Industry Requirements: Reliability and Performance Table for Multimode Optical Interconnections

1) General performance factors: ---Factors that are important or relevant to real world performance characteristics and needs as generic system requirements. This is not to address any polymer or technology for waveguide creation, which is covered in the polymer attribute tables---but only what is really needed for a practical stable polymer interconnection system.

Subcategories	**Minimal Acceptable**	**Typical / expected**	**High performance**
Total System optical loss at 850nm/980nm ***1**			
Few cm guide lengths	2 dB +/-1dB	1.5 dB +/- 0.5dB	1.0 dB +/- 0.3
Up to 10 cm lengths	<5 dB	<4dB	<3dB
20 cm or greater	<10dB	<8dB	<6dB
Effective Tg ***2**	150Tg	200 Tg	300+Tg
Effective CTE ***3**	<100ppm	50ppm	20ppm
Acceptable range for waveguide losses	<0.4dB/cm	<0.2 dB/cm	<0.1dB/cm
Acceptable radius of curvature (ROC) with min. loss	10mm	5mm	2mm
Acceptable coupling goal loss range ***4**	0.7dB/couple	0.5 dB/ couple	0.3dB/ couple
Acceptable loss max increase over time	0.2dB/cm /yr	< 0.1dB/cm /yr	<0.05dB/cm/yr

***1** System optical loss is the critical issue. Low material losses with high coupling or configuration loss (ROC etc.) can be practically the same system impact as high material losses and low coupling losses. System losses can includes all bulk material loss at important wavelengths, scatter due to waveguide formation processes, WG configurations like bends (ROC), I/O coupling, back reflections , alignment issues; NA and size mismatch. System loss for long lengths could be reduced with WG+OF hybrid designs

***2** Effective Tg is the max sustained T above which the system losses mechanical properties and robustness---self supporting polymer go limp, bonded to board have a higher effective Tg

***3** Effective CTE determines the T range over which how well alignment can be maintained for example between polymer guides and solid state components, ie if the CTE is 100 ppm alignment over a broad range is difficult with sources that have a 15ppm CTE, polymers with <50 ppm have a reasonable alignment T range

***4** Coupling loss impacted by direction as to or from a) graded index OF from step profile WG, b) NA max differences, c) size /overlap as well as other factor like axial alignment, air gap etc.

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2) Configurations ---acceptable application requirements like bonding to surfaces, covering large areas or selected links like with strips, being embedded inside or in between substrates, existing both on or off board for an interconnect link. How is the polymer guide to be embodied for a practical application? What is really needed or expected to be practical

Subcategories	**Minimal Acceptable**	**Typical / expected**	**High performance**
Board Surface; coverage (%) application specific	5 to 30%	5 to 50%max	5 to 90% max
Embedded between boards application specific	No liekly	Optional	Optional
Size cut or uncut	Few cm sq or lengths	Up to 20 cm	>20 cm
Flex off board in part	Bonded	Bonded & unbonded	Bonded & unbonded

3) Installation processing—what are the requirements for attaching or processing waveguides in situ to make for acceptable applications that form reliable links

Subcategories	**Minimal Acceptable**	**Typical / expected**	**High performance**
Self supporting guides ***1**	optional	Yes	yes
In situ process guides ***2**	optional	optional	optional
Bonding treatments, agents, board prep	Epoxies	Epoxies,	Epoxies
Cleaning/solvents		PET ether	PET ether
Thermal range acceptable to bond	46C	65C	100C
Pressures (embedded) ***3**	5psi	10 psi	20psi

*1 self supporting guides can be pre made, machined, connected and QC'd then bonded all or in part to substrate board—what are the acceptable issues for bonding, aligning reliably, induced distortions during installation-- that provide are acceptable industry performance
*2 spin coated or guides built up on the substrate during construction, --what are issues, solvents allowed, imaging for alignment, etching, in situ coupling / connectorization overall connecting acceptable to industry practice.
*3 guides embedded between boards---what are acceptable pressures for board, for waveguide films to remain viable. Unique coupling issues inherent for interfacing to surface components such as use of lenes, vias, or direct link to surface etc. Coupling is functionality covered below

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4) Functionalities – what are acceptable and needed functions for reasonable broad range of applications. How diverse must allowed functionality be to have a practical system. These could be one function or many depending or the application requirements.

Subcategories	**Minimal Acceptable**	**Typical / expected**	**High performance**
Point to point, lengths,	0.5 to 5 cm	0.2 to 10 cm	0.1 to 20cm
# in arrays – high density	Several	12+	50+
Single or multi layers	One layer	Up to 2 layers	> 2 layers
Pitch	500 um center to center	250 um center t0 center	50 um center to center
Embedded components in waveguide grid	none	some	Yes
Board edge connectors	MT style	Yes MT style / or small ferrules	Custom or std MT or small ferrules
Bkpl to Daughter board 90 deg connectors, array/layers	no	yes	yes
Mirrors in - or out of-plane	Edge only	At edge & within plane	At edge & within plane
splitting, combining star couple(mixing) crossovers switching	None None None none	Up to 1x16 Up to 8x8 Up to 11 as needed none	To 1x32 Up to 32x32 Up to 50 Opt mech/bubble
Coupling efficiency *1	<1dB/couple	<0.5dB/couple	<0.5dB/couple
Bandwidth / length max			

*1 Coupling involves alignment, size or overlap, NA matching or mismatch, off axis angles, air gap, ---but bottom line is the allowed or acceptable loss before performance is unacceptable

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5) Industry accepted electronic component assembly process compatibility – After guides are in place what are acceptable conditions for adding electronic or E/O components before loss of properties. Conversely, if E/O, E chips or components are already in place what must requirements be for application or installation of waveguide links to achieve properly aligned acceptable performance etc.

Subcategories	**Minimal Acceptable**	**Typical / expected**	**High performance**
IR solder reflow Temp & time max *1	200C @ 0.5 min	300C @ 1 min	400C @ 10 min
Convection/solder bath *2	no	no	possible
Solvent cleaning impact *3	Loss inc. < 0.1 db/cm	Min. loss increase of <0.05 dB/cm	No impact under typical operations
T = Temperature			
t = time			

*1 IR solder reflow T and t where acceptable changes for min performance impact due to low or no increase in material loss, coupling/alignment satisfactory, distortion (microbend issues) okay etc.
*2 most polymers have real issue with extended high T impacting items in *1 above, but if required what is min acceptable impact at min T an t
*3 some solvents have major impact on unprotected polymers like hazing, scattering, cracking etc. particularly alcohols, benzenes. Solvents like PET ether are usually fine with no impact

6) Operational conditions –What are the expected and accepted operating conditions essential for a viable optical link/interconnection system to be practical and deployed?

Subcategories	**Minimal Acceptable**	**Typical / expected**	**High performance**
Std. Temp range	0 to 80C	-45C to 85C	-55 C to 150C
Mil spec range	no	-55C to 125C	-65C to 150C
Moisture impact *1	Minimal	Minimal / protectable	No issue
Operating environment - hermeticity needed?	no	Not typical	Hermetic req.
Local T max (ie laser facet)-sustained	85C	125C	150C
Radiation Rad units, time, loss	no	50% loss, 50 % recover in 24 hours	None!?

Thermal cycle T, t max	0 C to 85C 2 hour	-45C to 85C / 2 hour	-55C to 150C ½ hour
Inertial shock – std spec	No issue	No issue	No issue
Vibration - std spec		?	?
Vacuum out gas - impact	Min.	Low to 0	none
T = Temperature			
t = time			

*1 moisture impacts different wavelengths, different polymer structures, and is significantly increased in time, severity with temperature. Removal can return to pre moisture conditions or leave permanent change

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7) Lifetime / shelf life conditions – What are expected and essential characteristics that must be met to sustain viable performance, like how high a T and over what time, temperature and humidity limits, Arrenhenius extrapolations for allowed loss increase over time at a wavelength and at a sustained T, other degradation induced losses like cracking, hazing, etc over time

Subcategories	**Minimal Acceptable**	**Typical / expected**	**High performance**
Temp max range & t	85C	125C	200C
85C/85%RH& t *1	<1 hour	<4 hours	Req.
Loss inc. time at Temp for λ	1yr at 85C @ 850nm with <0.2dB/cm	ie 5yr at 85C @ 850nm with<0.1dB/cm loss inc.	No impact
Loss degradation in time *2	<1dB	< 0.5 dB	<0.2dB
T = Temperature			
t = time			

*1 A currently used test for adverse impact and lifetime but not a practical test or environment for real world, and also has adverse impact on solid state components, very corrosive
*2 System loss degradation regardless of source has a limit for real applications –so what is acceptable loss limit for system performance. Degradation sources for polymers can be thermal (max or min T, cycling, spikes and/or sustained), water/moisture at T and t, uv (t,P and wavelength)}, thermal shock, solvents, multiple flexing or other mechanical distortions, structural integrity like delamination etc. All these are attributes of the various waveguide polymers and technologies---here what is acceptable by industry for implementation is the question.

8) Solid state components, light sources, detectors, chips, electronic interconnections ----------------Polymer optical interconnects are only part of the issue for a stable reliable high speed system as the entire system must be subjected to the same operational environment and remain stable, and have acceptable lifetime----and no one system component should be held to a higher standard. Thus for light sources, detectors, chips , electronic interconnections, fixtures etc., what are the acceptable operational and storage condition standards (in terms of T max / min, solvents, moisture at T&t, shock, etc. before degradation or failure for these system it components. Much of this needs to be fleshed out to provide limits to which all parts of the system are measured against for stable reliable performance. For example if the VCSEL's start degrade at say 100C then should polymer interconnects remain stable at 125C. Obvious life time projections from Arrenhenius plots or other routes provide useful data that is important –but not for necessarily for operational constraints.

Subcategories	**Minimal Acceptable**	**Typical / expected**	**High performance**
VCSEL's –T, moisture etc.-- ------	85C <50%	90C < 60%RH	95C <80%RH
Edge emitting lasers T,		Same as above	
LED's		?	
chips		?	
Electronic connectivity		?	
T = Temperature			
t = time			