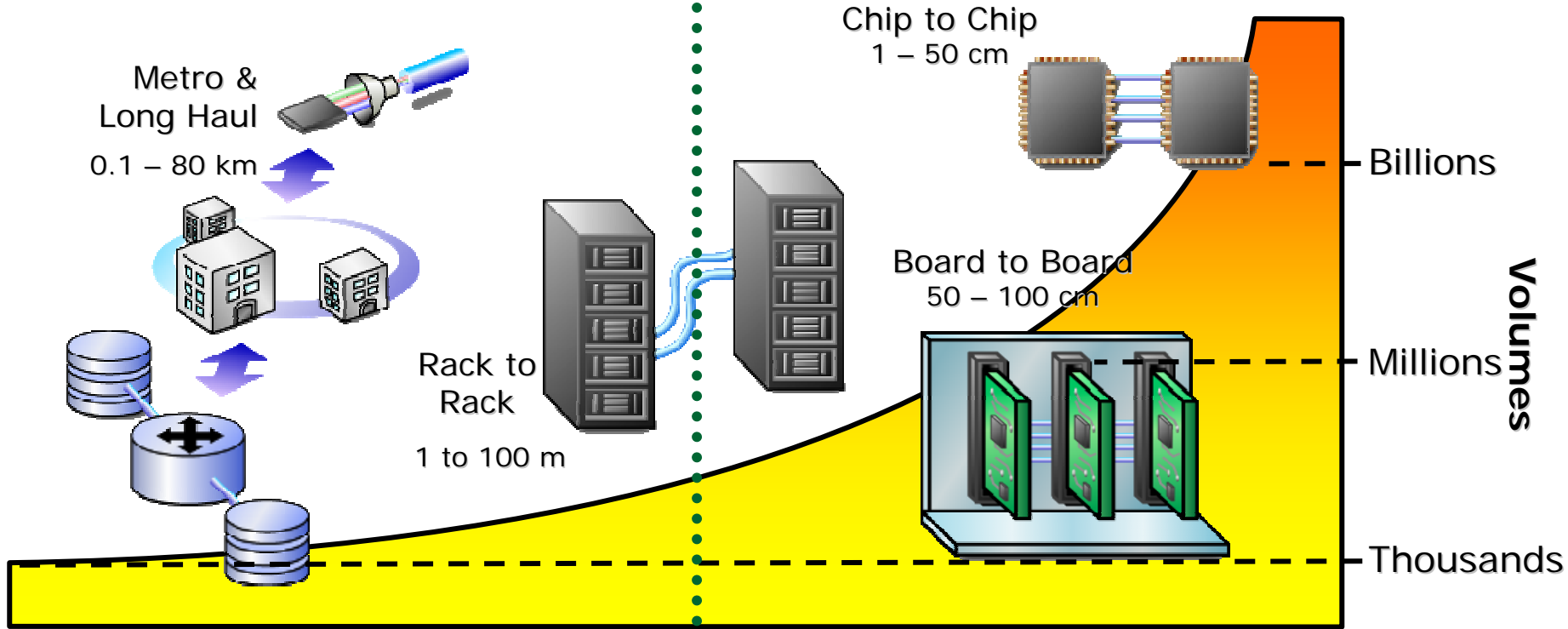
20-year degradation
< 0.08 dB/cm at 17 dBm input power
< 0.02 dB/cm at 10 dBm input power

Polymer lifetime well over lifetime of other components in system

Interconnects

\$100's / channel ← → ¢1's / pin

Optical | **Copper**



Decreasing Distances →

5000 WAN Nodes
Routing Subsystem
\$250/ch
TAM ~\$50M

Drive optical to high volumes and low costs

1 Billion Cell Phones
Optical Data Bus
~\$2.50/ch
TAM ~\$5B

Cell vs. WAN: 2 orders of magnitude lower cost per channel
Yet 2 orders of magnitude larger total addressable market



Optical Interconnects

Initial Productization & Path to Maturity



1973

1st LCD Watch

Unique advantages: size, weight, power

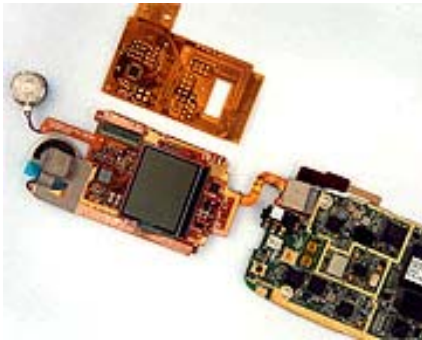
LCD Displays



2007

52" LCD HDTV

“Low requirement” market driver  **Maturity to “high end”**

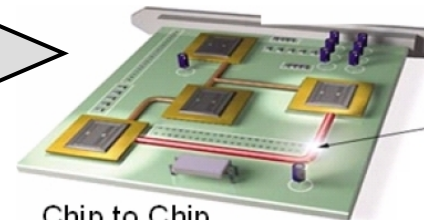
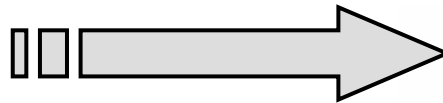


2008

1st Cell w/ Optoflex

Unique advantages: BW, EMI, SAR, HAC, reliability

Optical Interconnects



Chip to Chip



Board to Board

2010-2025

High end server w/ optical interconnects

BW: Bandwidth
EMI: Electromagnetic Interference
SAR: Specific Absorption Rate
HAC: Hearing Aid Compatibility



Optical Interconnects

High End Needs Met over Time

- Bandwidth
- Reliability
- Design Tools
- Standardization of sub-components
- Manufacturing/Test Infrastructure
- Cost per element



Handheld Communication Devices

Leading the Way in Innovation

Applications requiring optical solutions are typically associated with:

- High end
- High cost
- High data-rate

Handheld communication devices require low cost, are relatively low end (vs. supercomputer), and have moderate data-rate requirements, *but* they have high volume that can drive innovations and standards in optical interconnects, and will see the first commercial adoption of these technologies

Precedence – cell phones have driven innovations in:

- High density interconnects (HDI) technology used in PCBs to reduce size and weight, and enhance electrical performance
- Power efficient chip technology, including low-power HDMI (High Definition Multimedia Interface)



Optical Interconnects

Drivers in Handhelds

Handheld devices have rapidly increasing:

- Resolution of displays
- Resolution of cameras
- Speed of CPUs / GPUs
- Storage capacity

➔ Resulting in:

- Higher data rates within these devices and to the outside world

➔ Therefore requiring:

- Continuous innovation in data bus technologies

Copper interconnects are reaching their limits in high-end handhelds:

- Smartphones
- Personal digital assistants (PDA)
- Portable multimedia players (PMP, e.g., iPod)
- Wireless handheld game consoles (e.g., PSP)



Consumer Handhelds

High-End Products



PDA
(Palm TX)[®]



Pocket PC PDA
(HP iPAQ hx2495)[®]



Smartphone
Phone, email, messaging,
GPS, browser, organizer,
media player
(BlackBerry 8800)[®]



Touchscreen Phone
Phone, email, messaging,
maps, browser, organizer,
media player
(Apple iPhone)[®]



Cell Phone
Phone, messaging,
media player, MoD,
VoD, location-based
services (LBS)
(Motorola Krzr)[®]



GPS Navigator
(Garmin Nüvi 670)[®]



Handheld Computer
(OQO 02)[®]



Game Console
(PlayStation Portable [PSP])[®]



Tablet PC
(Motion Computing LE1600)[®]



PMP
Portable Multimedia Player
(Apple 80MB Video iPod)[®]



Mobile Media Companion
(HP iPAQ rx4240)[®]



Optical Interconnects in Handhelds

Technical Drivers

- Bit rates needed in data buses of advanced handhelds:
 - up to 700 Mbps in 2007
 - 1.25 Gbps in 2008
 - 5 Gbps in 2012

- Electrical interconnects are bottleneck, high bit rate links formed with dense parallel copper lines have:
 - Electromagnetic interference (EMI) issues cost significant time & resources, delay time to market
 - Increasingly complex electrical flex interconnects
 - 6+ layers air-gap polyimide flex
 - 50+ pin fine-pitch connectors
 - Thermal dissipation issues due to proximity of highest power consumption components (e.g., CPU & GPU) because of limited data rate of long electrical interconnects

- EMI complicates compliance with regulations including:
 - Specific Absorption Rate (SAR)
 - Hearing Aid Compatibility (HAC)
 - Out of band frequency interference



Optical Interconnects in Handhelds

- Optical interconnects in handheld devices can:
 - Bus high bandwidth signals through a simple serial interface
 - Eliminate the data bus contribution to EMI and SAR

- Passive and active optical interconnect technologies that enable high-performance optical data buses in handhelds are mature, including:
 - VCSELs
 - High speed detectors
 - Electronic drivers (TIA, etc.)
 - Polymer optical interconnects (flex strips & POF)



Optical Interconnects

Application Drivers in Handhelds

Emerging applications requiring high-bit-rate data buses in handheld devices include:

- Live gaming – latency not tolerated in real-time battles where reflexes matter
 - ▶ Shoot'em ups: *Halo, Counter-Strike*
 - ▶ Quest games: *World of Warcraft*
- Portable global positioning system (GPS)
- Capturing and displaying high-resolution images
- Capturing & playing high-frame-rate high-resolution video

Optical Interconnects in Handhelds

Application: Live Gaming

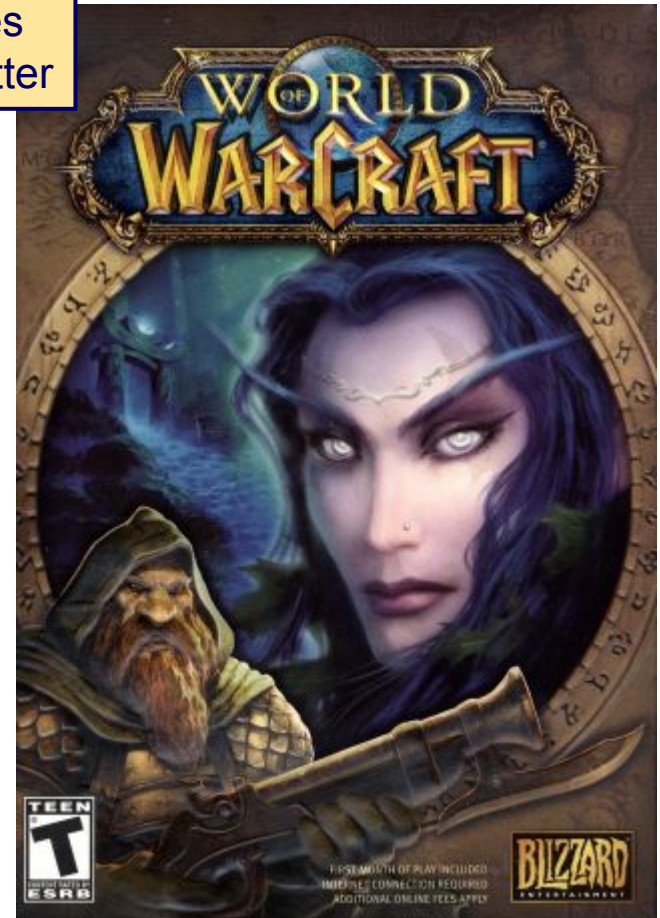
Latency not tolerated
in real-time games
where reflexes matter



Halo Wars[®] is a real time strategy game; will be released in Fall 2007



Counter-Strike[®] is a team-based, tactical shooter game; puts a team of counter-terrorists against a team of terrorists



World of Warcraft[®] is a massive multiplayer online role-playing game



Optical Interconnects

Use in Handhelds

High bandwidth links for handhelds that can benefit from optical interconnects

Internal to Handheld Device:

- Hi Res Camera (CMOS sensors) to CPU & Storage
- GPU to Hi Res Display (LCD cells)
- CPU to GPU
- Core to Core

External to Handheld Device:

- Handheld to HDTV / HD monitor
- Handheld to Storage Device (e.g., PC Hard Drive)
- Handheld to HD Eyewear



Big Screen HDTV
1920x1080 Resolution (2.07 Megapixels)
(SONY)[®]



Desktop PC
(Dell)[®]

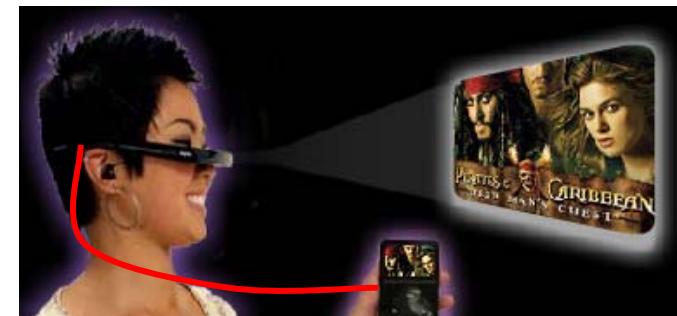


HD Notebooks

WUXGA (Wide Ultra Extended Graphics array)
1920x1200 Resolution (2.30 Megapixels)
(Dell)[®]



DuPont Proprietary



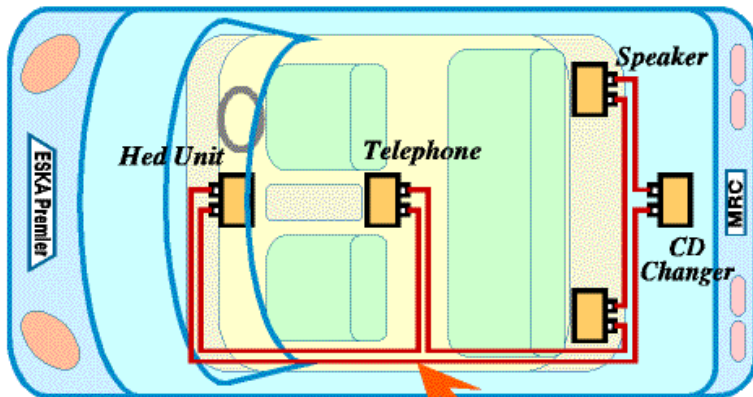
3D Video Eyewear
Virtual big screen viewing of
3D HD rich media content
(my vu)[®]



Plastic Optical Fiber

Existing Consumer Applications

POF is ideal medium for short range high bandwidth links, as needed between handheld devices and external equipment. POF was invented by **DuPont** in 1968.

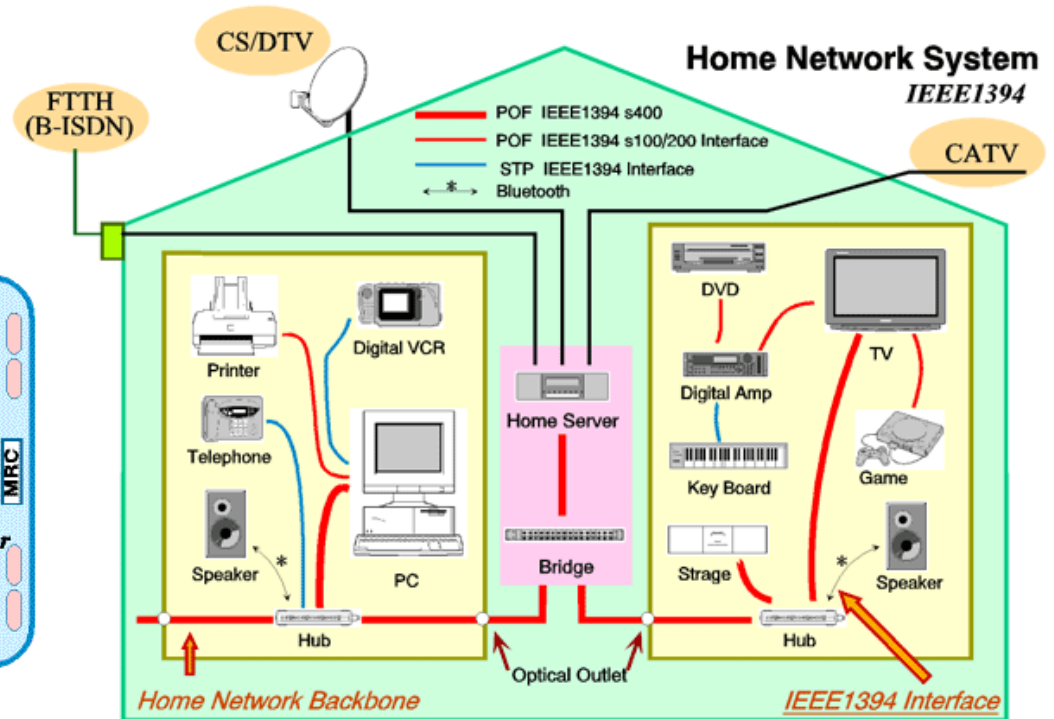


<車内ネットワーク例>

Eska Premier™

Copyright (C) Mitsubishi Rayon Co.,Ltd.

POF-Based Car Network



Update : 2000.2.1

Copyright (c) Mitsubishi Rayon Co.,Ltd.

POF-Based Home Network

Mitsubishi Rayon Eska™ POF is based on **DuPont Teflon® AF**
 Teflon® AF is 4,5-difluoro-2,2-bis(trifluoromethyl)-1,3-dioxole



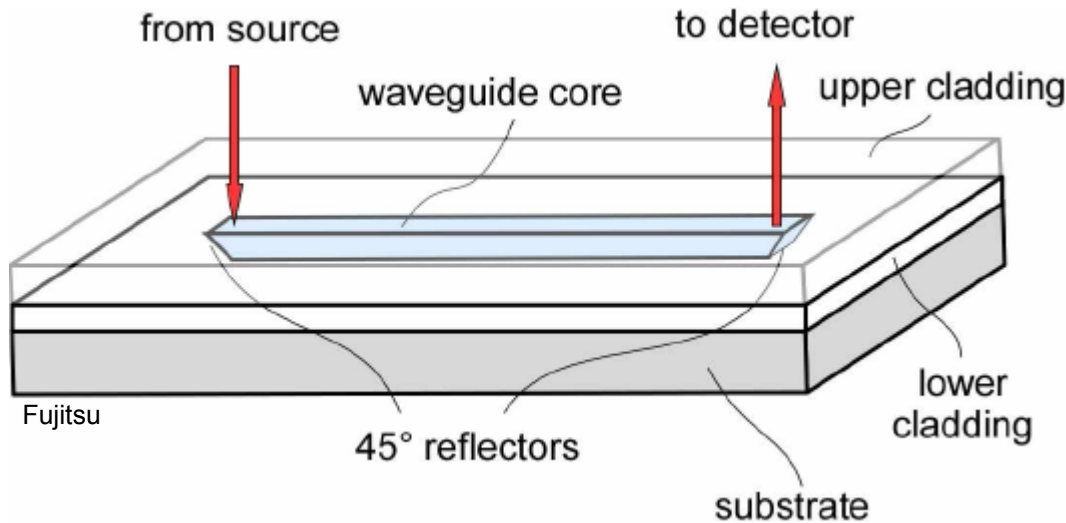
Interconnects in Handhelds

Competing Technologies

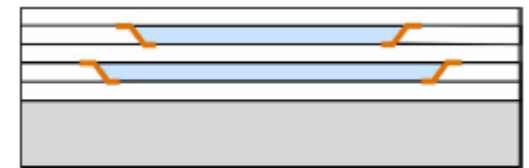
	EMI / SAR Reduction	Mechanical Reliability	Novel Design Enabler	Power Consumption	Cost
Copper Flex Parallel I/F	Red	Red	Red	Green	Green
Micro Coax Cable Parallel I/F	Yellow	Yellow	Red	Green	Yellow
Copper Flex Differential Serial I/F	Yellow	Yellow	Yellow	Yellow	Yellow
Coax Differential I/F	Yellow	Yellow	Yellow	Yellow	Yellow
Optical Serial I/F	Green	Green	Green	Yellow	Yellow

Motorola (partially)

45° Out-of-Plane Mirrors



Multilayer 3D structures



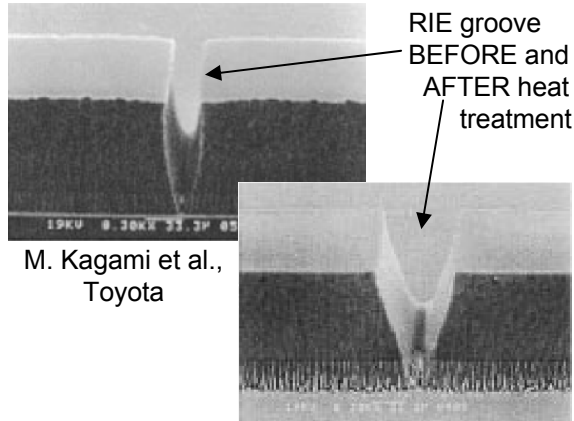
Requirements for 45° out-of-plane mirrors:

- High reflectivity (>80%)
- Precise mirror plane position ($\pm 2-3 \mu\text{m}$)
- Possibility of *up* and *down* routing
- Symmetry of *in* and *out* coupling
- Full integration with waveguides
- Robust and cost-effective manufacturing process
- Possibility of multilayer 3D structures

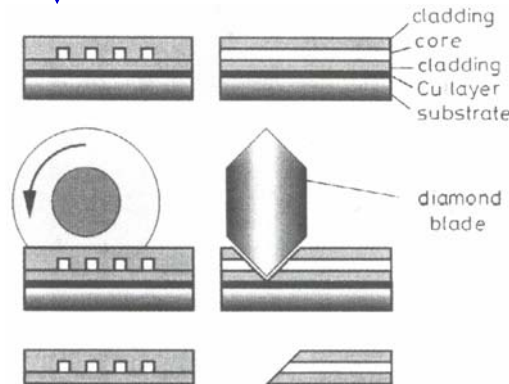
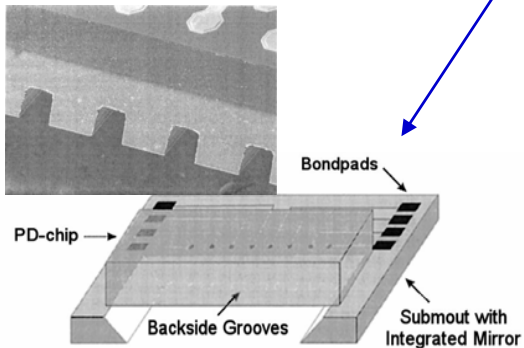
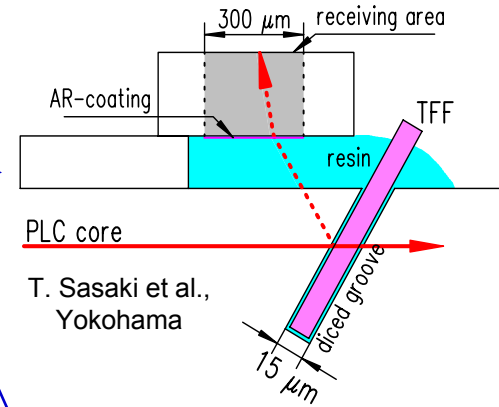


Out-of-Plane Mirrors

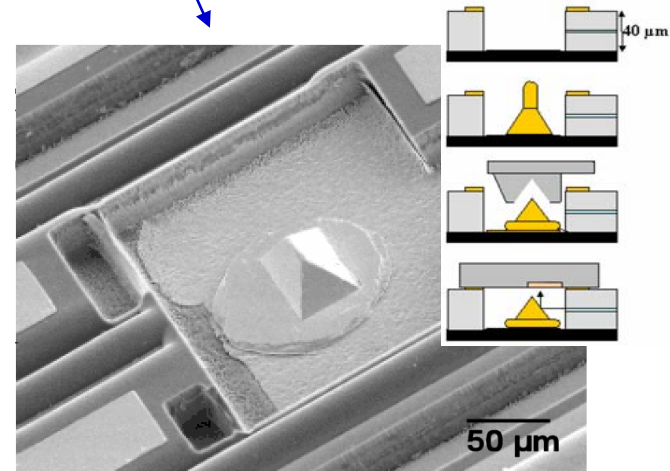
Fabrication Approaches



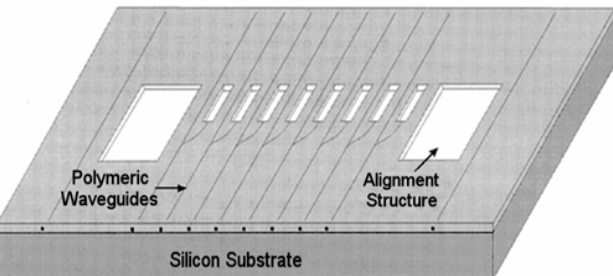
1. Reactive ion etching
2. Thin Film Filters
3. Anisotropic etching
4. Embossing
5. Dicing
6. Excimer laser ablation
7. Laser direct termination



Yoshimura et al., NTT



M. Oda et al., NEC



J. van der Linden et al., JDS Uniphase

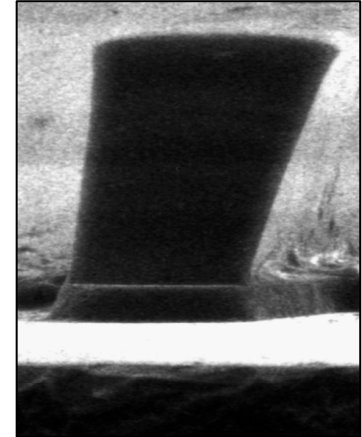
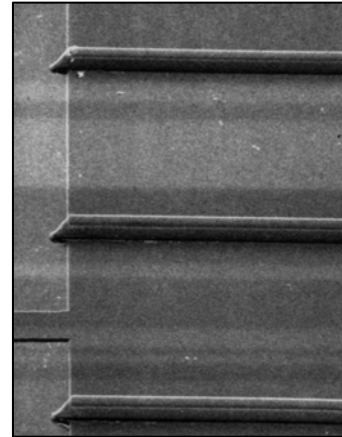
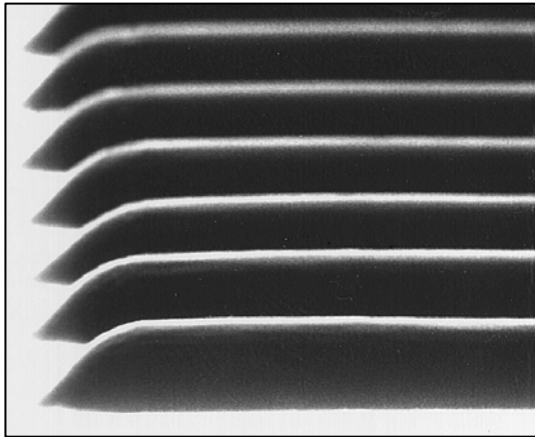


Polymer Optical Interconnects

45° Angle Termination

45° angle termination of waveguides allows 90° out-of-plane bending of the light for the coupling of light from VCSEL's into waveguides or from waveguides into detectors

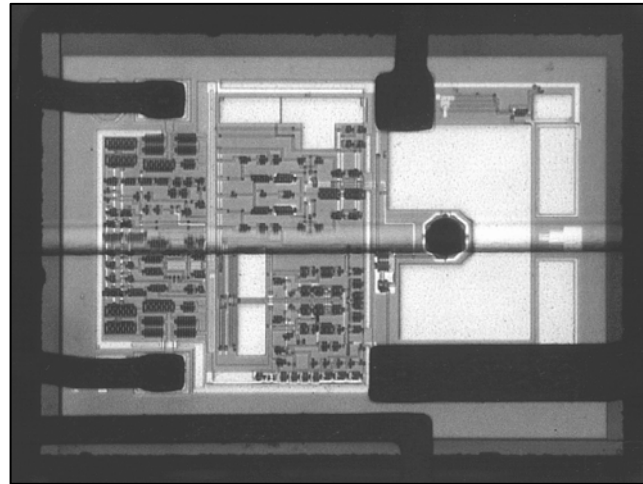
45° angle termination can be achieved during the waveguide fabrication with laser direct writing or through post-processing using Excimer laser ablation



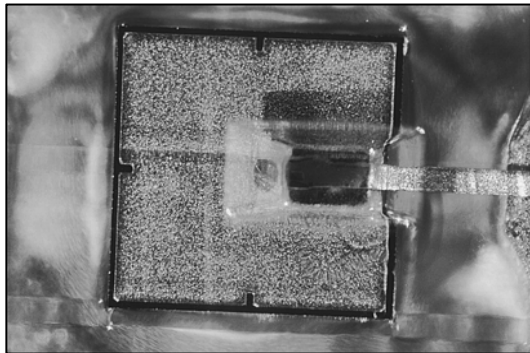


Polymer Optical Interconnects

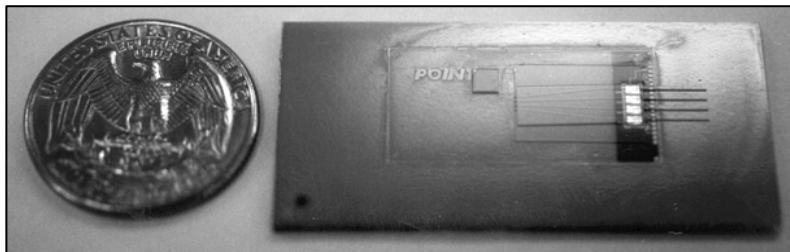
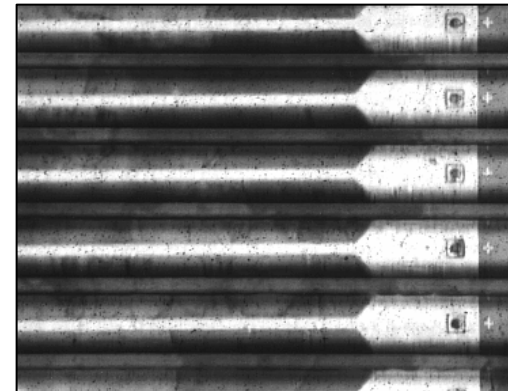
Interconnect on high-speed receiver



Interconnects on p-i-n detectors



Interconnects on VCSEL Array

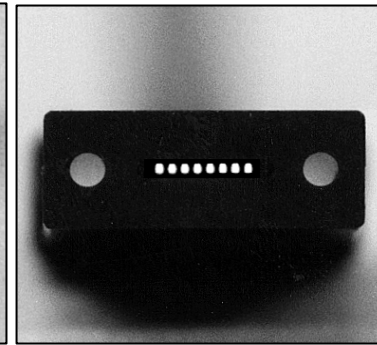
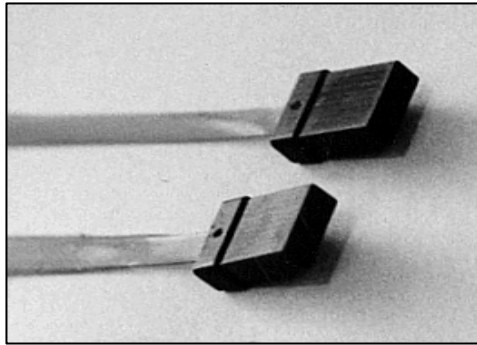
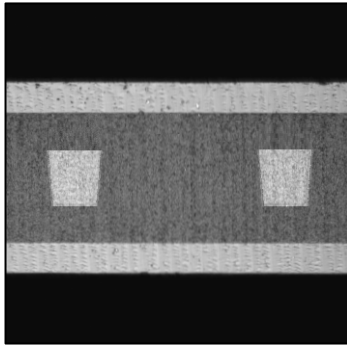




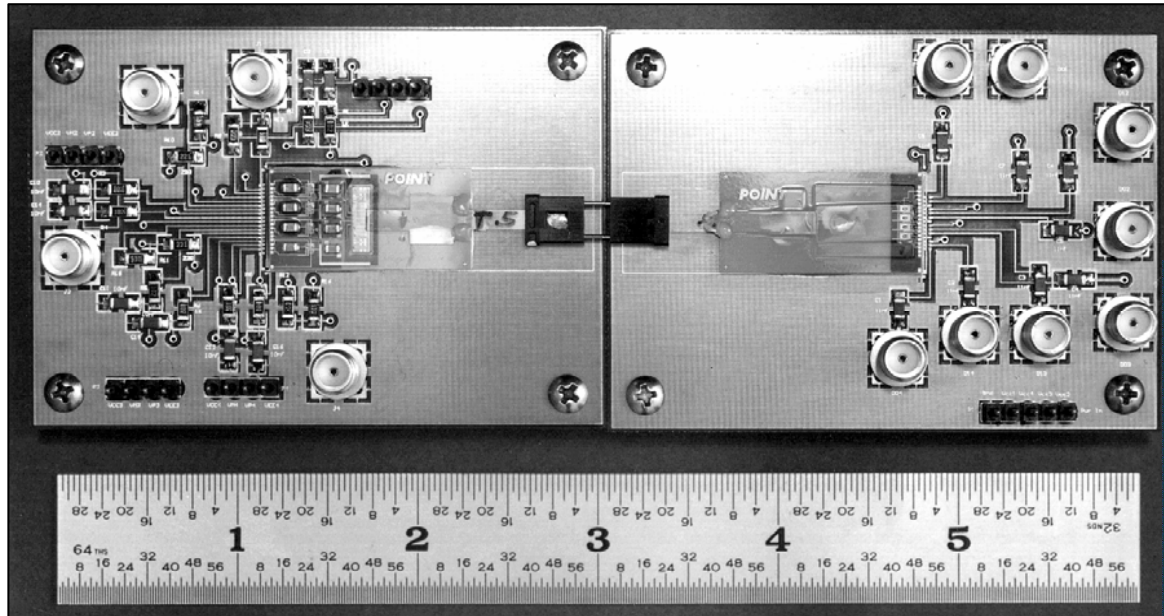
In-Plane Connections

Optical Connectors for Pluggable Interconnects

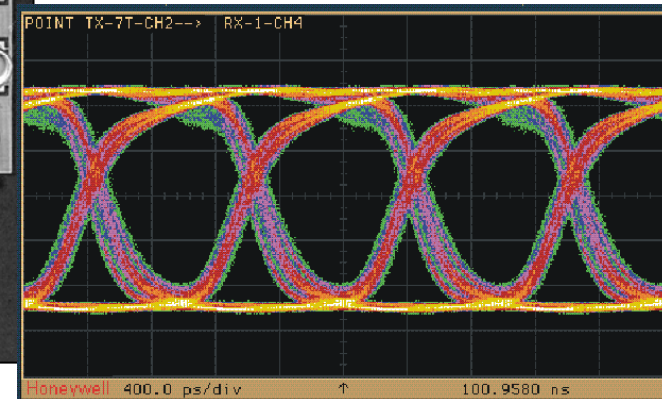
Flexible Interconnect Strip



MT Connector



Interconnected Transmitter & Receiver Boards



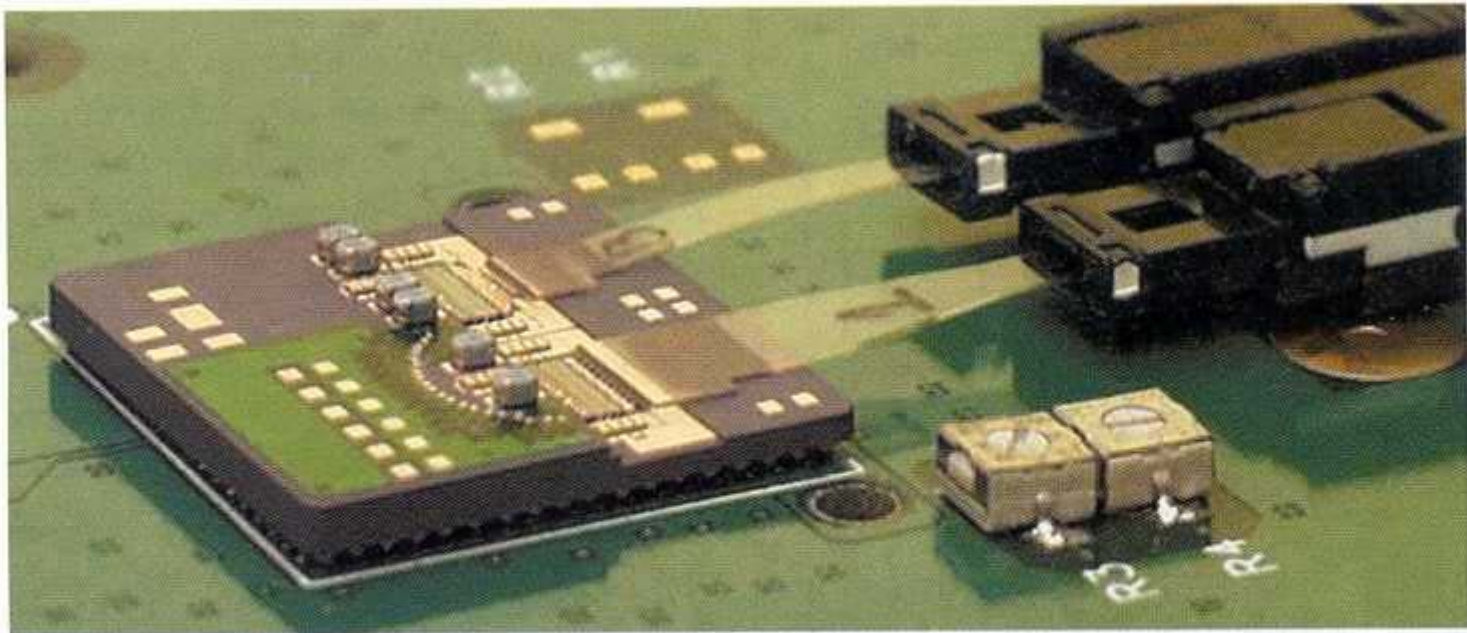
622 Mbps



Intra-Board Interconnects

VCSEL-Based Transponder using DuPont Polymer Optical Interconnects

Industrial Physicist, June 1999



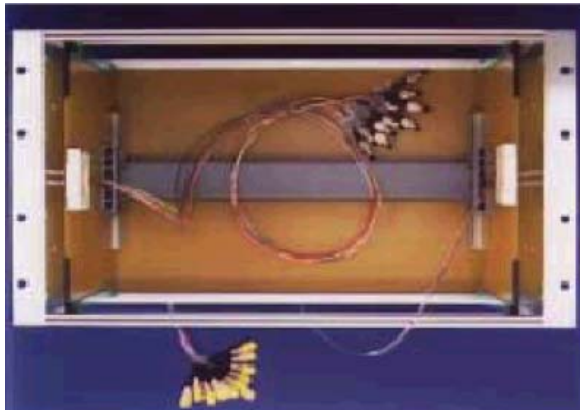
Hewlett-Packard Laboratories

Figure 1. In this optoelectronic device, signals from a computer on the left drive arrays of surface emitting lasers that output signals through 12-channel polymer waveguides (Polyguide) and connectors to the optical-fiber ribbon. Return signals pass through photodetectors back to the computer.

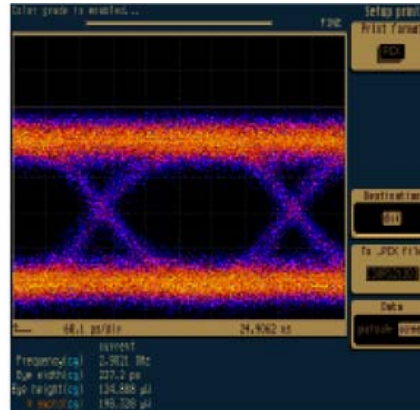


Polymer Optical Interconnects

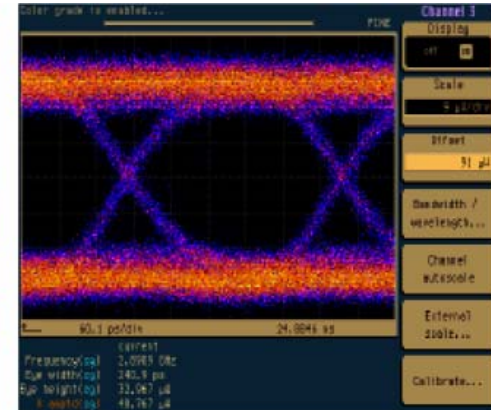
144 Channel Polymer Optical Backplane



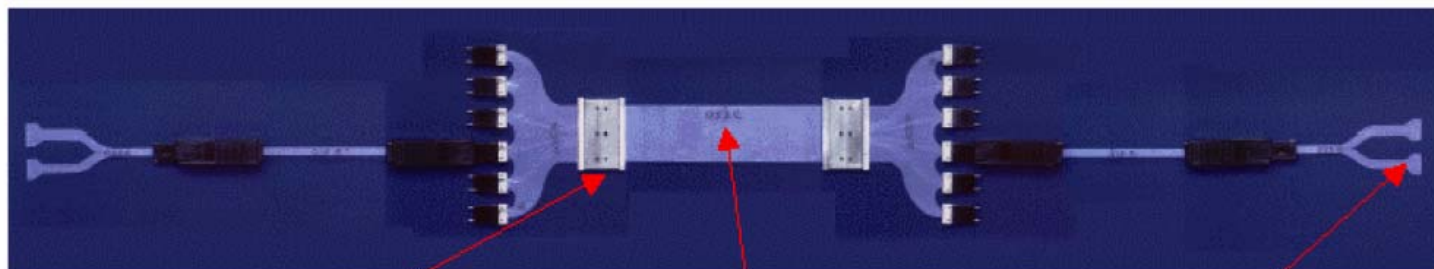
-15 dB loss



2.9 Gbps Input



Output Eye Diagram



Super MT Interconnect

144 Channel Polymer Backplane

Tx/Rx Interface

Losses include 6 separable interconnects and 51.6 cm of multimode polymer optical Interconnect

Bus and Board Conf. 2002





Communications Technology Roadmap at MIT

The Communications Technology Roadmap is a 3-year (Jan '06 – Dec '08) consortium program managed by the MIT Microphotonics Center and lead by industry experts, with the goal of developing a roadmap for the field of microphotonics in areas including telecommunication, datacommunication, computing, imaging and learning, with emphasis on the convergence of electronics and photonics.



Communications Technology Roadmap at MIT

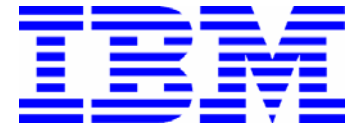
The CTR consortium has 3 Technology Working Groups (TWGs):

1. Cross-Market Applications:
 Technical Requirements & Architectural Options
2. CMOS (Si) Platform
3. Integration, Packaging & Interconnection (IPI)



IPI TWG Participants

Air Force Research Lab
 Analog Devices
 Clayton & Associates
 Corning
 DuPont Photonics Technologies
 Fairchild Semiconductor
 Fujitsu
 IBM
 Intel Corporation
 MIT
 Reflex Photonics
 Rohm & Haas
 Siemens
 University of Oxford





IPI TWG Output

White Papers identifying current technical challenges, future technical requirements & possibly converged integration and packaging strategies for emerging markets, covering 3/5/10 year time horizons. IPI TWG student research project will help answers these questions.

Strategic Roadmap with market-based technical challenges, opportunities and barriers to implement a converged architecture, timeline by which the challenges must be addressed, and impacts if industry cannot meet the roadmaps or convergence opportunities.

Prototype of pluggable optical module addressing some of the needs of an emerging market, developed at MIT ME department with industry guidance.



Focal Topics

Emerging Applications Needing Optical Solutions

Applications

- Optical interconnects in consumer products ← [White Paper #1](#)
- High density PWB optical interconnects ← [White Paper #2](#)
- Optical interconnects between processors in compute applications
- Integrated optical components for Edge & Access networks
- Large-matrix optical cross-connects for Wide Area Networks (WAN)

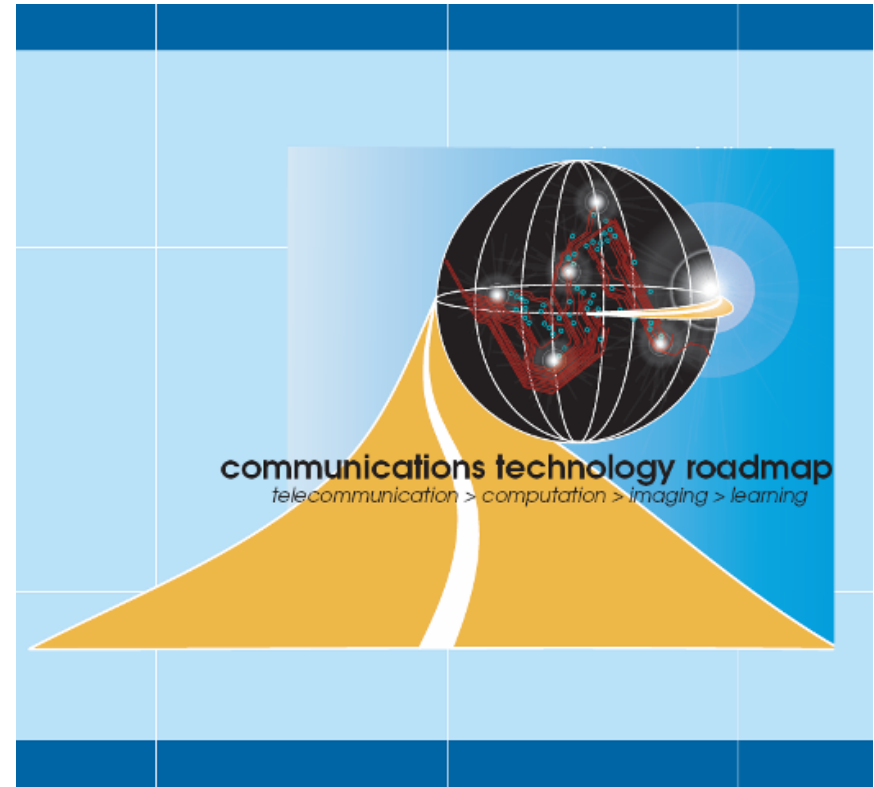
Optical Solution Examples

- Flexible optical bus in flip phones for display & capture
- High-density optical backplanes / optical PWB
- OE/EO chips integrated in pluggable package
- Pluggable splitters (access) & tunable filters (metro edge)
- DWDM & switch matrices in pluggable packages



Participation in IPI TWG

- If interested in participating in the IPI TWG and helping shape the roadmap for Electronic-Photonic Integration and Packaging, contact:
Louay Eldada:
louay.eldada@usa.dupont.com
Rich Grzybowski:
grzybowski@corning.com
- Meeting frequency/times:
 - Teleconference every 6-8 wks (Fridays 11 AM Eastern)
 - Meetings twice a year at MIT (Spring & Fall)



<http://mph-roadmap.mit.edu>