10 Gbps Polymer Optical Fiber Links

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Outline and Introduction

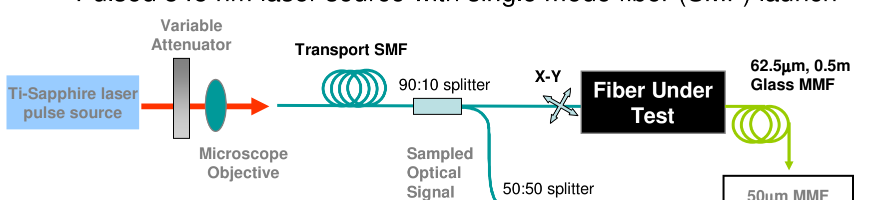
- Improved DMD measurement setup
- Leverage perfluorinated GI-POF's wide bandwidth and low-cost / low profile packaging concepts
- Heterogeneous integration of optics and electronics on a chip-on-board (COB) platform
- Prototype non-imaging optical concentrator made by diamond turning unfilled polyetherimide (PEI)
- Pinhole test and 10 Gbps link demonstration
- Pilot manufacturing NIOC with fiber alignment features made with single-cavity injection molding of PEI
- Concept of chip scale package for integration of optics and electronics with passive alignment

Goals

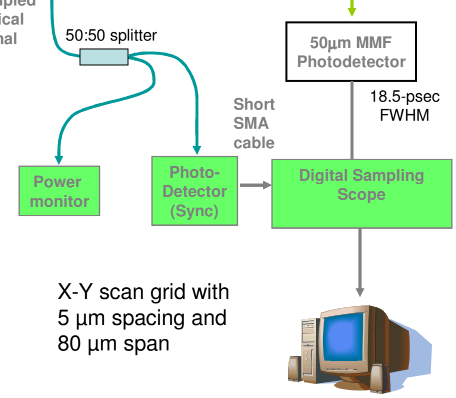
- Demonstrate a 10 Gbps link with the potential for low cost without exotic packaging process
  - Passive alignment if possible
  - Standard packaging equipment and process flow
  - All the other cost factors that go along with POF media
- Leverage the effects of a high degree of intermodal coupling in POF
  - Short links are limited by loss before bandwidth
  - Reduces link dependence on fiber imperfection
  - Reduces the dependence on launch conditions
- Demonstrate low cost collection optics
  - Non-imaging concentrator, hemi-aspheric surface
  - Integrated fiber-alignment and packaging features

DMD Measurement Setup

- Pulsed 845 nm laser source with single mode fiber (SMF) launch

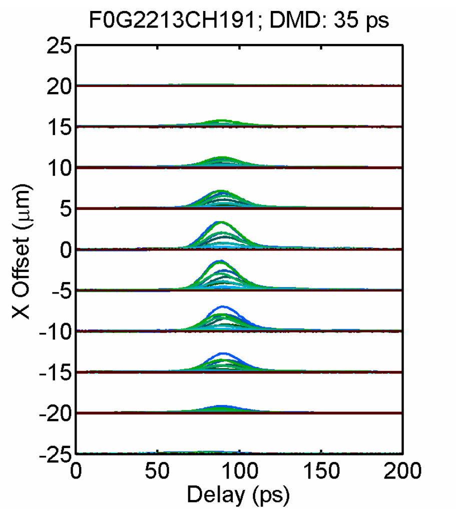


- SMF splitters for monitoring probe signal
  - 22 psec FWHM
  - < 3 psec Jitter
- Scan the SMF position across the input face of the POF
- Capture and detect nearly all of the power exiting the exit face of the POF under test



Full DMD scan: Typical example

- Impulse response supports 100m for all launch conditior
- Figure shows responses for all launch positions
  - For each X-offset, the Y-offset impulse responses ai superimposed
- Differential modal delay (DMD) metric = 35 psec
  - Temporal width at 25% of peak power considering all responses
  - DMD limited by the resolution of the reference pulse with FWHM of 22 psɛ



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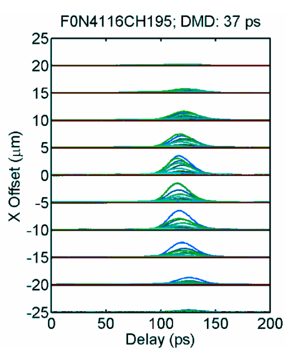
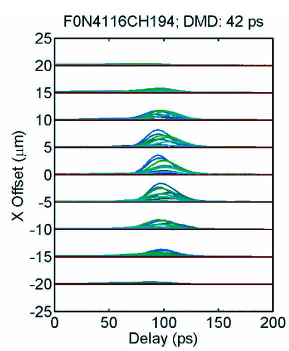
More DMD Scan Data

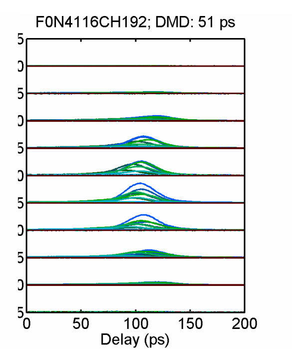
- POF types: 62 um core
- Channel capacity > 25 Gbps over 300 m
  - ~40 Gbps over 100m
  - ~30 Gbps over 200 m



Length: 100m
DMD: 37ps



Length: 200m
DMD: 42ps



Length: 300m
DMD: 51ps

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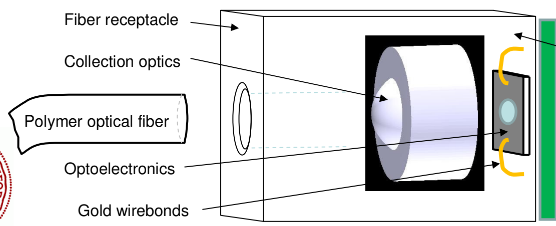
Packaging Integration Approach

- Chip-on-board (COB) packaging approach
  - Flexible platform for prototype design iteration
  - Contains collection optics and optoelectronics
- Hypothetical migration to mass-production
  - Eliminate secondary manufacturing operations when possible
  - Avoid active alignment steps, beyond pick-and-place
  - Employ standard process equipment and process flow
  - Chip-on-board (COB) approach selected for prototyping
  - Laminated chip scale packaging (CSP) for production



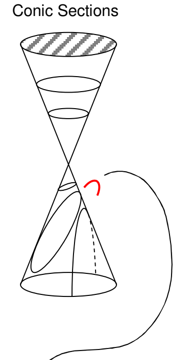
Non-Imaging Concentrator

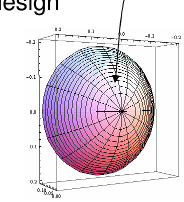
- Desire to have a planar rear surface
  - Simplifies alignment, and lens molding
- Desire to eliminate air gap behind lens
  - Reduces reflections
  - Mechanical stabilization of lens to optoelectronics
  - Protects O/E from particulate contamination
  - Keeps opaque encapsulation compound out
  - Reduces transmission of external forces to O/E
- Hemi-aspheric concentrator
  - Lens shape is an ellipsoid of rotation

$$(1+K)z^2 - 2zR + y^2 = 0$$

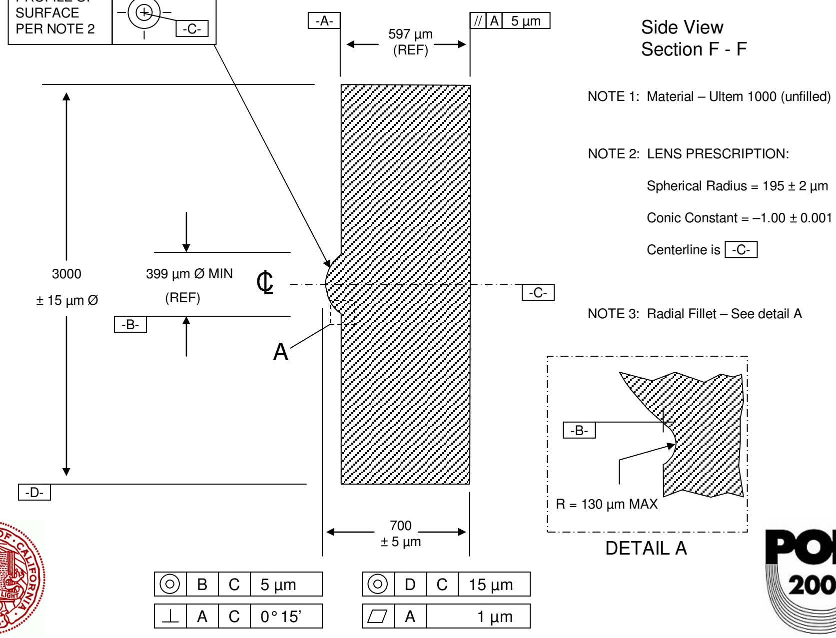
  - Relaxed imaging requirement in Zemax merit function
  - Optimized and distilled into a manufacturable design
- Avoid antireflective coating
  - Good cost savings
- Small *R* makes for short overall length
- Aspheric lenses can be hard to test

Conic Sections

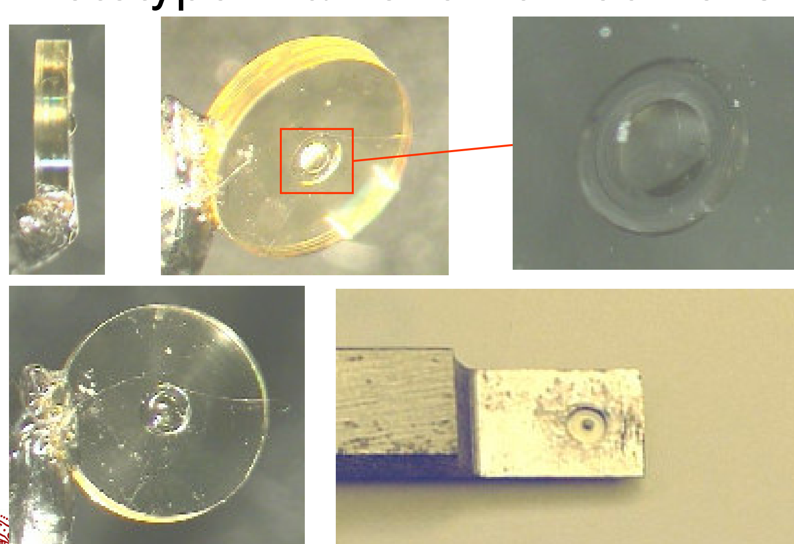




First Design: Diamond turned hemi-aspheric concentrator

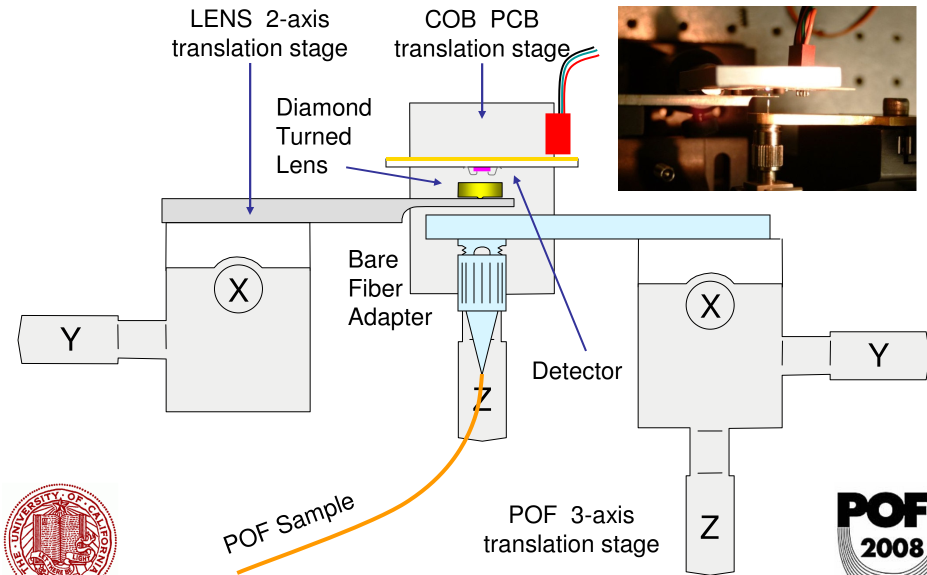


Prototype Diamond Turned Lens



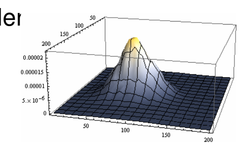
< 300 nm surface figure error

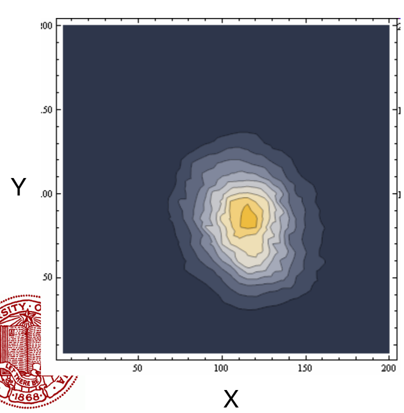
Alignment Setup for Coupling

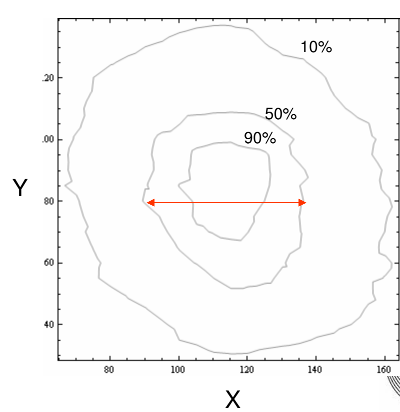


Pinhole in lieu of Detector

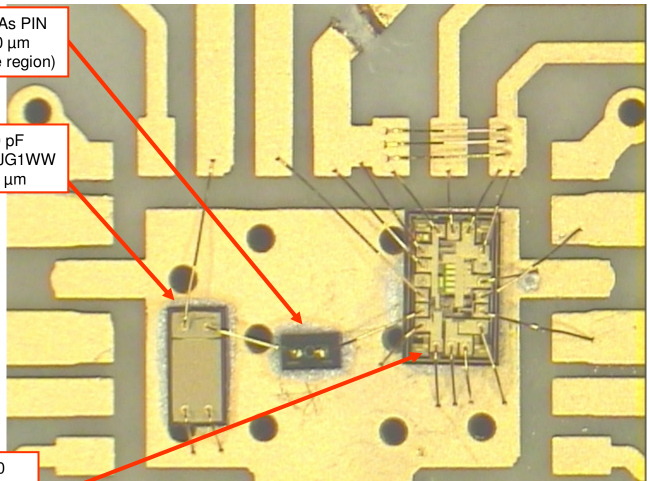
- Equipower contour map of beam waist behind SPDT concentrator
- Fiber approximately 350 microns from front of le
- 20 um pinhole, 40x40 microns
- Section at Z = -100 microns from lens
- FWHM approximately 50 microns
- Beam waist shift due to missing adhesive



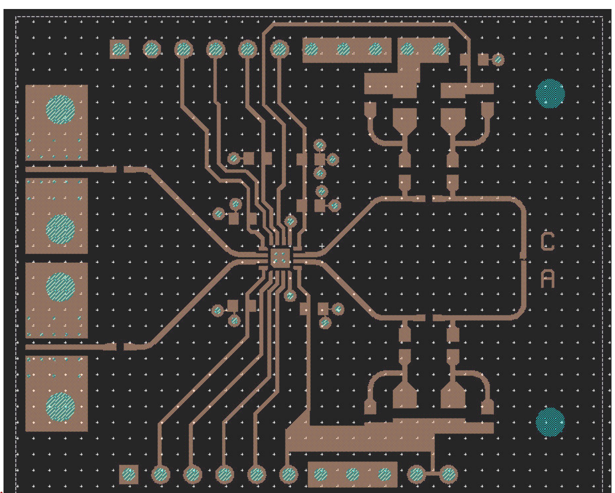


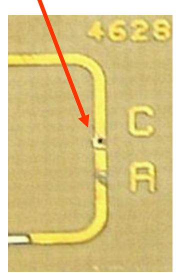


Detail of Receiver COB Assembly

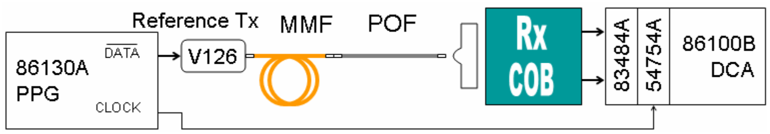


Transmitter COB PCB and VCSEL





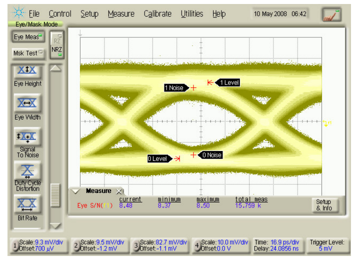
VCSEL has bottom electrode, so electrically conductive die attach adhesive is required

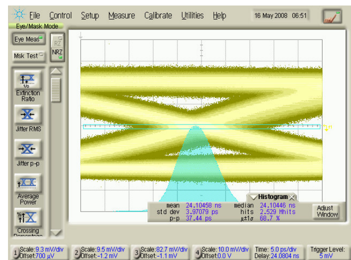


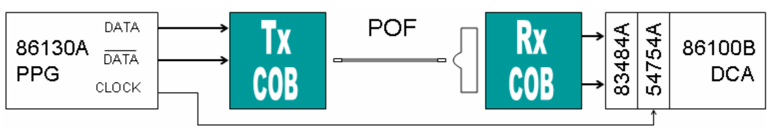
COB RECEIVER TESTING

- 10 Gbps PRBS 2^{31}-1
- California Scientific V-126 source
- 0.3 m of 120 µm Chromis fiber
- COB Rx board with Maxim TIA
- Cosemi MXP7001 GaAs detector

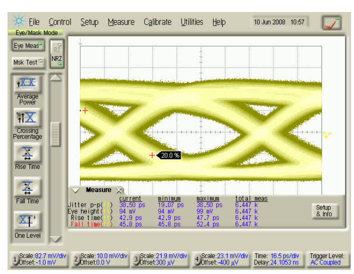
  75 um/.22 pF detector
- Measure SNR, infer Q
- SNR measured to be 8.4 which implies a BER of <10-15 at about 0.4 mW optical power
- Low jitter measured 40.3 psec

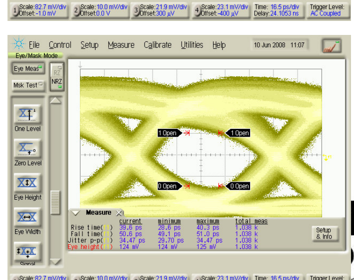






- COB Tx and Rx
- 10 Gbps PRBS 231-1
- Analog Devices ADN2530 driver
- ULM Photonics VCSEL
- 10 m of 120 um Chromis fiber
- COB Rx board with Maxim TIA
- Cosemi MXP7001 PIN detector
- Ran 30 hours error-free
  - $<10^{-14}$:1 BER at 99.99% CL



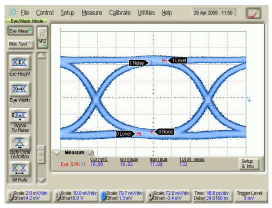


Top Image: Moderate bias current and modulation amplitude

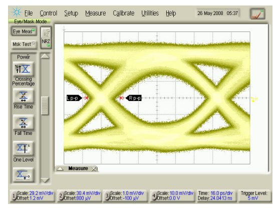
Bottom Image: Maximum bias current and modulation amplitude

Misalignment Sensitivity

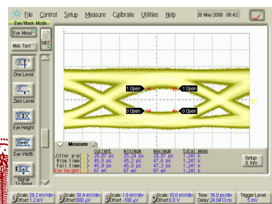
- Coupling efficiency ~ 3 dB at best alignment
- Adjust fiber-to-lens decentering and longitudinal position



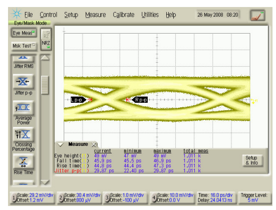
Electrical Reference



At best focal spot



50 um misalignment in y-axis

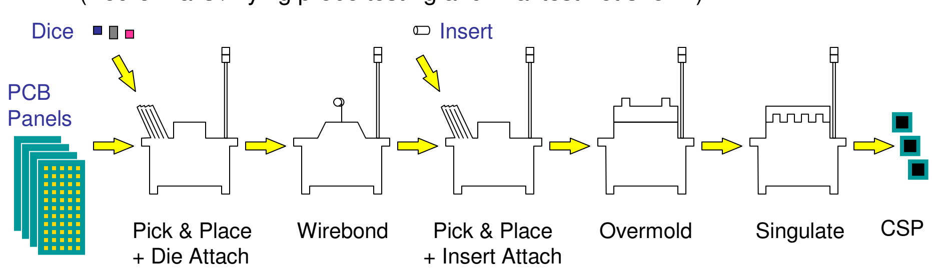


600 um misalignment in z-axis

Scaling to Production

- Path from COB to chip-scale package (CSP)
- Must use standard equipment and process flow

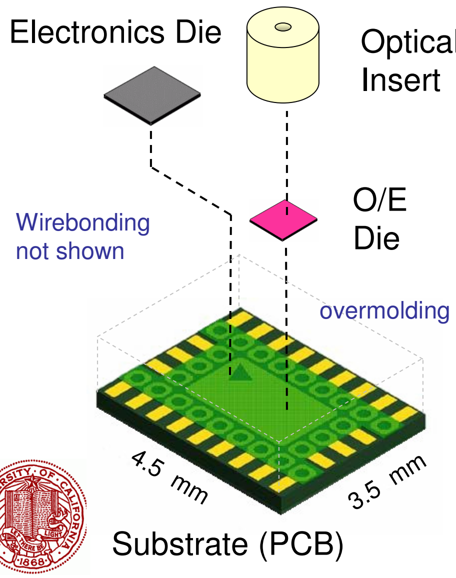
(Bed-of-nails / flying probe testing and final test not shown)

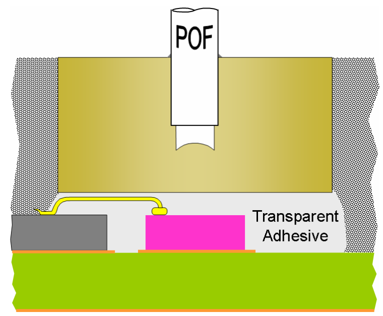


- CSP has extremely low parasitic Ls and Cs
- CSP has a very low profile and thermal impedance

Brief thermal excursions during curing, overmolding, and soldering to the host board by the OEM user

CSP Placement / Integration





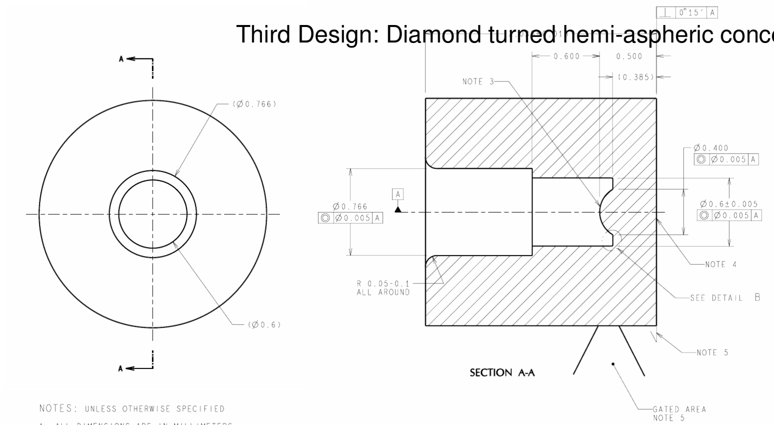
Cross-section of CSP with POF installed

Backside XY tolerance summary of standard P&P and best-of-class P&P

TOLERANCE (peak-peak or 6σ)	±1 mil with die edge location (single camera system)	±1/4 mil with detector aperture location
Detector-to-die	± 0.025 mm	N/A
Die placement	± 0.025 mm	± 0.006 mm
Insert tolerance	± 0.005 mm	± 0.005 mm
Insert placement	± 0.025 mm	± 0.006 mm
Total RSS	± 0.044 mm	± 0.010 mm

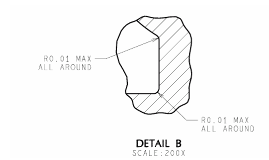
- Similar exercise for angular uncertainty
- RSS value used as input for Monte Carlo simulation
- Polar coordinates for fiber-in-bore uncertainties
- Simulations indicate the dual-camera P&P adequate

Third Design: Diamond turned hemi-aspheric concentrator



NOTES: UNLESS OTHERWISE SPECIFIED

1. ALL DIMENSIONS ARE IN MILLIMETERS.
2. MATERIAL: ULTEM 10-1000 UNFILLED.
3. ASPHERIC LENS PRESCRIPTION:
   RADIUS: 0.195±0.002, DIMENSION SUBJECT TO CHANGE.
   CONIC: -0.640 ± 0.001, DIMENSION SUBJECT TO CHANGE.
   ROUGHNESS: 100 Angstroms RMS MAXIMUM.
   SURFACE FIGURE: 2 FRINGES MAXIMUM AT 632.8nm.
   CENTROID OF LENS IS DATUM -A-.
4. THE OPTICAL SURFACE THAT APPLIES ONLY TO
   CENTRAL ZONE INDICATED.
   ROUGHNESS: 100 Angstroms RMS MAXIMUM.
   SURFACE FIGURE: 2 FRINGES MAXIMUM AT 632.8nm.
5. FLASH IS PERMITTED IN THE RADIAL DIRECTION 0.3mm.
6. SYSTEM DESIGN:
   FRONT GAP: 600 MICRONS REFERENCE.
   REAR GAP: 200 MICRONS REFERENCE.
   EFFECTIVE FOCAL LENGTH: 313 MICRONS REFERENCE.
7. FOR REFERENCE: ULTEM OPTICAL CHARACTOERISTICS:
   n = 1.633 AT 850nm
   Atten = 0.28 dB/mm AT 850nm
   Abbe = 50



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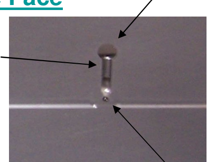
Tool & Die Work

Cooling

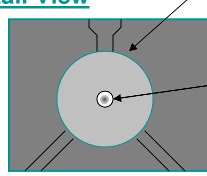
Ejector

PARTING LINE

Die Face

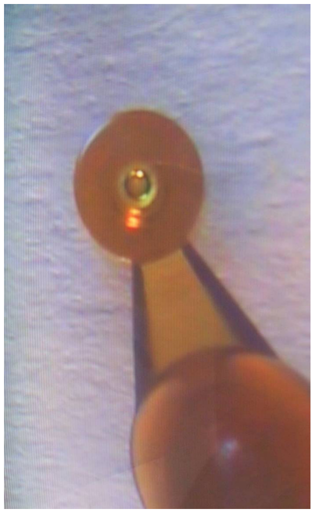


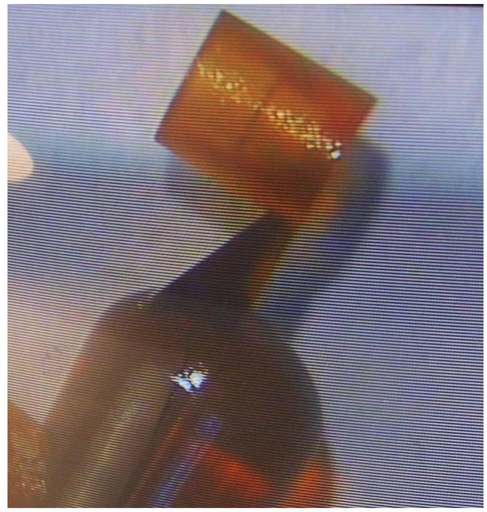
Detail View



Optical Insert Molded in PEI

As ejected from the die with gate and sprue attached





Conclusions and Future Work

- Wide dynamic range, high temporal resolution DMD measurements to fully characterize the temporal behavior of perfluorinated GI-POF
  - Gaussian impulse response, wide bandwidth
  - DMD data shows performance nearly independent of launch conditions
- COB demonstration and path to CSP has been shown with potential for very low cost in volume
- Compatible with pick-and-place, die attach, wirebonding, and overmolding processes used by semiconductor fabs
- Optical concentrators have been diamond-turned and tested with our automated test setup
- Molded optical inserts have been fabricated from PEI
- 10 Gbps link demonstration BER $<10^{-14}$
- Next step is testing the molded inserts and alignment studies
- After that, encapsulated packaging with custom silicon chips

RECENT PUBLICATIONS http://alum.mit.edu/www/dahlgren
R. Dahlgren and K. Pedrotti, "Tolerancing and corner cases in optical simulation," Proc. SPIE 7068 *Optical System Alignment and Tolerancing II.*
R. Dahlgren, J. Wysocki and K. Pedrotti, "Non-imaging optical concentrators for optical interconnect" Proc. SPIE 7059 *Nonimaging Optics and Efficient Illumination Systems V.*

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Lessons Learned, Acknowledgement

- POF is a high-fidelity medium due to large intermodal coupling
- Manual placement of 250 x 250 x 250 µm VCSEL die with a delrin tweezer is easier said than done
- The MSM photodetector that was evaluated, while having low C, was unsuitable due to the carrier transit time and high bias voltage
- Pay particular attention to O/E die alignment fiber receptacle alignment modeling and tolerance stackup
- Success on a shoestring due to a team effort:

UCSC Astronomy Dept.
SCIPP
Santa Cruz Institute for Particle Physics
National Semiconductor
The Sight & Sound of Information
Georgia Institute of Technology
AVAGO
TECHNOLOGIES
भारतीय प्रौद्योगिकी संस्थान खड़गपुर
Indian Institute of Technology
Kharagpur
the UC
Discovery Grant
Success is a great investment
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