Low cost optical interconnects

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ABSTRACT

Optical interconnects to couple light from single mode fiber to waveguides and photonic elements have remained expensive due to tight alignment tolerances, materials choices, fabrication methods and assembly processing techniques. Methods that have been used to lower the cost of optical interconnects will be reviewed and compared to current and future market application demands. Design approaches, fabrication methodologies, and assembly processing techniques for optical interconnects to meet future lower cost market application demands will be shared.

Keywords: optical interconnect, low cost, fabrication methods, assembly processing

1. INTRODUCTION

Optical interconnects couple light signals to and from optical fibers, optical waveguides, and optoelectronic chips such as photodetectors and lasers. Coupling alignment requirements range in dimension from wide tolerances for multimode fiber (MMF) with core dimensions of 50 !m or 62 !m to narrow tolerances for coupling to single mode fiber (SMF), core dimension typically 9 !m.

The costs of optical interconnects and device packaging has been a determining factor in the cost for optical communication transponders as detailed in Figure 1 of reference 1. Costs for optical couplers are driven by optical alignment tolerances, application requirements, and the market size.

Cost is a relative term. For example, an optical interconnect that may be considered low cost for telecommunications applications far exceeds allowable costs for Fiber-to-the-Home (FTTH) applications. Likewise, the cost for traditional fiber connectors may exceed the total transponder cost for chip-to-chip communications applications by one order of magnitude.

2. OPTICAL COUPLING COST DRIVERS

Costs for optical interconnects include their bill-of-materials (BOM) costs and their assembly costs.

2.1 Bill-of-Materials (BOM) costs

All the individual elements (optical, optoelectronic, mechanical and electrical), mount structures, subassemblies and packaging constitute an optical interconnect's BOM. BOM costs for photonic communication devices can represent a significant portion of the total cost for a device or optical interconnect. In general the larger the number of components or subassemblies the higher will be both the BOM cost and assembly cost. Historically tight alignment tolerance components have had a higher BOM and assembly cost.

An example of the large number of components in optical interconnects assemblies is to examine standard fiber connectors. Components in fiber connectors include precision tolerance ferrules and sleeves, mounting body, spring, and fiber boot.

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2.2 Assembly costs

Assembly costs for optical coupling methods are driven by optical component alignment tolerances with tighter tolerances being more costly. Optical component positional alignment tolerances can be divided into the different cost groups of: submicrometer, 1-5 !m, and greater than 10 !m. The capital cost of assembly process equipment is substantially greater and the processing time per alignment is longer for each smaller tolerance group, as detailed in Table 1.

Passive alignment of optical components provides for lower cost coupling than active alignment. In passive alignment, pick-and-place assembly equipment aligns components based upon fiducial marks without optical power coupling, monitoring or feedback control to the motion controller. Passive alignment times are much faster and are compatible with existing electronics industry automated assembly equipment.

Table 1. Assembly cost is driven by optical alignment tolerances.

Component Optical Alignment Tolerance (!m)	**Assembly Attachment Processing**	**Assembly Equipment**	**Assembly Time**
< 1 !m	Special Attachment Methods & Highly Skilled Process Set-up	Custom & Expensive	Slow
1 – 5 !m	Normal Die Attach Processing	Flip-Chip	Fast
10 – 20 !m	Normal Surface Mount Processing	Standard Surface Mount Automated Pick and Place Equipment	Very Fast

Assembly processing for optical interconnects often involves multiple assembly steps. For example, the assembly of fiber connectors, a butt coupling of optical fiber end faces, requires the assembly steps of: stripping off the fiber's protective buffer layer; inserting the fiber and adhesive into ferrules; curing the adhesive; polishing the ferrule/fiber end to a protrusion height and curvature specification; measuring the end fiber/ferrule end face shape; mounting the ferrule into a connector body with a precision ferrule bore, and spring load; applying adhesive to the connector body, fiber boot and fiber buffer and curing the adhesive. Assembly steps for active photonic devices such as a laser transmitter are much more involved consisting of multiple attachments of subassemblies, alignment and attachment of optical and optoelectronic elements and hermetic package processing.

2.3 Arrayed interconnects

One way to reduce the effective cost of optical interconnects is to configure arrays of interconnects in one coupling structure. Arrayed fiber connectors are available using SOB v-grooves and fiber ribbon configurations. Transponders using arrays of Vertical-Cavity-Surface-Emitting-Lasers (VCSEL) and arrays of photodetectors on one photonic chip have been used to lower interconnect costs in applications such as in 4 channel Coarse-Wavelength-Divison-Multiplexer (CWDM) transponders and have been explored for applications in board-to-board optical communication. Configurations of optical coupling to 2 dimensional arrays of VCSELs and photodetectors require custom connector interfaces. In arrayed interconnects fiber pluggability or "plug-and-play" configurations offer more value and deployment acceptance for their optical communications application markets.

A different approach to lowering optical interconnect costs by array design is to array all the active elements and multiplexing components into a single Photonic-Integrated-Circuit (PIC) and use a single optical interconnect for the high bandwidth wavelength division multiplexed (WDM) transponders. This lower cost WDM transponder approach has been deployed in InP based PICs [2] and in Si based PICs [3].

2.4 Low cost considerations

The following guidelines apply to configuring low cost options for optical interconnects:

1. Low cost bill-of-materials (BOM)
2. Fewer number of components and assembly process steps
3. High optical coupling efficiencies at high yield manufacturing
4. Larger alignment tolerances for assembly processes
5. Passive alignment rather than active alignment
6. Fast assembly processing times
7. Ability of fabrication methods to be scaled to high volume production rates
8. Compatibility with existing industry high volume assembly equipment and processing infrastructure

3. OPTICAL DESIGN

Optical design determines optical alignment tolerances. Assembly costs are determined by optical design and assembly processing design. Optical design choices include: butt coupling of similar sized waveguides; evanescent coupling along the waveguide skin length; and projection coupling.

Figure 1 schematically shows the two choices in optical design for projection coupling between two waveguides. If a single lens is used, submicrometer alignment tolerances are required for all components in two lateral axes (x, y) and micrometer tolerances in the depth axis (z). However, if two lenses are used there is no depth (z axis) sensitivity between the two lenses if the beam is collimated.

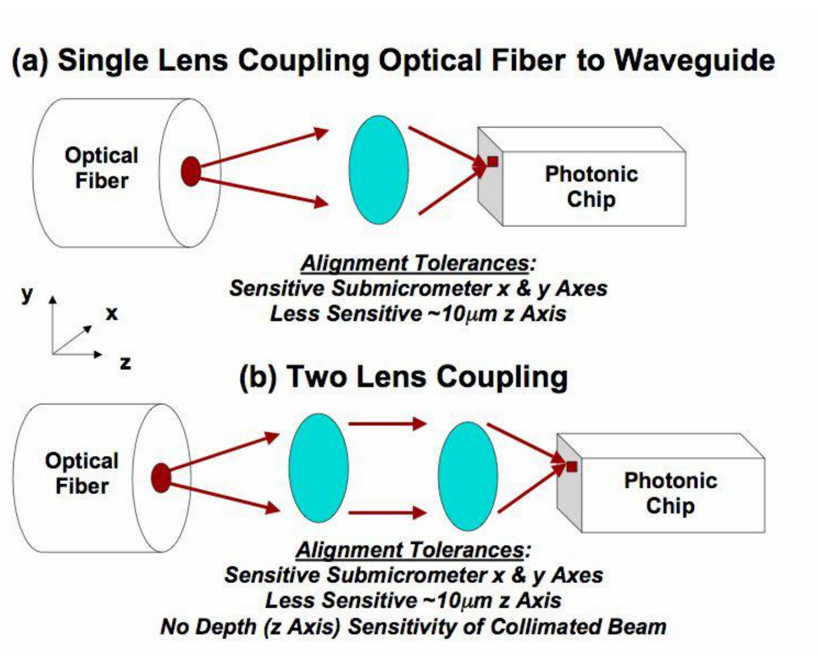

Fig. 1. Lens configurations for projection optical coupling of an optical fiber to a planar waveguide. (a) One lens, and (b) Two lenses.

4. LOW COST CONFIGURATIONS

This section describes a number of configurations that have advanced optical interconnects in terms of lowering cost. These configurations are presented in progressive order of lowering optical interconnect costs.

4.1 Silicon-Optical-Bench (SOB) and V-Groove butt coupling

SOBs provide a subassembly precision platform of well, platform and v-groove structures. SOBs lower assembly costs by enabling passive optical alignment of components and by reducing the number of parts to be assembled. SOBs are fabricated by wet KOH anisotropic etch of <100> silicon and are often pattern metallized for die attach and signal traces. SOBs are inexpensive and have been used in datacom transponders. A common configuration is to mount an edge emitting laser on a platform aligned to a v-groove for fiber alignment. The fiber is usually cleaved at a small angle and butt coupled to other photonic elements on the SOB.

Butt coupling of fibers placed in SOB v-grooves to etched facets of Planar-Lightwave-Circuit (PLC) waveguides has been a popular choice for coupling to FTTH transponders[4] and for coupling to silicon optical motherboard configurations postulated for chip-to-chip or board-to-board communication applications[5].

4.2 Ferruled fiber pluggable Transmitter-Optical-Sub-Assemblies (TOSA)

Another approach to lower optical interconnect costs is to reduce the number of components and to reduce the number of assembly steps by forming an integrated optical and mounting structure using the low cost scalable fabrication method of injection molding. The Transmitter-Optical-Sub-Assembly (TOSA) and associated Receiver-Optical-Sub-Assembly (ROSA) shown in Figure 2 has seen wide deployment. This design integrates a single lens into a mounting structure that has a precision bore for a pluggable ferruled fiber with an end stop, and a mounting structure for alignment and adhesive attachment to the top of hermetically sealed TO-can packages. The TO-can contains the active elements and their electrical connections. The TOSA body provides a pre-alignment of the lens to the inserted fiber. TOSAs are fabricated in plastic by injection molding with Ultem® being the plastic of choice. Injection molding is a fabrication method that is mature and scalable for high volume production. This scalability also has led to progressive reductions in price of injection molded TOSAs by a factor of 5X since their introduction. The development history of pluggable TOSAs is detailed in reference 6.

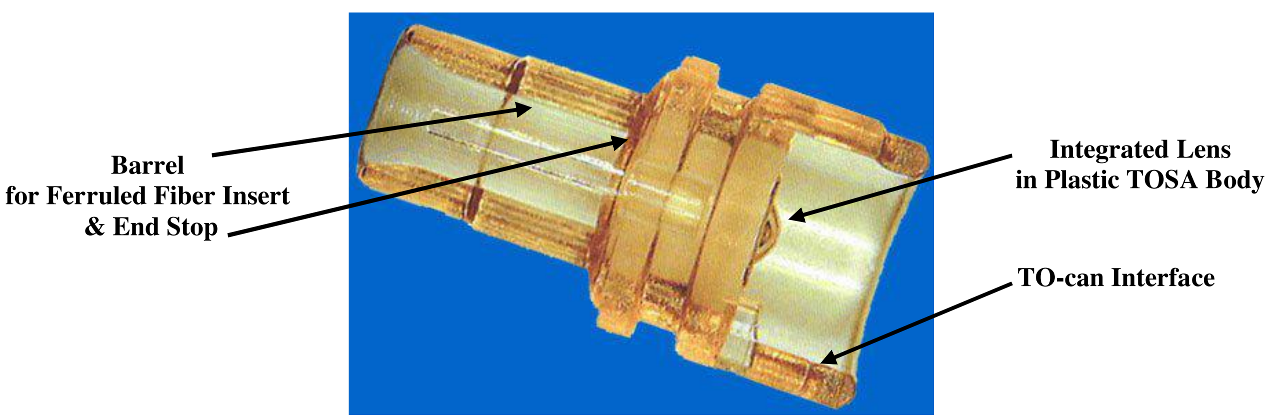

Fig. 2. Typical injection molded TOSA assembly. Ultem® plastic body incorporates a lens, barrel for ferruled fiber insert with barrel stop and mounting structure. Most frequently the plastic TOSA is glued to a TO-can laser package.

4.3 Evanescent coupling of lasers to PLC waveguides

Evanescent coupling of lasers to PLC waveguides has been made via a "Laser Surface Mount Converter" in the laser chip[4,7]. The laser chip is die bonded to a PLC top surface using passive alignment at ±2 μm alignment tolerance to PLC waveguides. This coupling attachment effectively seals the optical path, thus removing the need for hermetic packaging for laser reliability.

Evanescent coupling of planar waveguides to optical fiber is extremely difficult due to submicrometer tolerance control in removing fiber cladding and in maintaining evanescent contact distance with the planar waveguide.

4.4 Diffraction grating couplers

Optical coupling via scattering of light in diffraction gratings offers a method for low cost out-of-plane optical coupling. The gratings are low cost as they are lithographically aligned and are formed by wafer level etch processing. High refractive index contrast gratings and mirror metallization are required for high coupling efficiencies. Diffraction grating coupling efficiency is sensitive to light polarization and wavelength. Diffraction grating couplers have been implemented in silicon monolithic photonic circuits as "holographic lens" configurations at 1 μm alignment tolerance and with coupling efficiencies of up to -1.4dB (73%) into 0.1 μm^2 silicon-on-insulator (SOI) waveguides from optical fiber and from surface mounted lasers on the chip front-side[3]. This method works with both ridge waveguides and buried waveguides.

5. FUTURE DIRECTIONS FOR LOW COST OPTICAL INTERCONNECTS

Low cost optical interconnect developments are likely to use projection coupling across the photonic chip front-side and back-side. Optical alignment tolerances will continue to increase to greater than 1 μm to enable lower cost assembly align and attach processing.

Low cost designs are likely to utilize fabrication techniques such as injection molding of plastic optical subassemblies for fiber couplers. Characteristics of these subassemblies are could include integrated lenses and passive fiber alignment pigtail attachment. Optical couplers for fibers, laser chips or photodetector chips to planar waveguides may also include out-of-plane beam turning elements.

These low cost optical coupling solutions will be compatible with electronics industry standard surface mount assembly processing with passive optical alignment and fast attachment times.

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