iNEMI Polymer Waveguide Sub Group------Summary of assumptions to date 2/27/05

Initial assumptions made to date by the Sub-Group for the polymer optical waveguide board level system summarized below are to be used as the basis for modifying and extending the information contained in the technology attribute table started by Ed Binkley. The goal being to provide sufficient information and sense of maturity for cost and performance comparisons for several leading polymer guide technologies configured in a generic board level optical interconnect system.

Assumptions:

1) Polymer waveguides to be considered are to be primarily made in self-supporting sheets with fully cladded guides for later bonding to board substrate surfaces or for some interconnections as flexible links. However, it was requested that the option be left to consider where appropriate building up guide layers on application specific substrates as a viable alternative. Waveguide containing films could be embedded between substrates but the added complexity for assembly and connectivity suggested that these applications be considered at a later time. Self-supporting waveguide containing film sheets permit precise configuration and micromachining for connectivity, minimizing unnecessary use of board surfaces, and allow for pre-evaluation to ensure performance criteria is met before bonding to boards. Alternative connectorization requirements need to be defined where appropriate when guide layers are built up directly on permanent substrates.

2) Waveguides are to be sufficiently large to enable multimode propagation and low loss coupling with primary wavelengths for the system to be considered in the 800- 850nm and in the 980nm range, with consideration for 1300nm postponed till a later time. The OIDA report noted the value inherent for considering both 800 and 980 nm regions.

3) For these cost comparisons the board configuration to be considered is to be identical to that used for the black box 1 electrical system, namely 14 daughter boards and 2 switch boards connected to one backplane. Use of interposer (or small) boards mounted parallel to the daughter board may be considered.

4) Only polymer waveguide optical interconnects are to be considered for the cost analysis comparisons even though it is recognized that a practical embodiment would likely incorporate a hybrid system. A hybrid system aimed at optimizing system performance and cost would use polymer guides for links, functionality, high density, and coupling combined with fiber or fiber ribbon arrays, or fibers embedded in plastic sheets (Optoflex or equivalent) for interconnectivity particularly in the backplane where longer runs may be required.

5) The polymer waveguide system will cover realistic coupling between VCSEL's and photo diodes, be on daughter boards, thru the backplane to other daughter board coupling and to off board interconnects. Backplane to daughter board 90 degree interconnections must be blind mate and latchable and compatible with electronic pin connections in separate or unified housings. Both parallel array links and functionality options will be considered where appropriate including splitters and star coupler distribution, crossovers, and dense circuitry configurations. Optical switching would be a future consideration.

6) Technology maturity will be assigned for each of several technologies to be considered along with maturity for each important attribute using a scale of [1] to [4]; namely [1] literature, conceptual stage

or early feasibility only, [2] laboratory demonstration, preliminary proof of concept, evaluation and testing, [3] prototypes constructed and delivered for evaluation, and/or demonstration or system design development, limited pilot production, initial application specific testing, [4] commercial product deployment, extensive testing, manufacturability demonstrated. Critical attributes include all aspects of guide creation, connectorization, system and application performance, manufacturability, production costs, and capital costs.

Technologies selected are considered good candidates for creating fully cladded self supporting multimode waveguide containing films of relatively large dimensions amenable to preprocessing with waveguides defined by photoimaging of either the guides directly or the tool used for guide construction.

<u>Polymer waveguide technology: process, characteristics, general capability</u>

Technology-- General Attribute	**Light induced self development –[3]**	**Etching (wet chemical or RIE)**	**Embossed**
Representative practitioners	Optical CrossLinks, Inc.	Rohm&Haas/Shipley, IBM,	OptoFoil-Fraunhofer Institute, IZM
General process description	Pre coated photosensitive acrylate monomer &binder polymer on temporary carrier 1foot wide 100+ feet long. Contact photomask uv exposed waveguides. Monomer diffusion mass transfer creates higher density polymer guide. “Self-developed” guides are cladded with similar polymer, interdiffused, fully exposed, and bake cured. [3]	Siloxane based negative acting system that processes like a Photoresist. Compatible with CMOS and PWB manufacturing and waste streams. Loss @ 850nm 0.025dB/cm. Embedded waveguides demonstrated with minor increase in loss. Initial data shows good stability @85/85 for over 2500 hrs [2.5}	Hot Embossing of commercial available polymer foil using special negative tool made by high quality lithography and galvanic metallization. Filling of grooves with polymer of higer index of refraction. UV curing. Cladding lamination with same foil as used for embossing (undercladding). Several drying end tempering steps.
Effective CTE & Tg ---impacts Trunout,Tsolder reflow, and bonded substrate to flex link option	Robust outer layers w high Tg (>200C+) and low CTE <50ppm for T/mech prop. ;permits IR reflow 300C 30 sec. [3]	Tg >200C, CTE ~ 120ppm. Isothermal TGA shows no significant decomp upto 50 hours. Initial tests pass solder reflow test [2.5]	Tg 207 °C CTE ca. 70 ppm
Field size / tool size Volume production potential	Largest photomask exposure to date - 18x12 inches. Typical 6 in. [3] Direct write guides demonstrated, large mask or mask on rotating cylinder options for very long guides.	Meter long waveguide demonstrated. Typical substrate size processed 12x8. Material shows good litho on large scale pwb exposure tools. [2]	5’’ [3] Not for very large backplanes but for modules
Optical loss	Bulk material, SM, and MM guides all same loss (no WG wall scatter) at 0.08 dB/cm at 840nm, 0.26dBcm at 980nm [3] System loss including connectivity is the key issue.	0.025dB/cm @ 850nm ~0.07 dBb/cm @ 980nm Measurements made on meter long waveguides [3]	< 0,2 dB/cm @ 850 nm [3], Lover loss with high quality embossing tools possible [2]

Guide size, index --range	4 to 100+ um sq. or rect. with 0.003 to 0.035 index to surround. Typical MM WG's 35x40um w NA ~.3 [3]	5-100um with contrast from 0.02-0.035. Typical wg 50x50 @-.25 delta n [3]	MM typical: 50 µm x 50 µm NA: 0,1...0,3 tuneable [3]
Density/pitch	MM guides with 4 micron space or greater. 10:1 hyperfine pitch Typical 50-200 um space. [3] Stacked for 2D arrays with 125 um vertical pitch in delivered product. [3]	8um L/S through 50um L/s demonstrated. 5;1 aspect ratios demonstrated [3]	MM typical 250 µm pitch [3], min. 50 µm

Polymer Waveguide Technology: Connectivity

Technology--Connectivity Attribute	Light induced self development –[3]	Etching (wet chemical or RIE)	Embossed
WG to/from VCSEL or PD's ---single or array	Film edge 45º I/O mirror (metalized) (~0.4dB loss) couple, precision within few microns both placement to solder balls and array runout [3] Stacked WG (4x12) array (+/-3um) to VCSEL arrays with butt coupling ferrule. [3]		Special coupling unit with: - 45° mirror on waveguide end - metallization for improved reflectivity [2] - 0,7 dB coupling loss for unit O/E Module is mechanically pluggable to the unit
WG to/from OF single or array ---loss impacted by overlap size variation and index profiles vs. GI OF	Direct butt / permanent or MT ferrule array [3] 0.5 to 1.5 dB WG to GI match dominates loss. Ferrule based on board edge or stand alone. [3]		Not in focus but possible
WG to WG	MT ferrule based arrays [3] and permanent splices [3] also direct waveguide to fiber single and arrays.[3]		Not in focus but possible
90º backplane to D board	Flex off substrate link with 5mm ROC and WG to WG couple for array connectivity. Single and dual layer guide MT style array connectors.[3] Blind mate/latchable housing with flex WG[1]		Special coupling unit with: - Mechanical supports for plug in forces - 45° mirror on waveguide end metallization for improved reflectivity [2]
Embedded component in WG film	LD (edge) and filters (WDM)embedded in WG matrix [3] Embedded or ink jetted lenses –free space [1]		Not in focus but possible by hot embossing [2]

I/O mirror arbitrary location	Optional single or multi-guide I/O mirror location within film (not an edge) [2]. Pre cut film to locate I/O mirrors on boards vs fiducals or solder bumps[3] and metalized option for high NA[3] Internal 90 to 45 deg. mirrors constructed.[3]		The special coupling unit is able to locate at arbitrary location on board – depends on the design
Grating deflection in or out of plane	Imaged gratings for in plane [2],		no

Polymer Waveguide Technology: System Applications

Technology--Applications Attribute	Light induced self development –[3]	Etching (wet chemical or RIE)	Embossed
Optical signal routing with waveguide options for very high density to standard OF 250 um pitch or larger			
- point to point links	WG arrays for on board, flex jumpers, 90˚film bend links with 5mm ROC [3]	On board and in board w/ 10mm bend radius [3]	Straight and bended waveguides, Splitters [3]
- crossovers	Low loss with internal guiding structure in crossover region [3]---complex routing link [2]		Tested [2]
- lenses	Photoimaged cascade [3] or embedded for vias and free space links [1]		Only at module side necessary
- mirrors	In and out of plane [3]		Depending on the embossing tool technology. The better way is to cut the waveguides itself in suitable angle [3]
Optical Functionality			
- splitters / combiners point to multi point or reverse	Standard tree branch (1x16) on board or self supporting connected & packaged with total excess loss <2dB at 850nm[3] or fan outs (1x 100) [3]	1x8 splitters with 1dB/split demonstrated [2]	Possible with embossing technology [2]
- distribution : multi-point to multi-point	Star couplers --tree branch format [3]		
- WDM	MM filter insertion with internal guide structure [2]		CWDM possible
- switches	MM bubble switch [2] Single mode phase change thermal demo'd with embedded Peltier control.[2]		TO switches possible

Polymer Waveguide Technology: System Performance / Reliability Issues

Technology-- System Attribute	Light induced self development –[3]	Etching (wet chemical or RIE)	Embossed
System optical loss	Coupling interfaces losses particularly NA/size with step profile WG to graded index profile (GI) OF (typ. 0.5 to 1.5 dB) dominates over material/guide losses until lengths 20 cm or greater		
Reliability / stability	Robust package materials w low effective CTE (typ. ~ 50ppm) and high effective Tg (200C+) used for all items below	85/85 stability up to 2500hrs [3]	
- IR solder reflow	Demo'd with no pitch or loss changes at 300C for 1 minute on board substrate [3]	Past initial testing @ 270C [2]	Demo'd okay at 280C for 1 minute on board
- thermal cycling	Stable – 55 C to 125 C continuous cycling with repeatable no change in loss over every 2 hours cycle for months[3]	Passed 100 cycles from – 40-125 cycling every 15 minutes [2]	Schock 0 – 125°C 600 cycle loss <0,03 dBm 1000 Cycle Loss < 0,1 dBm
- time at temperature aging lifetime	Arrenhenius plot extrapolation---0.1dB/cm loss increase at 850 nm for 85 C for 5yr. and 10x less at 1300nm [3]		
- 85 C / 85%RH	Protection if needed achieved with metalization, SiO2 coatings, packaging.[2] With no barrier protection stable no change in loss at 850nm until ~4 hours then increasing loss with polymer structure modification but loss reversible up to 24 hours, after 24 modification permanent; At 1300nm immediate loss increase but immediately reversible when moisture removed. All polymers absorb moisture under these conditions thus 1300nm, 1550nm will have higher loss due to absorbed moisture if measured during these operational conditions unless barrier	No protection needed [3]	Loss after 50 h <0,05 dBm 300 h <0,08 dBm 1000 h < 0,3 dBm

	layers are used.		
- Coupling interface protection abrasion and solvents	Protected WG MT interface coupling 100 make/breaks with alcohol clean for each, no coupling loss increase [3]		
Hermetic packaging	Packaging to block moisture from reaching solid state VCSELs, PD's etc and interconnecting waveguides inside packages with optical guide array going thru package wall under development [2]		
Other reliability issues and /or requirements to be defined ; may be application specific			

Polymer Waveguide Technology: Manufacturability / Production Cost estimates

Technology-- Manufacturability Attribute	**Light induced self development –[3]**	**Etching (wet chemical or RIE)**	**Embossed**
Volume production	Manual WG films up to 5 sq ft per day –today [3] Reel to reel step and repeat (or cylinder roll) potential 10 to 100+ sq ft per day achievable		
- machining /assembly	Precise machining is critical but slowest step for thruput [3] –needs semi automation, faster cuts low precision areas, pick and place operations. Other tools [2]		
Cost estimates	Assumptions: 1) cost range given from low volume near term after production initiation with some fixturing &process improvements to higher vol. production with semi-automation out several years after production scale up , 2) assume reasonable hourly rates, All $ low to high volume after initial prod. manuf.		

- polymer materials	Materials required to make finished WG film package, ~$40 to $20 per sq ft est. all layers		
- waveguide imaging and processing for fully cladded and protected film structure	Costs ~several $100 per sq ft (batch size dependent); to ~$10 per sq ft with significant automation		
- micro machining for connectivity, coupling, special structures & configurations	Depends on complexity with est. $500 to$1500 / sq ft. average for reasonable coupling and/or component size & density, using machine vision fiducals imaged during WG exp. to guide laser machining. High precision tools where needed, low precision low cost for general cuts. Mirrors and optical surfaces achieved with precision tooling.		
-assemble/connectorize	Cost range based on assumptions above plus materials, processing, machining and assembly. Typ. coupling cost range: MT style conn. WG or Brd edge ~ $100 to $15 per unit with WG array. Brd to brd 90º $300 to $75 with internal WG array MT style connectivity and blind mate latch housing for MT'setc.		
- protective / metal	Coatings for protection or for metalizing mirrors or electronic circuits ~ $800 per vendor run with many components processed per run so ~$2 each to higher $ for large (fewer) components		
- testing	Needs automation, special designs for precision test fixtures (machine shop precision limitations on fixtures so precision upgrades needed). Estimates range from $75 to $5 per tested component with multiple guide arrays and coupling interfaces to		

	fully test critical operating attributes		

Polymer Waveguide Technology: Capital Equipment Cost best guestimates

Technology-- Process step	**Light induced self development –[3]**	**Etching (wet chemical or RIE)**	**Embossed**
Material preparation,	Vendor materials preparation using standard polymer processing chem. lab hoods and equipment like lab glassware, mixers, filters, pumps , solvent removal etc. Very batch size dependent, pilot scale [3] needs $15K; larger prod. volume $50K capital equipment needs		
Material coating	Pilot scale needs met with lab bench coating onto temporary Mylar substrates using $2K equipment [3]. Production scale coatings $1M to $5M investment with coating, drying, large roll film handling, clean rm environment—typically using coating vendors like Rexam, DuPont etc.		
Waveguide exposure and processing	Pilot scale low vol. production needs up to 10 sq.ft. per day per shift approx. $20K [3] including clean rm, air handling, exp box, film handling, ovens. Production volume of 100 sqft per day per shift ~ $300K investment, and 1000sq.ft. /day per shift $1M to $10M investment		
Precision machining	Pilot sacle low vol.production precision machining and support $400K [3]. High prod. continuous process tooling, and multi cutting stages w different lasers and tool options ~$1.5M		
Connectorization, Assembly, packaging	Pilot low vol. manual $10K equipment [3], low production with fixtures but manual $50K, semi-automated $500K		
Lifetime, reliability testing	Extended testing, multi		

	chambers continuous optical monitoring $200K to $1M potential		
Optical testing	Standard array of testing, special fixtures data collection $500K [3]; lrg vol production semi automated $1.5M		
System testing	Electronics and Optical full system $500K dependent on complexity		