

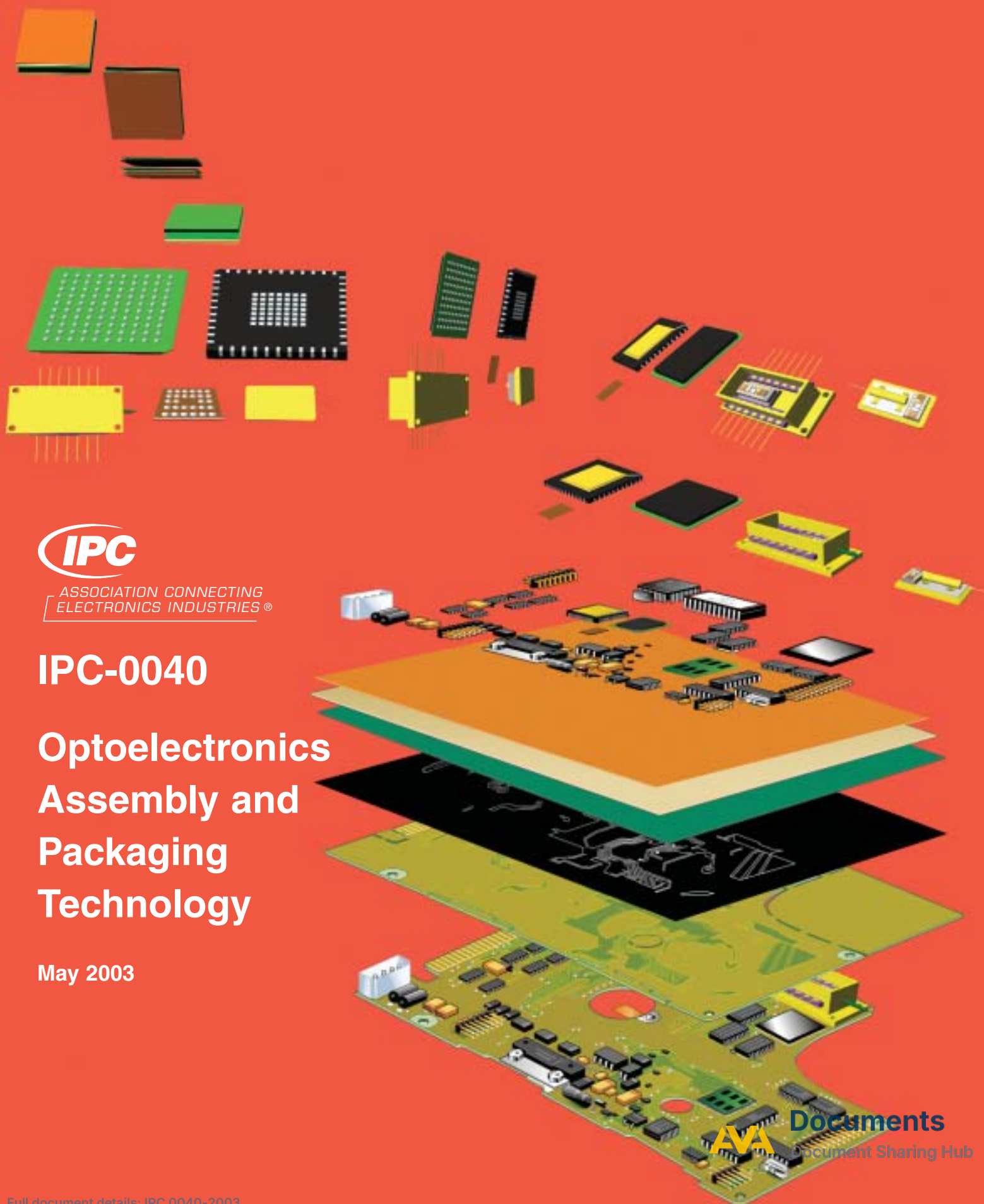


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IPC-0040

Optoelectronics Assembly and Packaging Technology

May 2003



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Optoelectronic Assembly and Packaging Technology

Developed by the Optoelectronics Assembly Subcommittee (5-25) of the
Assembly & Joining Processes Committee (5-20) of IPC

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Contact:

IPC
2215 Sanders Road
Northbrook, Illinois
60062-6135
Tel 847 509.9700
Fax 847 509.9798



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Assembly & Joining Processes Committee	Optoelectronics Assembly Subcommittee	Technical Liaison of the IPC Board of Directors
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Leighton MacMillan, Coretec Inc.	Akikazu Shibata, Ph.D., JPCA-Japan Printed Circuit Association	Jennifer Nguyen, Solectron
Rob Johnson, Corning Incorporated	Ben Velsher, Kyocera America Inc.	Jennifer Curran, Solectron
Diane Williams, Corning Incorporated	Dennis Fritz, MacDermid, Inc.	Doug Feicht, TechSearch International Inc.
Cloud Downey, Daiichi Jitsugyo America Inc.	Paul Magill, Ph.D., Coviant	Les Hymes, The Complete Connection
Dr. Dan Nelson, DGN Consulting	Martin G. Freedman, Molex Inc.	

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Optoelectronic Assembly and Packaging Technology

1 SCOPE

This document addresses the implementation of optical and optoelectronic packaging technologies.

The areas discussed include: technology choices, design considerations, material properties, component mounting and interconnecting structures, assembly processes, testing, application, rework, and reliability of completed optoelectronic products. Optoelectronic packaging technologies include active and passive components and discrete fiber cable, their characteristics, and the manner that these parts will become an integral part of the functioning module, board or subassembly.

1.1 Purpose This document is intended to provide general information on implementing optical and optoelectronic packaging technologies, for creating component mounting structures and assemblies that may be exclusively optically oriented or that are to perform a combination of optical and electronic functions.

1.2 Categorization Optoelectronic components are categorized by function (i.e., modulators, lasers, switches, detectors); optoelectronic assemblies are categorized by higher level functions (i.e., transmitters, receivers, amplifiers, transponders). See Figures 1-1 through 1-3.

There are four levels of optoelectronic packaging. These levels have been established to mirror previous packaging levels assigned to electronic equipment. They are intended to make a clear demarcation between manufacturing products intended for the optoelectronic market. The four levels are:

- **OPTO Level 0:** Uncased device (e.g., lenses. Isolator, laser diode, waveguide beam splitters, etc.)
- **OPTO Level 1:** Single device or multiple devices in a package (Multi-Device Subassembly (MDS) - a package integrating optical, optoelectronic components and IC components)
- **OPTO Level 2:** Modules and product boards (Transponder on a daughter card)
- **OPTO Level 3:** Mother board with product boards or cabling (Transponder mounted on a mother board)

It should be recognized that there are also levels of complexity included in each of the levels of optoelectronic packages. Level 0 complexity deals with unpackaged devices complexity primarily relating to the complexity or difficulty in the manufacturing process.

Levels 1 through 3 complexities relate to the assembly process(s) necessary to produce a quality optoelectronic

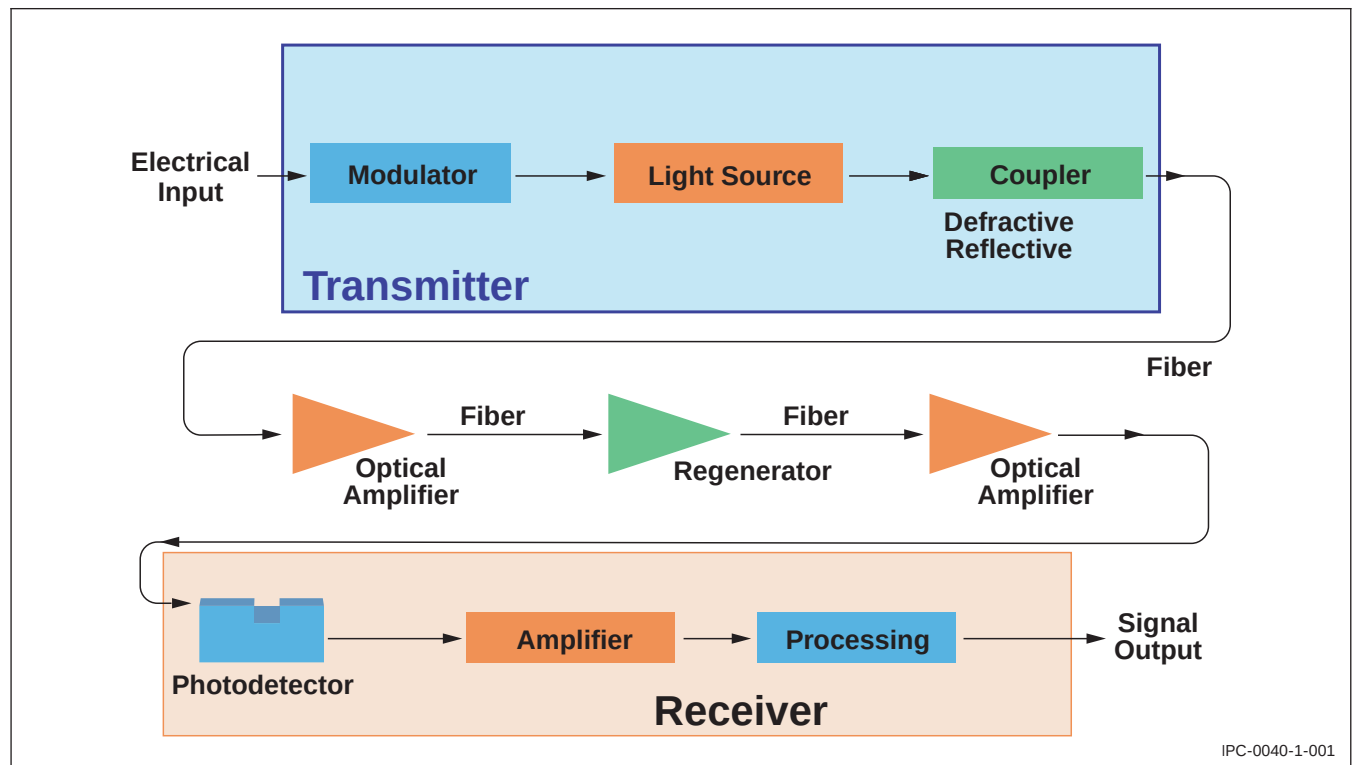


Figure 1-1 Optoelectronic Communication System Structure

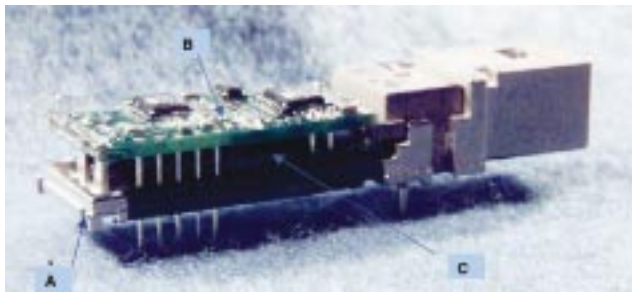


Figure 1-2 Typical Optoelectronic Assembly Hierarchy
 A) Metallized Plastic Bottom Support
 B) Optoelectronics Board Assembly
 C) Electronic Board Assembly

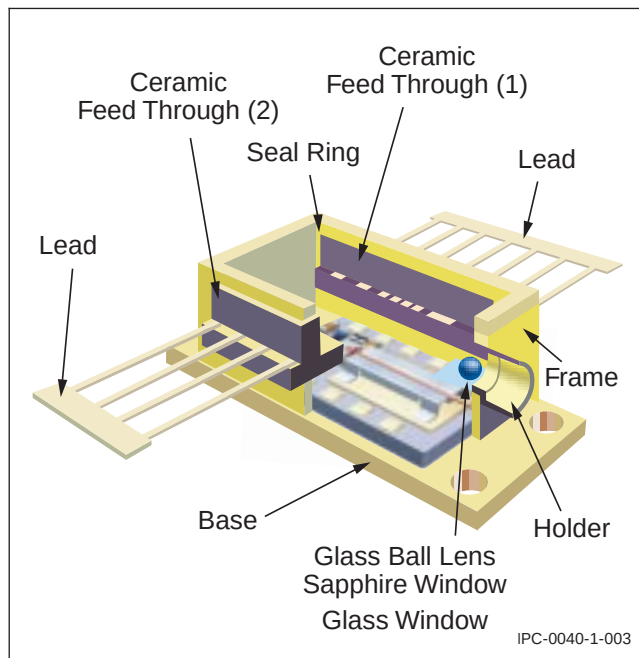


Figure 1-3 Typical Optoelectronic Components

product. Level 1 represents the first level of combining optical and electronic parts. Parts assembled may be a Level 0 device or may already be in some packaged form. Essentially Level 1 is a simple or complex component, consisting of many parts, which is intended to be further interconnected with other parts on the next level.

Level 2 represents product board or module where the entire assembly performs a specific function in an optoelectronic system. Both Level 0 and Level 1 devices/components are mounted and interconnected on the Level 2 assembly. The Level 2 products form the foundation and building blocks of the system that establish the bandwidth performance required by the customer.

Level 3 is dedicated to combining and interconnecting the Level 2 products. This packaging may include the cabinetry, the backplane into which product boards are inserted or the cabling (both optical fiber or wire) needed to interconnect the Level 2 products.

1.2.1 Complexity or Producibility Level When appropriate this document will provide three design and manufacturing complexity/producibility levels. Each level describes features, tolerances, measurements, assembly, and testing of completed products. Also included is the verification of the manufacturing process that reflects progressive increases in sophistication of tooling, materials or processing and therefore progressive increases in fabrication cost.

These levels are:

Level A: General Complexity/Producibility – Preferred

For low-density optoelectronic product applications, where the component assembly conditions have been developed to accommodate ease of assembly or high levels of automation.

The geometry of the parts being assembled are furnished devices that fit easily into the standard assembly processes for attachment and interconnection. These may include through hole and surface mount application all of which provide a wide process window for attachment and alignment processes.

Level B: Moderate Complexity/Producibility – Standard

Optoelectronic products with a moderate level of component density where the components and mounting patterns are furnished for all device families and provide a robust attachment condition for one or more attachment processes.

The condition should be suitable for solder reflow, or adhesive attachment, and may go through several processes to achieve a fully functional tested assembly.

Level C: High Complexity/Producibility – Reduced

High component density typical of portable and hand-held product applications. This level has the ‘minimum’ space available for attachment, has the least clearance between parts and offers the greatest challenge to incorporate automation.

The techniques used for assembly and alignment may not be suitable for all product use categories. Attachment features are minimal and the component count is high. Product packages in the BGA or FBGA format require Level C categorization.

The producibility levels are not to be interpreted as a hard/fast design or manufacturing requirement, but a method of communicating the degree of difficulty of a feature between design and fabrication/assembly facilities. The use of one level for a specific feature does not mean that other features must be of the same level. Selection should always be based on the minimum need, while recognizing that the precision, performance, conductive pattern density, laser/optical fiber integration, equipment, assembly and testing requirements determine the design producibility level.

The specific requirement for any feature that must be controlled on the end item shall be specified on the drawing.

drawing of the optoelectronic printed board or the optoelectronic printed board assembly drawing.

Optoelectronic levels are combined in the categorization description using the package level and complexity level designator to describe the characteristics of the part. Thus Level 1B describes a component that has moderate complexity where a Level 1C would be a very high dense and complex product.

Wherever possible the products shown in the illustrations have been designated as fitting into a specific category.

1.3 Classification of Products This document recognizes that optoelectronic products (components, modules, and assemblies) are subject to classifications by intended end item use. Classification of producibility is related to complexity of the design and the precision required to produce the particular component, mounting structure, module or optoelectronic assembly. Any producibility level or producibility design characteristic may be applied to any end-product equipment category. Therefore, a high-reliability product designated as Class “3,” could require Level “A” design complexity (preferred producibility) for many of the attributes of the optoelectronic product.

1.3.1 Performance Classes Three general end-product classes have been established to reflect progressive increases in sophistication, functional performance requirements and testing/inspection frequency. It should be recognized that there may be an overlap of equipment between classes. The optoelectronic product user has the responsibility to determine the class to which his product belongs. The contract should specify the performance class required and indicate any exceptions to specific parameters, where appropriate.

Class 1: General Optoelectronic Products

Includes consumer products, some computer and computer peripherals, as well as general military hardware suitable for applications where cosmetic imperfections are not important and the major requirement is function of the completed optoelectronic product. Components, modules and assemblies have a short product life (two to four years) and the environment in which they must operate is fairly benign.

Class 2: Dedicated Service Optoelectronic Products

Includes communications equipment, sophisticated business machines, instruments and military equipment where high performance and extended life is required, and for which uninterrupted service is desired but is not critical. Certain cosmetic imperfections are allowed. Components, modules and assemblies have a mid-range product life

(four to six years) and the environment in which they must operate consists of reasonable temperature limits and temperature change.

Class 3: High Reliability Optoelectronic Products

Includes the equipment for commercial and military products where continued performance or performance on demand is critical. Equipment downtime cannot be tolerated, and must function when required such as for life support items, or critical weapons systems. Printed boards and printed board assemblies in this class are suitable for applications where high levels of assurance are required and service is essential.

Combining Levels and Classes

In communicating between design and manufacturing, the methodology would include using the appropriate level, manufacturing complexity, and the class in which the final product must perform. Under this structure, a 1C3 would indicate a Level 1 product with a C complexity signifying a very dense package that must perform as a high reliability optoelectronic product.

1.4 Applicable Documents¹ Documents of the issue currently in effect form a part of this standard to the extent specified herein.

IPC-T-50 Terms and Definitions – In addition to the terms on electronic technology shown in IPC-T-50, Appendix B provides definitions and acronyms on optical and optoelectronic packaging.

IPC-9701 Performance Test Methods and Qualification Requirements for Surface Mount Solder Attachments

J-STD-003 Solderability Tests for Printed Boards

J-STD-006 Requirements for Electronic Grade Solder Alloys and Fluxed and Non-Fluxed Solid Solders

1.4.1 Reference Documents Many specific standards on the subject of optoelectronics have already been developed. These standards are listed as a reference in the appendices under the following organizational structure. Where appropriate, the URL of the organization has been included.

International Electrotechnical Commission Standards (IEC)² IEC standards are developed by technical committees of the International Electrotechnical Commission (see Appendix D).

Telcordia Standards³ Telcordia standards are developed by the telecommunications Telcordia consortia (see Appendix E).

1. www.ipc.org

2. www.iec.ch

3. www.telcordia.com

Japan Industrial Standards (JIS)⁴ Japan Industrial standards are developed by the member company representatives participating in JIS standards development (see Appendix F).

Military Standards⁵ Military standards were developed to assess the capability of products that primarily performed as electronic components. These methods included test conditions for stressing the component to ensure its robustness in the final assembly (see Appendix G).

2 TECHNOLOGY OVERVIEW

At the end of 2001, much of the buried optical fiber which comprises the global telecommunication, and internet-worldwide web network is carrying no traffic. It is 'dark,' or 'unlit' fiber. It is widely reported that somewhat less than 20% of buried fiber, which makes up the backbone, or superhighway, of this long haul (or long reach) network is actually being used. Meanwhile, advancements in Wavelength Division Multiplexing (WDM) are rapidly adding to the information carrying capacity, or bandwidth, of much of this buried fiber. Parallel advancements in laser transmission and receiver technology promise the near term deployment of 10 Gb/s transmitters and receivers. Early 40 Gb/s transmit/receive systems are in evaluation or latter stages of development.

Approximately 20 million miles of advanced fiber was added to the long haul backbone in the past two to three years. This fiber, and most of the fiber deployed since 1995, has the chemistry and characteristics to support these new technologies. The growing use of Dense WDM (DWDM) systems, and the advanced Erbium Doped Fiber Amplifiers, and Raman amplifiers, will vastly increase the bandwidth of the existing backbone, especially when used with the emerging 10 and 40 Gb/s transmitter-receiver technologies.

While it is true that much of the fiber buried before 1995 may not be able to support these new DWDM and 10-40Gb/s technologies, this legacy fiber is performing well in the healthy and busy internet-telecommunication backbone of today. It is projected that the telephony will consume a continually diminishing portion of network capacity, as data transmission demands continue to escalate. In five years, or less, telephony may consume less than 5% of network bandwidth, so telephony markets will not light up the dark fiber. The data bandwidth demand is required to push the telecommunications industry back into growth mode.

It is expected that individual users in the office, or campus networks, and users at home will create this data demand-pull. Currently the datacom or premise networks are con-

nected with relatively low bandwidth optical pipes to the backbone. Most home users are connected to the backbone through extremely low bandwidth modems due to service provider limitations in making high bandwidth connections to local neighborhoods, to "the curb," or to the home. The users at these access points in the business complexes, educational campuses, and the neighborhoods will supply the data demand-pull if given the local capability. This local capability could be provided by extensions of fiberoptic networks to provide convenient and low cost broadband to these users. If individual computer users were provided with real broadband (e.g., 1 Gbit Ethernet) connections to their offices or homes, the expected data demand-pull would be tremendous. Assessments of electronic and optoelectronic equipment demands for various telecommunication network segments predict that the value of the equipment needed for each mile of deployed fiber will increase radially from the backbone to the access rim. Equipment values per mile of fiber may be 100 times, or more, the value of backbone optoelectronics.

It is apparent that demand from the network rim will drive growth in the telecommunications industry. Other sources of data demand are promised by the expected growth of remote storage service providers, and remote application service providers. But the promise of these emerging business opportunities is also limited by availability of real broadband connectivity to these users at the rim. These emerging services will certainly face other obstacles, but users are unlikely to show wide support until use of remote application software and remote hard drives is as seamless and quick as the use of local hard drives and the application software installed upon them. If the broadband service is supplied to these users, true exploitation will drive demand for personal or very local broadband transmit-receive hardware. This may take the form of laser transmitter-receiver hardware in local network nodes or hubs, or it may result in optical network interconnect cards (ONIC) with laser transmit-receive hardware being installed in personal computers, just like video cards. This enormous volume demand that these markets could represent will require very low cost laser transmit-receive hardware. Most of the optoelectronic industry is focusing on the cost reduction of backbone optoelectronic hardware. While this is necessary, success in this area will not light up the network, consume existing bandwidth, begin to consume the bandwidth of promised 40 Gb/s DWDM systems, and provide a growth stimulant to the telecommunication industry. Focus needs to shift to providing real broadband connectivity to the network rim, and to manufacture of truly low cost optoelectronic hardware for individual users and the local area networks.

4. <http://www.jisc.go.jp>

5. www.dod.gov

Telecommunications has embraced photonics as the highly preferred mode for terrestrial and undersea communication. The packaging and assembly industry are learning the new rules of light as the new technology is being added to electronics.

As the industry and its customers become accustomed to the freedom of portable electronics, the trend to wireless is accelerating. With cellular phones and Internet laptops talking to each other, fiber optics, its components, its design characteristics, and all of its system issues become extremely important and are growing at a hectic pace.

2.1 Optoelectronics in Optical Communication Systems Figure 2-1 shows characteristics of Long-Haul Networks and how these are tied into the multiple regional backbone providers for residential, cellular, and corporate networks.

Optical transmission is moving closer to the home and business, moving from the long haul lines to Metro and

City access products. Businesses as well as home commodity products will find the capability of optoelectronic products providing more services. Figure 2-2 shows examples of optoelectronic components and modules in such systems. As optical communication systems continue to evolve, optoelectronic products will play an increasingly important part in their development.

2.2 History of Optoelectronic Packaging Optical fiber appears throughout the systems, and an optoelectronic transmitter converts an electrical data signal into an optical one which is amplified over larger distances wherever necessary, and finally reaches an optoelectronic receiver which converts from optical back to electrical signals. Various packages have been created that help accomplish this, although many of them do not require hermetic sealing, their characteristics are such that they fit into a metal can (TO can), or have the butterfly characteristics with the leads extending that can then be easily assembled into the standard electronic printed board.

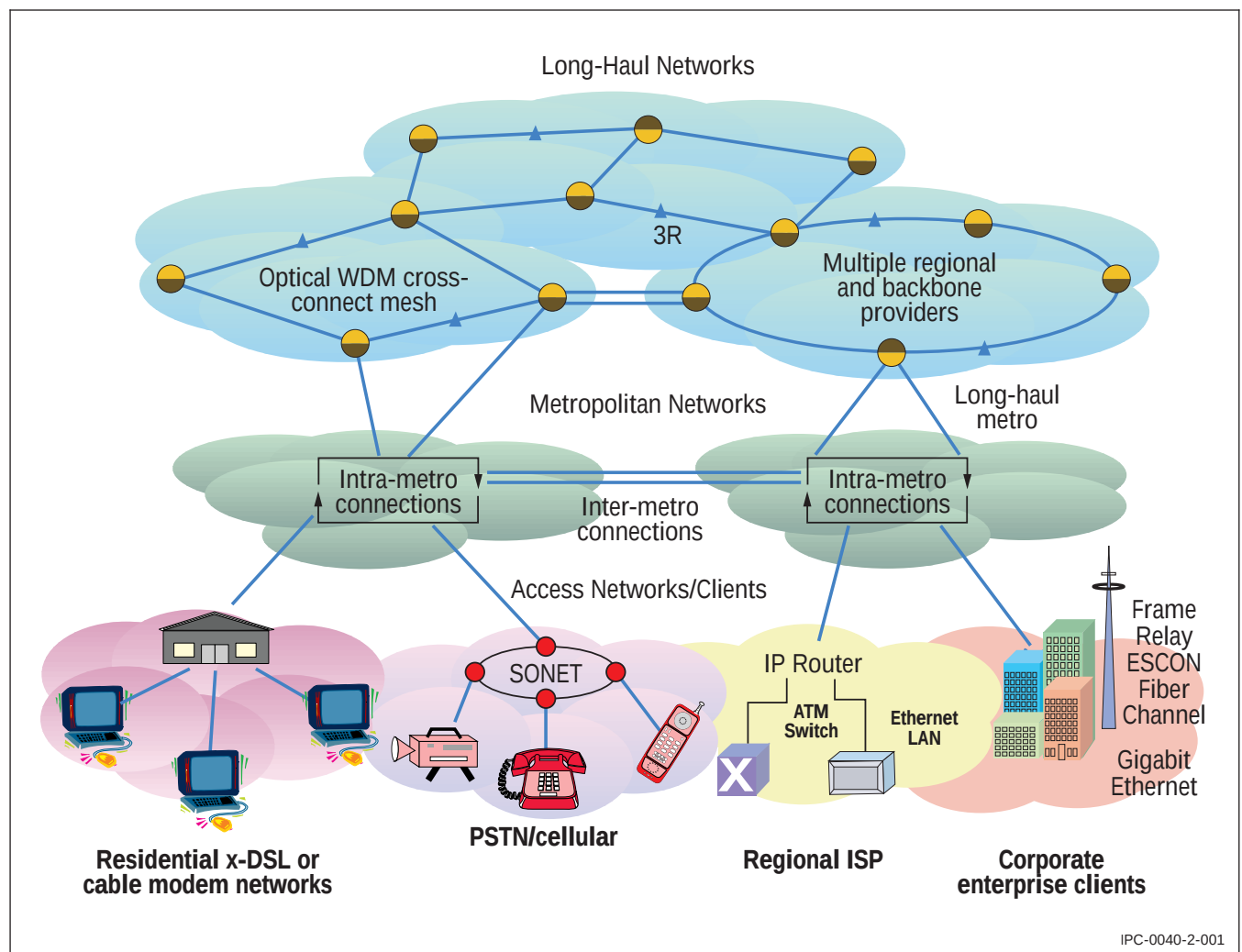
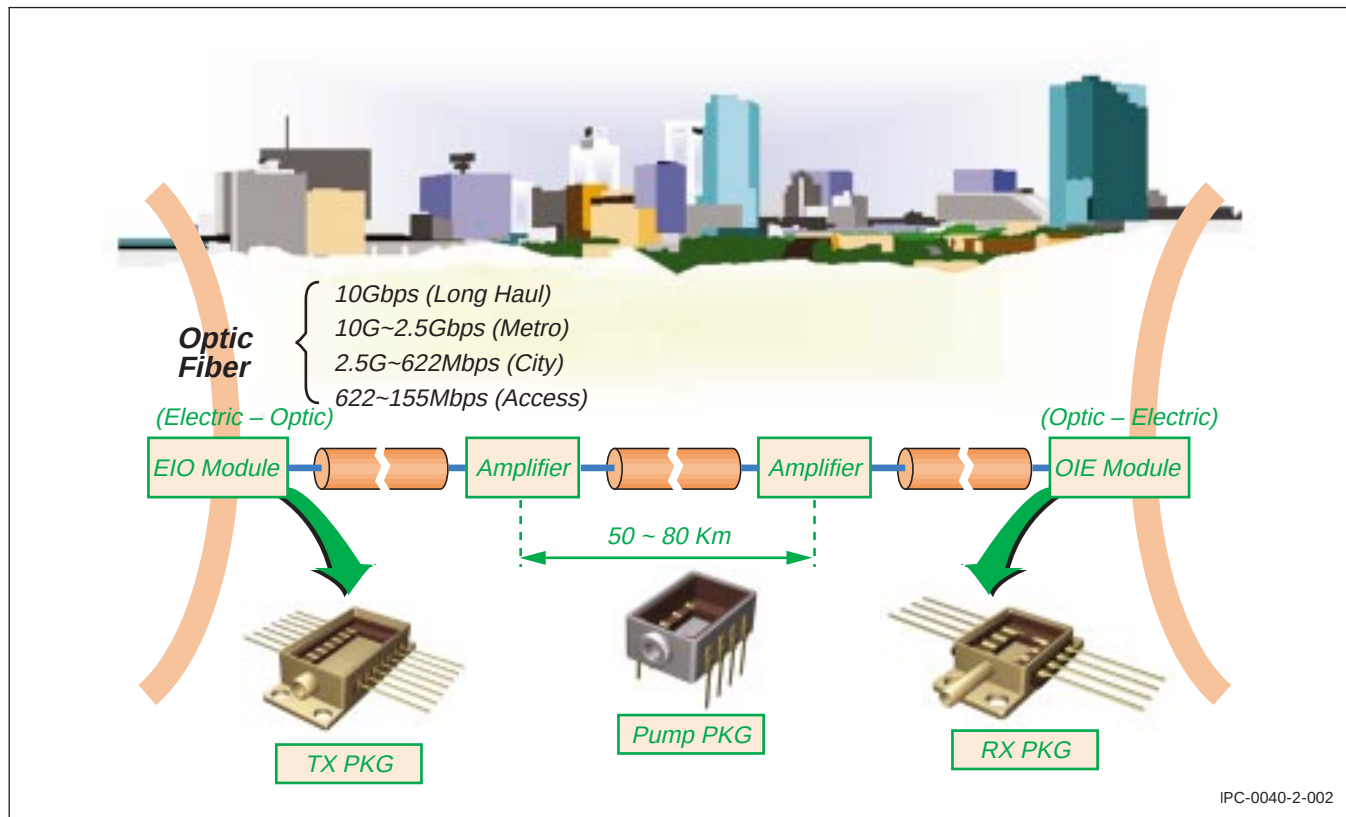


Figure 2-1 Network Example



IPC-0040-2-002

Figure 2-2 Optoelectronic in Fiber Optic Systems

At the moment there are few standards around to help promote optoelectronic packaging. The main players have not really cooperated to make their proprietary data open to the industry and encourage competition. It is very similar to the early days of surface mount technology, where those companies who had invested heavily in the research to make surface mounting a reality were not ready to divulge those process secrets that gave them a competitive advantage. This is the same issue today with fiber optics.

As manufacturing becomes more outsourced, it will become more and more important to have an industry infrastructure that is ready to manage and adopt the conditions for the fiber optic culture. This includes the fabrication of the device, fabrication of the package or component, fabrication of the board assembly, and tying all of that into the total system configuration.

Test methods and measurement systems are necessary that will help evaluate the quality of the component; software must be made available to help both design and simulation in the testing arena. At the moment, the mechanical outlines of components are provided on data sheets rather than by a standards organization such as JEDEC, which gives the mechanical standards for semiconductor integrated circuit packages. Designers who handle library symbols must scramble to interpret the conditions described on component manufacturers data sheets in order to encode the infor-

mation into the CAD library for proper assembly placement and interconnection with the remaining electronic parts.

Test equipment is a big challenge. With the variety of different parts that exist, it is not easy to have one piece of equipment that will handle all the different products that are needed for the optoelectronics assembly. This will change as devices in systems become more uniform, however the drivers must be cooperative and moving in the direction of standard mechanical outlines for the parts, and standard features for the interconnection products.

2.3 Optoelectronic Modules Optoelectronic systems and subsystems are typically based upon products that are comprised of optoelectronic modules that are assembled on printed circuit boards with other electronic components, and interconnected with optical fibers and copper circuitry. These optoelectronic modules may be broadly grouped into two major categories: Active Modules and Passive Modules. Active Modules are generally defined as “Active” if the module contains at least a component which generates an optical output due to the application of an electrical signal (laser diode, light emitting diode), or if the module generates an electrical output due to the application of an optical signal (photodiode, etc.). In both cases, either an optical-to-electronic (OE) or electronic-to-optical (EO) conversion is performed.

Passive Modules are generally defined as “Passive” if the function performed by the module is optical in nature, involving no OE or EO conversion. The components contained in the module may be exclusively optical elements (lenses, etalons, isolators, optical fibers, fused optical fibers, planar waveguides, gratings, etc.) that are optically interconnected upon a mechanical substrate. In many cases a passive module incorporates electronic circuitry (e.g., temperature sensing device with feedback to regulate a heater, or a thermoelectric cooler/heater), but no OE or EO conversion occurs.

It is quite common for some of the optical functions provided by Passive Modules to be incorporated into Active Modules using discrete components, resulting in an increase in the Active Module functionality through “hybrid integration.” Technological advances are also allowing some of the optical functions provided in Passive Modules to be incorporated into individual components, along with integrated circuitry and an OE or EO conversion through “monolithic optoelectronic integration.” Since the resulting module provides an OE or EO conversion, it is referred to as an active module.

Advancements in monolithic optoelectronics may reduce the occurrence of existing passive modules, reducing the incidence of optical-optical interfaces, and improving optical signal integrity. Optical material research promises development of optical analogs of transistors and integrated circuits, predicting that future modules may provide most active and passive functions via monolithic optical integration. Ongoing innovations in passive optical signal processing suggest that new generations of passive modules are likely to continue to emerge.

2.4 Packaging and Hermeticity Optoelectronic packages can be divided in two distinct categories. These are hermetically sealed packages and those that are protected from the environment but are not hermetically sealed.

2.4.1 Hermetic Packaging Active photonic devices (laser diodes, photodiode detectors, etc.) are commonly assembled in hermetic packages. This may be accomplished by use of a package dedicated to the individual active device or the active device may be part of a more complex assembly comprised of multiple elements and packaged in a larger hermetic housing. A dedicated active device package is most commonly a TO (Transistor Outline) can with a lensed lid, and glass-to-metal sealed connection pins (see Figure 2-3).

The TO can unit may be interconnected to passive optical components and electrical components (ICs and passives) using a ceramic substrate, and hermetically sealed in a larger metal, ceramic, or hybrid/composite metal-ceramic housing. Coupling of the optical signal to or from the packaged active device to an optical fiber may be accomplished

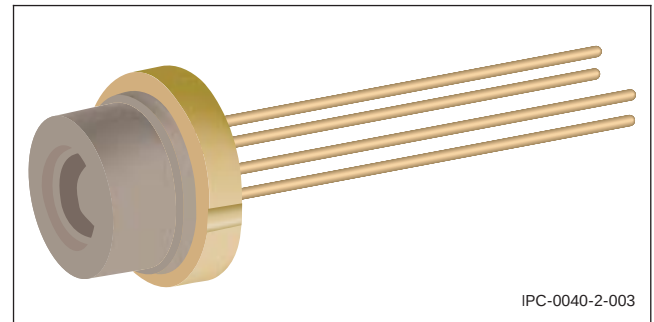


Figure 2-3 Example of Hermetic TO Can Package

within the hermetic housing or through an optical window into the hermetically sealed housing.

Alternatively, the unpackaged active photonic device may be assembled onto a submount and then attached to a larger base, which provides heat sinking and areas for subsequent optical component and fiber attachment. This assembled unit comprises an optical subassembly, measuring only a few millimeters on an edge. Figure 2-4 provides an example of an optical subassembly (ref. ADC Telecommunications Inc.). The optical subassembly is then attached to a substrate, to a housing floor, or to a thermoelectric cooler which is bonded to the housing floor. The optical subassembly may perform a Transmit or Receive function if it interconnects a laser diode or photodiode, respectively. These Transmit and Receive subassemblies are often referred to as TOSA (Transmitter Optical Sub-Assembly) and ROSA (Receiver Optical Sub-Assembly) units.

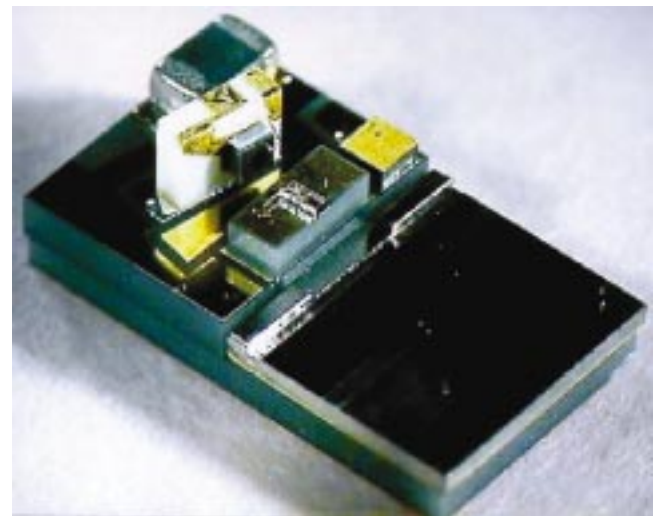


Figure 2-4 Example of an Optical Subassembly

The metal, ceramic, or hybrid/composite metal-ceramic housing containing the OSA may also provide interconnection with an electrical subassembly, and other optical elements. Coupling of the optical signal to or from the bare or packaged active device to an optical fiber may be accomplished within the hermetic housing or through an optical window into the hermetically sealed housing.

2.4.2 Nonhermetic Packaging Low cost, nonhermetic active optoelectronic modules will similarly include a light source or a receiver, and electronic components. While all optoelectronic devices may not be suited for nonhermetic, organic polymer-based packaging, where it is possible, nonhermetic packaging promises very significant cost reductions. Low cost, nonhermetic optoelectronic packaging has the greatest application opportunity in the campus, enterprise/premise, and general access network segments. Optoelectronic systems installed in these environments can be expected to require a much shorter application lifetime than systems servicing the long haul backbone due to short periods of innovation that can be expected following this high volume exploitation of high bandwidth optical communication. Several nonhermetic packaging methodologies may be followed.

In the first configuration, the nonhermetic module may interconnect a hermetically sealed active device in a TO can with nonhermetically packaged electronics (ICs and passive components). Here, the leads of the TO can unit may be bent and formed to a desired geometry, then soldered to a small printed circuit board (PCB) interconnect substrate. ICs, packaged in small nonhermetic packages, and nonhermetic passive components (typically resistors and capacitors) may also be soldered to the PCB.

In a second configuration, the TO can-packaged photonic device may be soldered to a PCB substrate, where the ICs are attached in a chip on board (COB) mode. These unpackaged ICs are attached to the substrate using conventional die attach adhesives and wire-bonded to the substrate, or the ICs may be flip chip bonded to the substrate. The wire-bonded devices are then covered with a liquid encapsulant (typically epoxy or silicone-based). Flip chip bonded ICs are generally underfilled with a similar encapsulant. Passive electronic components are soldered to the substrate.

In a final configuration, an unpackaged (no TO can) active photonic device (light source, or receiver) may be used in the module, along with the unpackaged ICs just described. In this case, the photonic component may be wire-bonded or flip chip attached to the PCB substrate. These photonic devices may then be encapsulated with a suitable refractive index polymer material. This type of nonhermetic packaging is most suitable for photonic devices that are well passivated so as to allow the device to perform for the required application lifetime without failure.

Numerous variations of these nonhermetic packages are emerging. One class of package that offers significant cost reduction is based upon a metal leadframe. In this first leadframe configuration, the electrical and optical components are bonded to the leadframe, and electrical connections are made with wire bonding or via flip chip bonding. In some cases the active photonic device is molded with a

polymer with the desired refractive index, and a lens is simultaneously formed in the molding process. After assembly, the leadframe unit is overmolded with another polymer based (typically epoxy) compound.

In a second leadframe configuration, the leadframe is pre-molded with an epoxy compound to form a housing, leaving the surface of the leadframe segments exposed in the housing floor. Assembly of photonic, optical, and electronic elements in the housing cavity then follows. The assembly volume is then sealed with a housing lid, or via encapsulation with appropriate polymer-based materials.

2.5 Theory of Optical Fiber Fiber optics is based on a principle known as refraction. As light passes through various materials it refracts, or changes its speed and direction. This change in velocity is also dependent upon the wavelength of the light. Thus, light at different wavelengths travels at different speeds and directions in the same material (the way a rainbow is created from white light passing through a prism, every color of the rainbow represents a different wavelength). The change in direction of light going from one material into another is also affected by the angle at which the light approaches the new medium. At certain angles, the light is refracted so much that it is actually reflected back into the first material. This is known as the fiber's acceptance angle. The index of refraction of a material is the ratio of the velocity of light in a vacuum to the velocity of light in the material. Using 1.0 as a base, the higher the number, the slower light travels. The index of refraction can be controlled and changed by adding dopants to the fiber material. The material used in conventional optical fiber is silica glass. It has a refractive index around 1.5.

The materials used in optical fiber must be very pure and free of defects. If a fiber has defects, the light passing through it will lose power, or be attenuated. Intrinsic attenuation is caused by impurities in the fiber that result in light scattering or light absorption. 96% of total intrinsic loss is caused by scattering, while 3-5% is caused by absorption. Extrinsic attenuation is caused by cracks in the fiber material. Macrobending is a visible bend in the fiber that causes cracks, while microbending is cracks due to pressure on the fiber.

At a minimum, optical fiber has three layers: core, cladding, and coating. The core is the center layer where most of the light in the fiber travels. The cladding surrounds the core and acts as a boundary to the light in the core. Core size varies depending on fiber type while the most common cladding diameter is 125 μm . Other sizes exist for specialty fibers. The refractive index of the cladding is slightly lower than that of the core. Depending on the angle of the light traveling through the core of the fiber, most of the light will be reflected off of the inner surface of the cladding.

it simply then, light, travels through a fiber core by bouncing back and forth within the boundary the cladding provides. For some angles, the light is not reflected by the cladding and is therefore not transmitted down the fiber, causing the light signal to become attenuated as it travels. A general cross-section and depiction of how fiber optics works is shown in Figure 2-5. Coating (also known as jacket or buffer) layers surround the cladding and provide strength and flexibility to the fiber. The first coating diameter may be from 240 μm to almost 1 mm. Depending on ruggedness requirements and application, extra jacket layers and strength members may be used. There are two general classifications of optical fiber: multimode and single-mode.

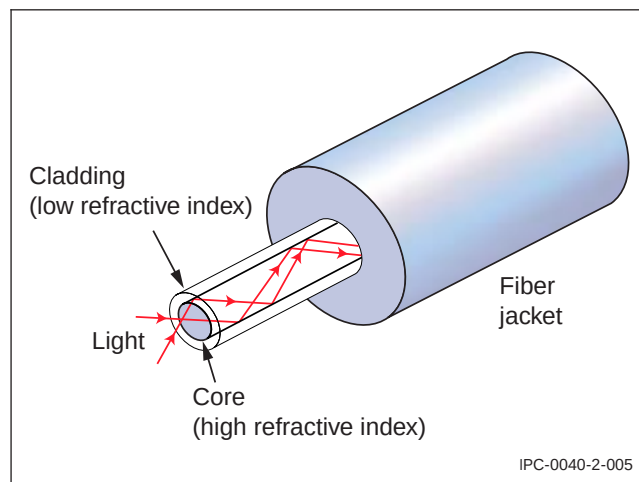


Figure 2-5 Operational Principles of Optical Fiber

2.5.1 Multimode Fiber Multimode fiber (MMF) has a core diameter most commonly of either 62.5 μm or 50 μm and guides the light by forcing it to “bounce around” inside the core region of the fiber as it travels along the length of the fiber (see Figure 2-6).

It is the difference in the index of refraction between the core and the cladding that keeps the light from escaping because of total-internal-reflection at the interface. This difference also determines the numerical aperture (NA) that relates to the maximum angle of incident light accepted by the fiber. The NA of the 62.5 μm fiber is larger than that of

the 50 μm fiber, so that from a packaging perspective the latter fiber can not generally accept as much light from a large-angle source.

Furthermore, multimode fiber allows several propagation modes for the light, some of the light passes straight down the core and rarely bounces off the interface between the core and cladding - these are called the low-order modes - while other parts of the light rapidly bounce back and forth off the interface as they travel through the fiber - these are called the high-order modes.

The overall effect of these different modes of propagation gives rise to modal (also known as temporal or spatial) dispersion and produces a superposition of many light patterns one on top of the other (see Figure 2-7).

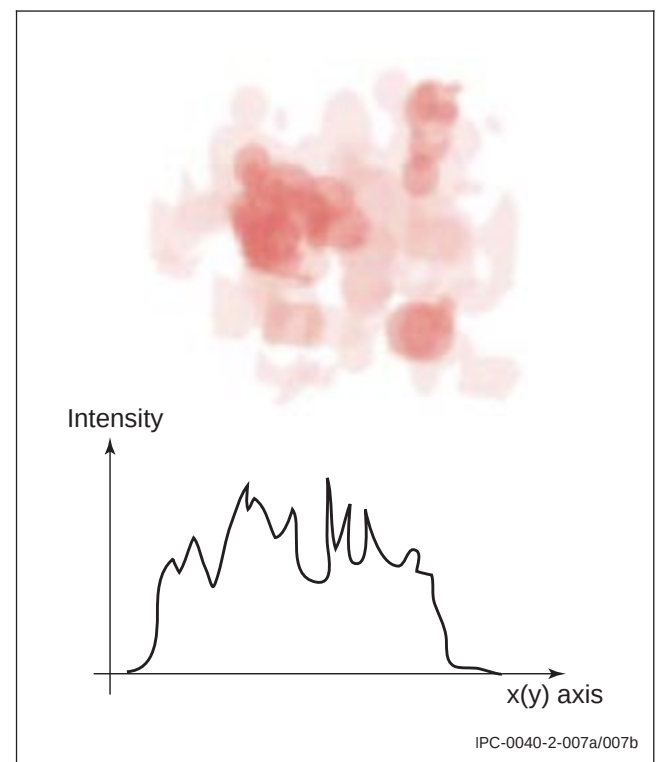


Figure 2-7 Output Pattern of Light of MMF

The modes occur because part of the light takes a longer path than other (see Figure 2-8).

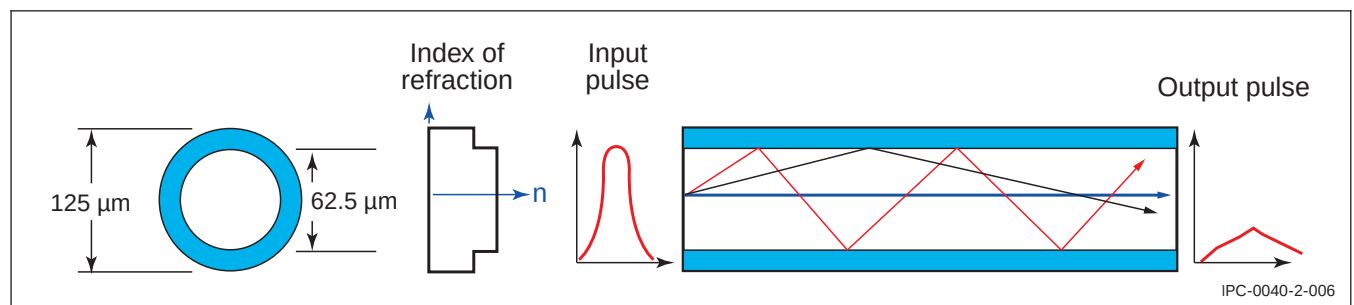


Figure 2-6 Dimensions and Propagation of Multimode Step-Index Fiber

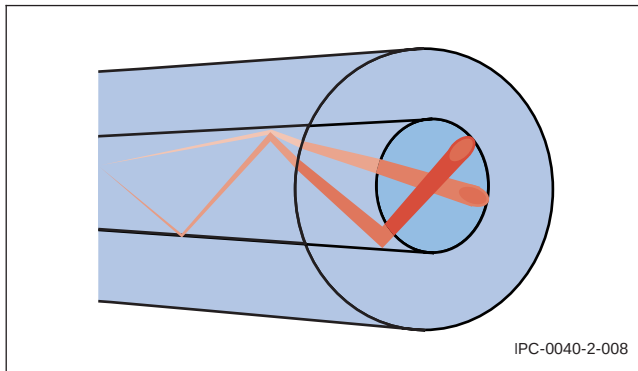


Figure 2-8 Propagation Modes of MMF

As the light pulses travel down the fiber, the delay between the more direct light and the reflected light increases and the pulse begins to stretch-out. If the pulses are sent at greater than a particular rate, subsequent pulses begin to blend into one another and the individual pulses cannot be detected. This is why, for example, multimode fiber is limited to about 500 m, though the exact limit depends upon the signal bit-rate (see Figure 2-9). For these step-index fibers, a smaller NA also means less modal dispersion.

Another type of multimode fiber is called Graded Index Fiber. In graded index fiber, the refractive index is not constant within the core but decreases from the center, as a power law, to the cladding. The refractive index profile across the core is close to being parabolic, and the rays are curved trajectories (see Figure 2-10). Such a refractive index is capable of minimizing modal dispersion.

2.5.2 Single-Mode Fiber The fundamental operation of a single-mode optical fiber is quite different from a multi-mode optical fiber. Single-mode fiber (SMF) uses a very small core, usually around 8 microns in diameter, and with a smaller core-clad index difference. Here core size is not well defined, since the refractive index profiles of single-mode fibers can be very complicated, and then it is difficult to say where the core ends and the cladding begins. Differences in the indices of refraction, between the core and the cladding allow only one propagation mode in the fiber for wavelengths greater than the cut-off wavelength, usually 1260 nm or less (see Figure 2-11). But as light refracts it also exists outside the core; this is called the evanescent wave and results in a mode field diameter larger than that of the core. The mode field diameter ends up to be about 11 μm for an 8 μm diameter core, but this depends upon wavelength.

The wavelengths typically used in single-mode optical fiber were originally chosen to match either the lowest possible attenuation of glass at 1550 nm or the point of zero wavelength dispersion at 1310 nm.

As light propagates through an optical fiber it becomes attenuated by a number of processes that depend on the wavelength of the light. Attenuation is due to scattering of the light by the glass structure (mostly Rayleigh scattering) and absorption due to chemical impurities and water content. Absorption has been almost eliminated in modern processing procedures. Chromatic dispersion causes a broadening of the light pulses, like modal dispersion, except this

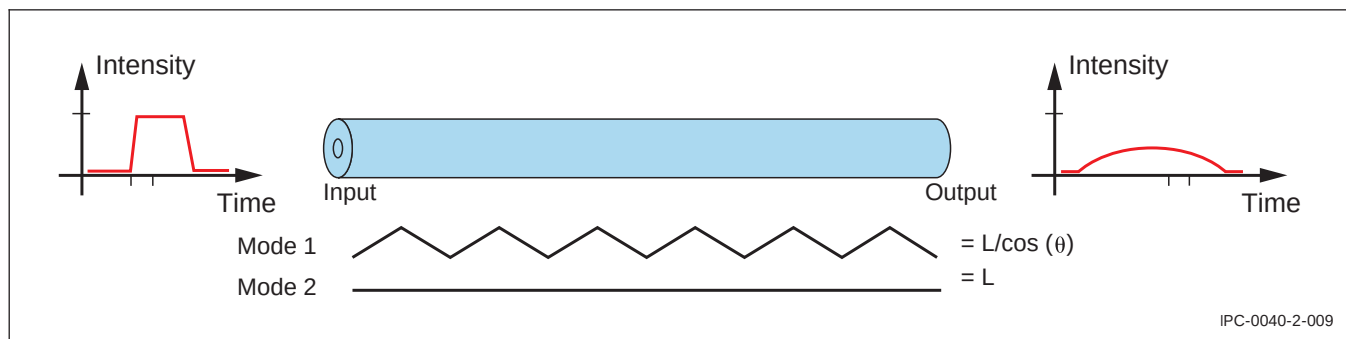


Figure 2-9 Effect of Modal Dispersion on Optical Pulses

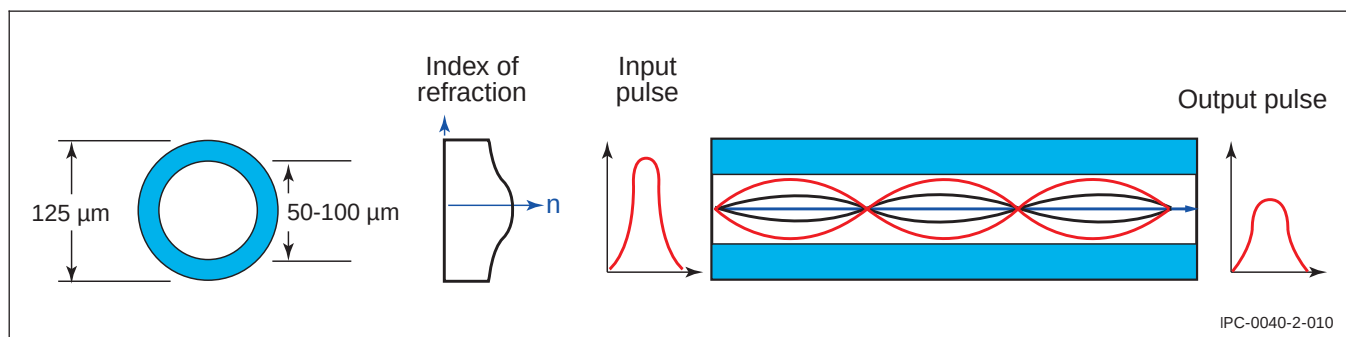


Figure 2-10 Dimensions and Propagation of Graded Index Multimode Fiber

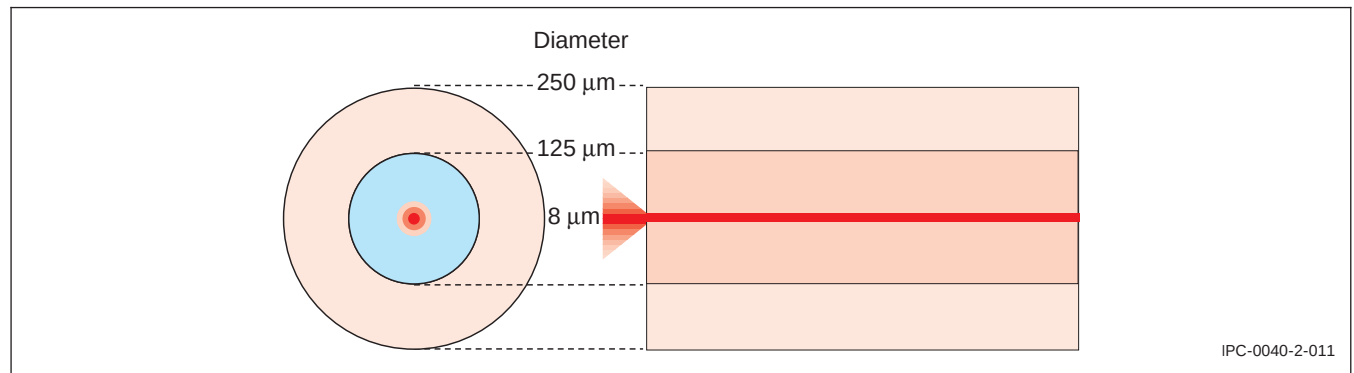


Figure 2-11 Dimensions and Propagation of SMF

phenomenon affects the individual wavelengths that comprise the light pulses. Just as a prism separates out the colors of the rainbow from white light, when a pulse is sent down an optical fiber, the wavelengths that make up that pulse travel at different speeds. Although the wavelengths that comprise the pulse start out together, they begin to separate as they travel along the fiber (see Figure 2-12).

To limit the amount of this chromatic dispersion, the 1310 nm wavelength band is used with the most common single-mode fiber. Other fiber types, such as the non-zero dispersion-shifted fiber, shift the low chromatic dispersion out towards 1550 nm, where attenuation is lower and some optical fiber amplifiers are more readily available.

The graph in Figure 2-13 shows that single-mode fiber has a capability of carrying signals over very long distances at very high bit rates - up to 400 km at 10 Gbps or greater. Multimode graded index fiber can carry signals up to 30 or 40 km, but only at bit rates less than 1 Gbps. Copper and multimode step index fiber are even less capable.

There are also other types of fiber like polarization maintaining fibers or active doped fibers that are not described here. The intent was not to be exhaustive but to give an explanation on how basic fibers function.

2.6 Automation Requirements As the demand for fiber optic components increased in the late 1990s and 2000, manufacturers focused on expanding capacity to meet it. This need for a rapid increase in manufacturing capacity exposed two fundamental problems with the component industry. First, virtually all of the manufacturing processes were performed manually and were not well characterized.

They were essentially the same processes that were used in the laboratory to develop the products. When demand grew, these processes were replicated on a large scale. Large numbers of people were employed, utilizing manual laboratory equipment in production. Yields were generally low and product quality was inconsistent. Second, the capabilities of the suppliers of materials and equipment to the component manufacturers were sorely taxed. Many of these suppliers had little experience with high-volume manufacturing. The material suppliers lacked the process control required for high yields and repeatable performance. The equipment suppliers had no experience supplying equipment that could be operated on a 24x7 schedule with low down time and low mean time to repair.

Many industry observers recognized that the fiber optic industry needed to automate its manufacturing processes to obtain the yield and quality control needed for manufacturing products in high volume economically. The semiconductor industry was held up as an example of a similar industry that had successfully gone through this transition. The semiconductor equipment industry had grown up to support the semiconductor component business and provide integrated solutions for high-volume component manufacturing. Many standards were developed to insure equipment compatibility, process control, ergonomics, and systematic installation and maintenance. This allowed semiconductor component manufacturers to purchase virtually everything they needed to build a fabrication or assembly facility. However, in the fiber optic industry, little of this infrastructure exists. The manufacturing experience and discipline needed to facilitate the conversion from manual processes to automated ones is lacking.

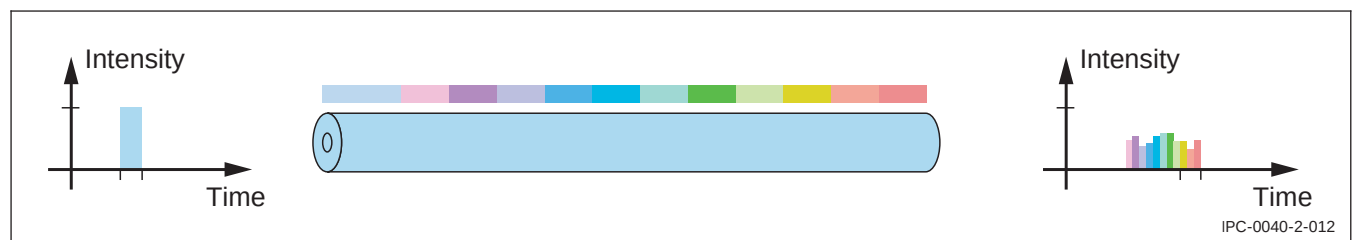


Figure 2-12 Chromatic Dispersion Effect on Optical Pulses

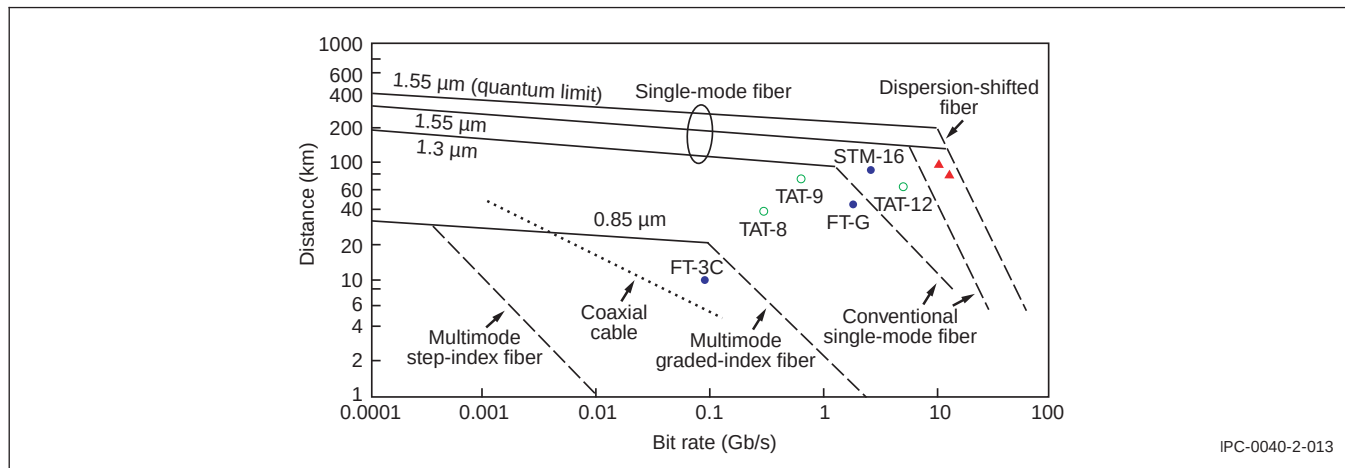


Figure 2-13 Single-Mode and Multimode Fiber Capability

Both component and equipment manufacturers recognize these shortcomings and are working to develop a fiber optic component manufacturing equipment industry and the standards needed to support it. Development of this infrastructure has slowed with the negative revenue growth in 2001, but most industry participants realize that this development is key to the future success of the fiber optic communications business.

2.6.1 Fiber Manufacturing Glass optical fiber is manufactured by drawing it from glass preform whose structure has the same aspect ratio and index of refraction profile as the finished fiber. The preform is melted near one end and that end is pulled away, drawing the melted glass down to the desired diameter. By controlling the temperature of the melt and the speed with which the fiber is drawn, the diameter of the resulting fiber can be tightly controlled. This, in turn, controls the diameter of the core. The drawn fiber is spooled on to a large drum. Then it is proof tested to insure it meets a minimum tensile strength and coated with a plastic buffer jacket. These processes are continuous flow processes, as an individual preform will be drawn into several tens of kilometers of 125 μm fiber. At this point, the fiber is tested to insure it meets the required optical performance. Then it may be further processed, adding more protective coatings, including in some cases, fibrous strength members, or metal armor. Fibers are also bundled into cables and in some cases, combined with copper conductors. Fibers are also combined into arrays in a flat ribbon format.

Since fiber fabrication is essentially a continuous flow process, it is amenable to automation. Also, the necessary process control required to maintain the dimensional tolerances needed for high performance single mode fiber require automated control of the drawing and coating processes. Fiber manufacture is one of the older and more highly developed manufacturing processes in the fiber optic industry. Both glass and plastic fiber manufacturing began in the 1970s. They have had nearly 30 years to mature.

Hence the level of automation and process control is very well developed, particularly when compared to the manufacturing processes in the fiber optic component industry.

Plastic optical fiber (POF) is another kind of multimode fiber. It is difficult to make single mode fiber using plastic material as it is very difficult to control the refractive index of the material in order to construct the structure used in single mode fibers. Attenuation of the optical signal is rather high and dispersion is significant. Plastic optical fibers may be used to transmit optical signals over a very limited distance, generally within 50 meters or less at present. Future technology may be able to overcome this limitation by producing POF that can be used over several 100 meters, as in applications for networks within a house or a small group of buildings.

2.6.2 Component Manufacturing Fiberoptic component manufacturing can be divided into several processes. These are listed in Table 2-1.

Table 2-1 Optical Component Manufacturing Processes

Processes	Components
Wafer fabrication	Semiconductor laser diodes, photodiodes, lithium niobate modulators, MEMS structures, arrayed waveguide structures
Semiconductor assembly	Semiconductor laser diodes, photodiodes, lithium niobate modulators
Fiber processing	Fiber Bragg gratings, fused fiber couplers
Micro-optic assembly	Pigtail assemblies, lens assemblies, collimators, Isolators, thin-film filters, circulators, modules

Wafer fabrication processes for optoelectronics use much of the same equipment and processes as silicon wafer fabrication. However, there are key differences, particularly in epitaxy. Optoelectronic wafer fabrication is also complicated by the fact that the exotic compound semiconductor wafers used for optical devices are much smaller and more fragile than their silicon counterparts. This is not the case for

material handling equipment used in silicon wafer fabrication cannot be applied to optical wafer fabrication. Also, the process requirements are different. Silicon technology has focused on decreasing the size of the surface features. This allows higher performance and increased functional density. In optical semiconductor structures, the emphasis is more on controlling dimensions in the vertical direction; the thickness, chemical composition, and uniformity of semiconductor layers. Thus the process control issues tend to be different.

The semiconductor material commonly used in optoelectronic applications is a combination of a Group III element and a Group V element. These groups refer to the column in the periodic table of elements. Group III elements commonly used in semiconductors are Al, Ga, and In. Group V elements commonly used include N, P, As, Sb or Bi. The very first laser was made of gallium arsenide which could generate near-IR light. Using these materials compounds with various compositions are now being used for a wide variety of applications in the optoelectronic arena. They are usually grown using the technique of Chemical Vapor Deposition (CVD). CVD is a process that causes an organo-metallic material to decompose into a vapor at high temperatures, and then be deposited onto a surface to grow a very thin layer (atomic thickness) of the desired composition.

Since the volume of wafers needed for optical components has been low compared to silicon wafer volumes, the process equipment industry has generally ignored the optical component industry until recently. Now, much of the technology that was developed for handling and processing silicon is being modified to handle the smaller and more fragile compound semiconductor wafers used for optical devices. This is essential to improving the yields in wafer fabrication. The manual handling of wafers is a large source of damage and defects.

Another complicating factor for laser diode manufacturing is that most of the high performance laser structures emit light from the edge of the die, not from the surface. This greatly complicates the testing of these devices, since no meaningful optical tests can be performed at the wafer scale. Thus, a wafer of lasers must be segregated into dice, the dice edges coated with the needed reflective coatings, and then each mounted on a substrate (called a submount), before each die can be tested. As there are no equivalent processes in the silicon world, these segregation, edge coating and submounting processes are highly manual.

A technique has been developed to emit light from a semiconductor laser not from its side but from its front surface. This type of laser is called Vertical Cavity Surface Emitting laser (VCSEL). Development of this type of laser makes it very promising to assemble optoelectronic modules on a printed circuit board, as a daughter board, or as a subassembly/subsystem of an optoelectronic system.

Many of the steps in the assembly processes for optical semiconductor devices are similar to those found in silicon, but have unique needs that prevent directly using silicon assembly equipment. The packages used for optical semiconductor devices are unique as they are designed to accommodate the optical fiber. Thus, the automated material handling systems used for lead frames, TAB, or flip chip silicon devices cannot be applied to the optical devices. Typically, die placement in the optical devices is much more accurate than silicon, since the die must eventually be coupled to an optical fiber.

There is a whole group of optical components that are made from fiber itself. Two of the most common examples are fiber Bragg gratings and fused fiber couplers. Fiber Bragg gratings are made by optically imprinting a pattern on a specially doped and prepared optical fiber. The optical printing slightly increases the index of refraction of the exposed regions along the length of the fiber. The result is a fiber that has alternating regions of high and low refractive indices along a portion of its length. This creates a Bragg grating structure. The number and size of each of the regions of different refractive index determines the spectral performance of the grating. Thus gratings can be made that are narrow band-pass filters, broad band filters, gain-flattening structures, dispersion compensators, and any other function that can be achieved with a multi-cavity filter.

Fused fiber couplers are made by taking two parallel lengths of bare fiber, twisting them together, applying tension along their lengths, and then fusing them together with high temperature. The resulting device is a four-port optical structure (each fiber creates a port at each of its ends) where the coupling of optical power between ports is a function of wavelength. These devices can be used as signal splitters, power monitors, and directional couplers.

Components with fiber attached present special problems to manufacturing. First, many of the process variables that determine product performance are not completely understood. This puts severe limits on the ability to improve processes, since it is not clear how much certain process conditions can vary without detrimentally affecting yield. Second, these products require that fibers a few meters in length be carried through the required processes. Also, in many cases, the optical performance varies with the tension on the fiber. Thus the handling and packaging used must supply this constant tension. Currently there is little off-the-shelf equipment that can be used for these processes. Most optoelectronic fiber component manufacturers have developed their own. Developing an equipment infrastructure is a complicated issue. Not only is the equipment highly specialized and unique to these fiber-based products, but the technology for making products that perform the same optical functions is continuing to evolve. As alternative methods for providing passive fiber coupling

are developed, the long-term potential for fiber Bragg and fused coupler devices is unclear. Thus it is difficult for equipment suppliers to develop a long-term strategy to support these products.

The next class of products is micro-optical assemblies. These products utilize small glass components, such as lenses, thin-film filters, fiber pigtail assemblies, and similar small optical components. They also often have small metal parts as well. These components and subassemblies are bonded together to form assemblies that perform specific passive optical functions, such as filters or isolators. Usually these components are then connected together in modules to perform more complex functions, such as multiplexers or dispersion compensators. In other cases they are combined with active components to build devices such as optical amplifiers or signal monitors. Devices such as MEMS switches and arrayed waveguides are also assembled with micro-optic components to provide their optical interconnects.

The manufacture of micro-optic components requires the precision placement of small glass or metal parts and bonding them with solder, welding, or adhesives. In many cases, the parts must be optically aligned. Often the mechanical precision of the parts is not sufficient to insure that the parts will be in optimum optical alignment when they are in mechanical alignment. Thus the alignment must be performed actively, with the device being tested while it is assembled. Then when optical alignment is achieved, the parts are bonded together to maintain the optical alignment in the finished component. In many cases, the optimum optical alignment requires that the position of the parts be adjusted in increments of 10 to 100 nm. Once the optimum alignment is achieved, it must be maintained through the bonding process.

The vast majority of micro-optic assembly is performed manually with the aid of specialized jigs and fixtures. The active alignment process has received a great deal of attention from both the components manufacturers and the equipment suppliers. There are several suppliers who provide automated capability for this process step. Also, fiber pigtailling (that is, inserting the end of a fiber in a glass or metal ferrule and bonding it in place) and fusion splicing are micro-optic assembly processes where suppliers are beginning to offer automated solutions.

The single biggest complication in the assembly of fiber optic components is the fiber itself. Virtually all of the parts used in fiber optic component assembly are rigid bodies and can be transported and positioned with conventional methods. The fiber is a non-rigid material. It must be protected from damage, captured to keep it from tangling, and its ends accurately positioned for assembly. Techniques for handling fiber in both manual and automated assembly and test are being developed.

2.6.3 Connectorization The problem of connecting optical fibers and efficiently coupling light from one to the other has received an enormous amount of attention for nearly 30 years. It is a difficult problem because of the close tolerances required to insure optimum coupling efficiency. The problem became even more difficult as single mode fiber became available. Single-mode fiber requires a connector system that can align the 10 μm cores of two fibers with sub- μm accuracy. The ends of the fibers must also be held in intimate contact so that there is no change in refractive index (which leads to reflection) caused by an air gap.

Several connector designs are available and in common use in the industry today. Most of them use precision ceramic parts to align the fibers. Most often organic adhesives are used to bond the fiber to the metal parts. In most cases, the fiber ends must also be polished to obtain a good optical finish. The preferred profile for the polished ends is a convex surface with the core of the fiber at the apex of the curve. This insures that the core of the fiber will come into contact with its counterpart in the mating fiber when the two connectors are mated.

One of the biggest issues with optical connectors is the requirements for the fiber ends. The optical coupling efficiency is reduced if there are defects in the surface of the fiber end, particularly in the core area. Scratches, dirt, and other defects can attenuate the light as it passes from one fiber to the other. Dirt particles outside of the core region can also prevent the two fiber cores from coming into intimate contact. The resulting air layer between the fiber cores causes reflections that reduce the coupling efficiency.

Several of the common connectors are designed for automatic assembly with fiber and much of the connector assembly process is automated. However, there remains a large percentage of connectors that are assembled by hand. The polishing processes to prepare the fiber ends after assembly are usually a combination of manual and semi-automatic processing. Inspection of the resulting fiber surface is often manual, though there are automatic visual inspection systems becoming available. However, until the industry settles on standard inspection criteria, optimizing the automated inspection is difficult. Each manufacturer and customer has its own inspection criteria. Optimizing an automated inspection system for all of these is a daunting task.

2.6.4 Optical Testing At this time, the state of the art for testing optical components is a mix of automated and manual processes. For the most part, the tests themselves, that is, supplying a known optical signal to the device under test and measuring the resulting output can be done completely automatically. The fiber optic industry is the beneficiary of several decades of electronic test automation. Virtually all optical test equipment is equipped with

computer control interfaces, such as GPIB or VME. Software drivers for controlling the test instruments and the interface hardware to connect it to computers are readily available. There are also a variety of programming languages and test development environments designed to facilitate test development that can be easily applied to optical testing.

The handling of the components under test, presenting them to the test fixture, and making the necessary optical and electrical connections is almost entirely manual. Since none of the packages used for optical components are similar to those used in semiconductor or printed circuit products, none of the highly developed handling and contacting systems used by these industries are applicable.

Furthermore, many users of fiber optic components are becoming increasingly demanding in their test requirements. As communication system performance increased, the design margins for optical networks are reduced. Therefore, to insure successful operation under all operating conditions, system manufacturers need components that are guaranteed to operate over the entire operating range. Usually there is insufficient characterization data on products to allow testing at a limited set of operating conditions. Therefore the system manufacturer requires the component supplier to fully test the product for all its specifications over the full operating temperature range. This presents a heavy test load to the component manufacturer.

The component manufacturer must develop the full suite of tests for the product. This requires a broad range of optical measurement equipment. This equipment can be organized into several different test stations, each testing a separate set of parameters, or into one large system capable of making all measurements. The component under test must be connected to each of these test systems. Since the connections are manually made, this significantly reduces test throughput. The number of connections can be significantly reduced with the large test system that can perform all of the required tests. However, such a system also requires a large optical switch that must be calibrated to insure consistent test results. Also, if not all components require all the tests that the system is capable of performing, some of the equipment in the large test system will be under utilized.

There are a variety of methods for making the optical connections for testing. The most common is to use fusion splices to connect the fibers of the component under test to the test system. Fusion splices provide a low-loss, repeatable optical connection. However, they are time consuming. Another method is to temporarily splice on connected pigtailed to the component under test. This is particularly advantageous if the component must pass through several test steps, each one requiring optical connections. A third technique is to use temporary fiber con-

nections such as fiber aligners with refractive index matching gels or solutions to improve coupling efficiency.

If the optical testing process is to be more fully automated, the component handling and optical connection problem must be addressed. This is a complex problem due to the wide range of products and the equally wide range of packages.

Another important area of active component testing is burn-in. Currently, most laser diodes and many photodiodes are subjected to extended operation before final packaging to insure their reliability. The burn-in times range from several hours to several days. This adds significantly to the manufacturing cycle time. Burn-in results are often lot-dependent, so the yield loss for this step can vary over a wide range. Since the burn-in times are long, extensive assets are required in this process for high volume products. As wafer fab processes become more controlled, the need for burn-in will be reduced. Also the drive to lower cost will reduce this need. However, it is still a requirement on the majority of active components.

2.6.5 Fusion Splicing, Other Optical Coupling Techniques Making repeatable low-loss optical connections is a major issue in fiber optic component manufacturing. For devices requiring active alignment, optical connections must be made so that the optical performance of the device being aligned can be measured and used as feedback to the alignment systems. All optical test processes require repeatable optical connections. Since the wavelength of light is short, making efficient optical connections requires great precision.

Fortunately some optical connections do not require precision positioning of the fiber. Power measurements, for example, can be made with a large-area detector or an integrating sphere. These methods only require that the fiber be placed in proximity to the detecting device so that all the light can be collected.

Coupling light from a source into a fiber is another matter. Here, particularly if the input power into the device under test must be known, coupling efficiency must be repeatable. Fusion splicing is the best method for obtaining a repeatable low-loss connection. Its main drawback is that the fiber ends must be correctly prepared or the yield of the splicing process would not be as high as desired. Semi-automatic fusion splicers are readily available. After the prepared fibers are loaded, the splicing is performed automatically. The main drawback is that the equipment is expensive and the process is time consuming. In many cases, the time taken to make all of the optical connections exceeds the test time of the device.

There are alternatives to fusion splicing that can be used for making the temporary optical connections for active alignment and testing. One common method is to use

fiber aligner. This device takes the two fibers and moves one with respect to the other until an optimum amount of light is coupled from the source to the device under test. Often an index matching fluid or gel is used to improve the coupling efficiency and eliminate back reflections. To obtain the input power level, the fiber downstream from the fiber aligner is cleaved and its output power measured. This gives the reference power level that can be used for calculating insertion loss or other optical characteristics. This technique is called the cutback method.

Along with fiber handling, automating the optical connection process is a key to automating fiber optic component assembly and test. At this time several equipment suppliers are beginning to offer equipment to automate these steps. However, these systems are very expensive, have limited throughput, and are not readily integrated into the assembly and test processes. Much development remains to be done in this area.

2.6.6 Fiber Handling The care in handling and sensitivity of optical fiber offers one of the greatest challenges toward improving the assembly process and reducing cost. Understanding the characteristics of the fiber provides insight into what can be accomplished through the use of assembly equipment.

2.6.7 Buffer Jacket Damage The acrylic buffer jacket enclosing the silica fiber provides protection to the fiber, preventing damage to the silica itself and reducing the rate of moisture ingress to the silica surface. Damage to the buffer jacket can occur from contact with hard and/or sharp objects. The resulting damage to the jacket can compromise the reliability of the fiber. The damaged buffer jacket can indicate the possibility of damage to the silica fiber itself. Micro-cracks in the silica can propagate under mechanical stress or in the presence of moisture. When the cracks intrude into the core area of the fiber, they cause the fiber's attenuation to increase dramatically. The crack propagation can take a substantial period of time to occur and thus will not usually show up in component testing.

Some component users are very concerned about this kind of potential reliability problem and therefore inspect all of the fiber that is visible to them for buffer jacket damage, rejecting any defects they find.

2.6.8 Bend Radius Optical fiber is a cylindrical waveguide and its optical performance is degraded when it is deformed from the ideal cylindrical structure. Bending it is such a deformation. For standard single-mode fiber, as the radius of bending decreases to below 30 mm, the attenuation due to the bending starts to become measurable. For bend radii of less than 5 mm, the attenuation becomes severe. At radii below 2 mm, mechanical damage to the silica fiber can begin to occur. This is a time-dependent phenomenon in that the longer the fiber is maintained in a tight bend, the more likely it is to incur mechanical damage. This damage is in the form of micro-cracks that can compromise fiber reliability, as described above in the section on Buffer Jacket Damage.

2.6.9 Fiber Ends The ends of optical fibers are stripped, cleaned and cleaved in preparation for splicing or testing. The optical performance of the cleaved surface can be severely degraded by subsequent mechanical damage or from particles or other contamination. In most cases, these degrading influences are avoided by minimizing the time between cleaving the fiber end and splicing it or mating it with optical measurement equipment. However, even if this time can be minimized, the cleaved surface must be kept as clean as possible. Glass is a good carrier of static electric charge, which in turn attracts dust. Cleaving should be performed in a dust-free environment. If the optical connection cannot be made immediately, the fiber end should be covered to protect it from possible contamination. Care must be taken that the system used to cover the end of the fiber does not itself contaminate the fiber end.

2.6.10 Summary The status and opportunities for automation in optoelectronic assembly are summarized in Table 2-2.

Table 2-2 Automation Implementation Opportunities

Process Class	Automated Steps	Steps Needing Automation
Fiber Manufacturing	Fiber drawing, coating, measurements	Fiber connections for testing
Wafer Fabrication	Process cells, recipes	Wafer transfer, handling
Semiconductor Assembly	Some die attach, wire bond, optical alignment	Bar handling, substrate assembly, package assembly
Fiber Processing	Power monitor for fused couplers, test measurements	Fiber prep, fiber handling, packaging
Micro-optic Assembly	Active alignment	Fiber handling, parts handling, cleaning, inspection
Connectorization	Connector assembly, fiber polishing	Inspection
Testing, Burn-in	Test measurements	Device handling, loading and unloading, fiber handling, fiber prep, optical connections
Splicing, Fiber Handling	Splicing, active alignment	Fiber handling, fiber prep

3 APPLICATIONS OF OPTOELECTRONIC PRODUCTS

The products produced by Original Equipment Manufacturers (OEMs) fall into eight basic market segments as defined by the U.S. Department of Commerce. Technology drivers within various market segments set different requirements. In 1995, the National Electronic Manufacturing Initiative (NEMI) identified five basic technology drivers within the eight basic markets.

These technology drivers were:

- Handheld portable – cellular phones, sub-notebooks, PDAs.
- High performance – supercomputers, high-end workstations.
- Harsh environment – automotive under-the-hood, military, avionics electronics.
- Low cost/high volume – camera, entertainment, mini-cam.
- Cost performance – high end personal computers, servers, high-end games, networking telecommunications.

In 2002 NEMI recognized the changing marketplace and modified the technology driver names. The 2002 drivers are

- Portable products.
- Large business systems.
- Harsh environment systems.

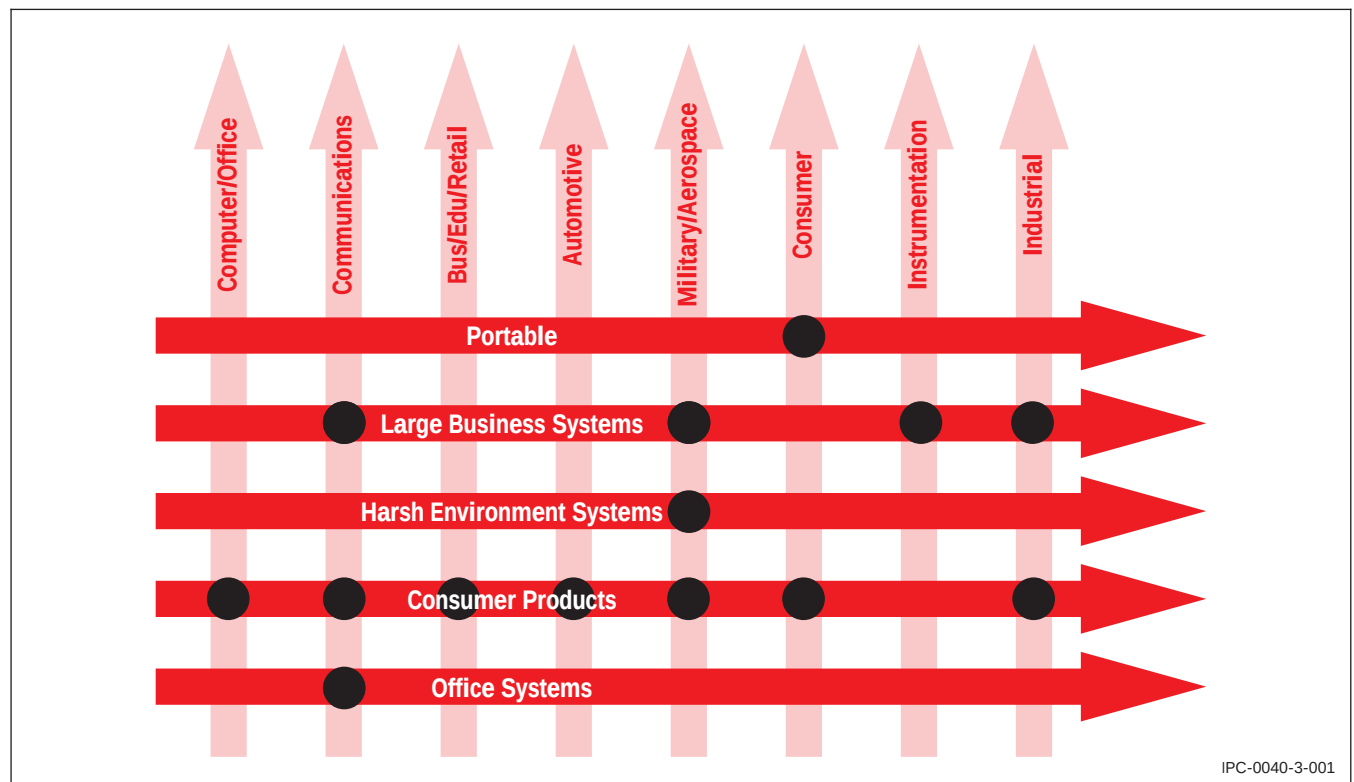
d. Consumer products.

e. Office systems.

Figure 3-1 shows the relationship of the eight basic markets and their technology driver counter-coordinates reflecting the five technology sectors. In most instances, electronic products have at least one product that fits into one of the technology sectors/market intersections. As optoelectronic products increase in usage, they will also have products at each of the intersections. The figure illustrates where the initial emphases will be placed on optoelectronic products. A circle has been placed at the juncture of a basic market and a technology driver to symbolize the fact that OEMs are projecting products that fit within that particular segment interconnect.

3.1 Consumer Products (Previously Low Cost) Consumer products span the spectrum of high demand products, and include low cost cell phones, personal computers, internet appliances, personal digital assistants (PDA's), video games, etc. The emulator characteristics for this sector are lowest possible cost abetted by high production volumes. Although cost is paramount (typical product is <\$500), the level of technology may be quite high. The typical useful life of these products is two to four years.

The product categories can be further divided into two domains; that of home optoelectronics that provide additional services or home functions, and entertainment related products including optoelectronic games.



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Figure 3-1 Market to Technology Driver Correlation with Optoelectronics Intersection Focus

The home optoelectronics segment includes home function controllers (built in) as well as portable MiniCAMS, Digital cameras, CD and DVD players. The characteristics represent:

- Interconnecting substrates that are low layer count, density is accommodated through use of High Density Interconnection (HDI).
- A move to remote access through laser beaming or wireless technology.
- A two- to four-year life cycle with attention to recycle or disassembly.
- Consumer demand that will require longer battery life or fuel cells.

The entertainment or games optoelectronics segment includes controllers for entertainment units and other portables that are not necessarily size driven. The characteristics represent:

- Interconnecting substrate sizes about 250 x 300 mm.
- Better human interface, e.g., voice recognition.
- Recycling requirements at end of life of the product.
- Using low cost interconnecting substrates.
- Data exchange over electronic and optical lines and remote/wireless.
- Large processors with big memory to support character and voice recognition.
- Better networking of game sets for multiuser linking.
- Connector methods that are used for high speed links, require RF, and optical interfacing.
- Better battery life or fuel cells.
- Single large level one components both I/Cs and lasers.
- Islands of density and use of sockets.
- Products that are upgradeable during life cycle.

3.1.1 Component Characteristics

3.1.1.1 Optical Communication Links Components are designed to provide cost effective, high performance fiber optic communication links for information systems and industrial applications with link distances of up to 2.7 kilometers. Some components, such as a 125 MHz analog receiver, can achieve data rates of up to 160 megabaud.

3.1.1.2 Mouse Sensing Low cost optical sensors are used to implement a non-mechanical tracking engine for computer mice. It is based on optical navigation technology, which measures changes in position by optically acquiring sequential surface images (frames) and mathematically determining the direction and magnitude of movement. The sensor is in a 16 pin optical package that is designed to be used with the HDNS-2100 Lens and HDNS-2200 Clip. There are no moving parts, and precision optical alignment is not required, facilitating high volume assembly.

The output format is two channel quadrature (X and Y direction) which emulate encoder phototransistors. The current X and Y information are also available in registers accessed via a serial port. Default resolution is specified as 400 counts per inch, with rates of motion up to 14 inches per second. Resolution can also be programmed to 800 cpi. The part is programmed via a two wire serial port, via registers.

3.1.2 Board Assembly Issues

3.1.2.1 Computer-to-Peripheral Many computer systems become servers for activities such as Local Area Networks (LAN) serving multiple users and multiple peripheral devices. Use of optoelectronic components to facilitate these actions requires a methodology to move data from and to the server between all the peripherals that are the users. In many instances, these functions are handled by optical connectors as shown in Figure 3-2. The hardware required consists of an optoelectronic Sub-Rack which fits into the computer/server or switching system. Data is fed usually from a multichannel optical connector that receives information from the various peripheral product optoelectronic assemblies.

3.1.2.2 Barcode Sensors The board assembly combines a range of tips to be used in conjunction with optical reflective sensors and as replacement tips for the wand products. This combination results in a high performance optical system, which is unique in its size and precision. In addition to the optical performance, the tips protect the sensors and act as mechanical holders. With a rugged sapphire front end, these tips are generally self cleaning and should last for many years under normal use. The bar code reader optical nest assembly is for custom applications and consists of a rugged sapphire ball bonded to a transparent polycarbonate assembly. A Bar Code Decoder IC is included in the assembly and offers flexible bar code decoding capability that is designed to give OEMs the ability to address a large number of industry segments and applications. Flexibility is made possible through sophisticated firmware, which allows the ICs to accept data from a wide variety of scanners and to automatically recognize and decode the most popular bar code symbologies.

3.1.2.3 Displays Display optoelectronic board assemblies consist of lasers, LEDs, and microelectronic components intended to actuate the display functions in a manner befitting the end-user's concepts. These functions are dedicated to information displays, warning indicators, and specific advertisement for various products. The assembly is designed to function either stand alone or in a manner where data is received from external sensors. The electronic portion segregates optical signals to the display.

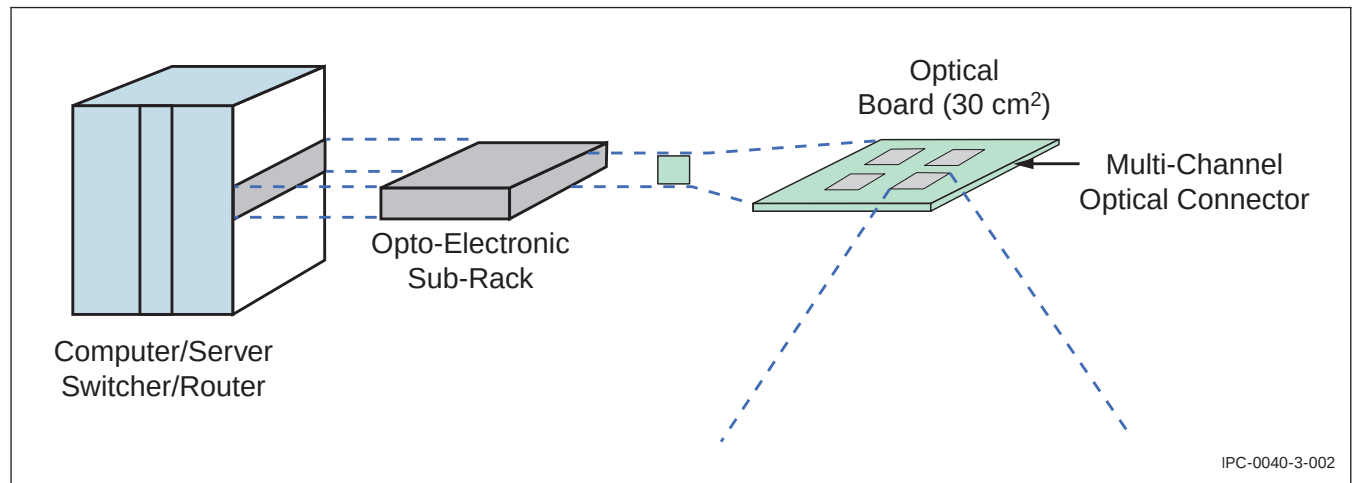


Figure 3-2 Optoelectronic Peripheral Exchange Functions

appropriate display function. Since some of these products must work externally, the assembly must be protected from environment influence. This is especially critical for the laser(s) to function properly.

3.2 High Performance (Office and Large Business Systems) The high performance driven products fall into two categories. Those categories represent Office System and Large Business System products. In addition there is a different goal for products that are continually operational monitoring data on a twenty-four hour basis, versus those systems that are functional on-demand.

Office System Products: These products are characterized by designs that aspire to maximize performance, while restraining costs to a few thousand dollars (typically \$1K - 5K). This emulator encompasses low-end servers, telecommunication line cards and high end personal computers - both desktop and portable. Volumes may be high, but are moderate compared to Consumer Products. Typical useful life is four to six years. The characteristics are:

- Emulator includes Office system products, small router, low end router.
- I/O explosion; ceramic array packages with high I/O count.
- Heat increase requirements for active cooling.
- Fiber optic interfaces a must.
- Embedded passives required for performance reasons.
- Size will vary; some will become bigger, some smaller.
- Little RF requirements for the electronic assembly.
- Power usage will increase.
- Large processors will be needed with a great deal of memory capability.
- Many systems will make use of daughter board (super component) concepts.
- Connectors will require High I/O and high frequency capabilities.

- Maximum use of HDI, with high layer count using a minimum of two layers of HDI material on either side of a multilayer core.

Large Business System Products: These products are characterized by designs that trade pure performance for cost. Typical applications are supercomputers, the most powerful servers, central switching systems and high data transmission rate routers that are at or near State-of-the-Art performance. High performance requirements drive the need for more expensive packaging, advanced interconnections, and highest performance devices. Production volumes are low to moderate. The typical useful life is up to 20 years. The characteristics break into two major functions:

• High Performance Systems (Mainframe/server/mass storage):

- Emulator is based on Super Computers and Telecom Switching systems.
- Higher layer count, use of micro vias with slight thickness increases.
- High frequency requirements increase impacting Dk and Df properties.
- Limited size reduction.
- Higher thermal requirements.
- Patches of High density printed boards for large BGA (45 mm sq) escapes.
- Reliability stays constant with those used in present equipments (circuit redundancy).
- PWB conductor width and spacing down to 75 μm and 60 μm with controlled impedance.

• RF and Microwave (10 GHz and greater):

- Emulator is based on high speed routers and switches; board size of 450 mm by 600 mm for Revenue Center of Gravity (RCG), and by 300 mm x 450 mm for State-of-the-Art (SoA) products.

- Massive fiber optic input.
- Special materials to handle impedance control with good Dk and Df properties.
- Active heat removal technology needed.
- Large array packages with some ceramic packaging requirements.
- High I/O and High Speed connectors.
- More layers and more voltage variations.
- Additional shielding at both the board level and the equipment level.
- Performance driven materials at higher cost.
- Thick boards in excess of 6.00 mm.
- High aspect ratio through holes

3.2.1 Component Characteristics

3.2.1.1 Optical Transceiver Optical transceivers are designed for use in short-reach multimode fiber optic links between Gigabit Ethernet networking equipment and is interoperable with all equipment meeting the Gigabit Ethernet industry standard. They are usually compliant with Small Form Factor Multisource agreements and requires a 3.3 V dc power supply. The electrical interface follows the 2 x 5 format while the optical interface uses the LC-Duplex connector.

3.2.1.2 Optical Receiver An optical receiver provides optical signal conversion and processing. These components typically contain InGaAs PIN photodiodes or APD's, and high sensitivity, wide dynamic range, transimpedance amplifiers, capacitively coupled to limiting amplifier stages with Positive/Pseudo Emitter Coupled Logic (PECL) output drivers. These photodiodes operate in the 1200 nm to 1600 nm wavelength band for telecommunication applications and 850 nm for datacom applications.

3.2.1.3 Infrared Detector The Infrared detector module is a low-height infrared transceiver that provides interface between logic and IR signals for through-air, serial, half-duplex IR data link. The module is compliant to IrDA Data Physical Layer Specifications 1.1 and IEC60825-Class 1 Eye Safety Standard. The module contains a high speed and high-efficiency 870 nm LED, a silicon PIN diode, and an integrated circuit. The IC contains an LED driver and a receiver providing a single output (RXD) for all data rates supported.

The module can be completely shut down to achieve very low power consumption. In the shut down mode, the PIN diode is inactive, thus producing very little photo-current even under very bright ambient light. The module also incorporates the capability for adjustable optical power. With two programming pins; MODE 0 and MODE 1, the optical power output can be adjusted lower when the nomi-

nal desired link distance is one-third or two-thirds of the full IrDA link. The module comes with a front view packaging option. It has an integrated shield that helps to ensure low EMI emission and high immunity to EMI fields.

3.2.2 Board Assembly Issues

3.2.2.1 Optical Transmitter Board The optical transmitter boards are intended to combine optical interconnection tied to electronic segmentation of the optical signals. In most instances, a multichannel optical connector is used to organize optical signals coming from waveguides into appropriate bandwidth channels commensurate with the functions being performed. Figure 3-3 shows an example of a typical optical transmitter board assembly. This product functions slightly different than an optical electronic assembly in that the main function is to transmit optical signals to the user's end product equipment.

3.3 Portable Products Portable products are usually hand-held systems and, at the moment, are not candidates for optoelectronic packaging. Their future functions may become a trend toward the sending of optical signals throughout an office or home environment. Their present characteristics are mostly electronic-based and have the following features:

Portable Products: Portable – Although manufacturing costs are extremely important, products in this emulator are driven by weight and size considerations. Products are small in size and of minimum weight, but may have high levels of function. Examples are cell phones (1G-voice, 2G-voice/data, 3G-voice/data/video) wireless personal digital assistants (PDA), notebook computers, navigational aids, etc. Volumes may be large but lower than those in the Consumer Products category. The useful life is typically three to five years.

3.4 Harsh Environments Harsh environment products must be protected from severe temperature and moisture swings. They are dedicated to work in automotive under-the-hood applications, severe aerospace, and below surface mechanical drilling and mining sensing operations. There are relatively little applications for optoelectronics in these severe environments, however as greater need arises for the benefit of either optical fiber or laser transmission, these products may become candidates for the optoelectronic technology.

Harsh Environment: Harsh environment is divided into two segments: Automotive and Aerospace products. The environmental extremes for products in this sector are varied and harsh. Both the moderate volumes of the automotive sector and the low production volumes of custom designs found in aerospace applications must reflect the unrelenting demand for lowest cost. The design goal

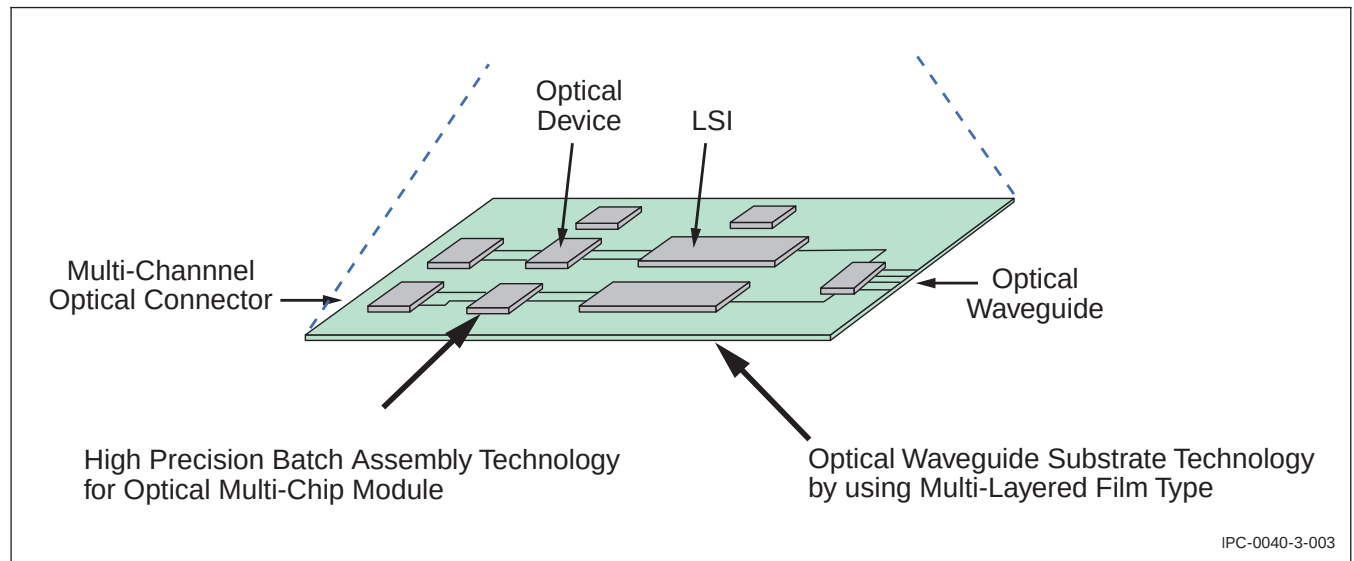


Figure 3-3 Typical Optical Transmitter Board Assembly

achieve the required quality and reliability with an expected useful life of up to 20 years. Defense Products are a subset of this sector that requires the highest levels of reliability and durability over a useful life of up to 40 years while they are built in low to modest volumes.

• **Harsh Environments – Auto:**

- Emulator is based on engine controller.
- Getting to deal with higher temperatures.
- Increased distributive functions (more place in the automobile).
- Smaller board assemblies; higher thermal, higher frequency and higher performance.
- Multilayer increase.
- Use of MEMS is included.
- Safety and reliability become major goals.
- Must accommodate the concept of intelligent vehicles.
- Not clear whether fiber optics will be needed for the future.

• **Harsh Environments – Aerospace:**

- Emulator is based on ATR communication module board type.
- Higher frequency impacting Dk and Df.
- Requires fiber optical interfacing.
- There will be a move to commercial devices.
- As heat goes up emphases on passive removal (as opposed to active heat removal).
- Requirements for dust immunity.
- Size stays much the same but looks toward smaller and lighter products.
- More use of area array type components: CSP or flip chip with underfill.

4 DESIGN CONSIDERATIONS

There are various levels of optoelectronic packaging. Figure 4-1 provides an illustration that highlights these levels.

Tables 4-1 and 4-2 provide information on the technology trends in both the physical characteristics and capability of optoelectronic parts and packaging. Table 4-1 shows the physical characteristics of the components and modules up to 2005, while Table 4-2 is an optical communication technology roadmap view of optoelectronics through 2011.

4.1 Level 1 Design Consideration

4.1.1 Optical Design This section briefly describes the design requirements for optical alignment in optoelectronic packages and gives a couple of examples of the processes used in industry.

The objective of the optical interconnect package design is to efficiently couple the light between two optical interfaces (being either passive or active components) such as

- Laser Diode and Fiber
- Fiber and Photodiode
- Modulator and Fiber
- Optical Multiplexer/Demultiplexer and Fiber

The two primary package design considerations for optical alignment are the placement accuracy of the components (relative position of different components) and the alignment sensitivity of each component (displacement corresponding to a given insertion loss) i.e., how good is our assembly equipment and when does it matter.

The primary goal in designing coupling interfaces is to minimize power loss. The goal for fiber to laser coupling is to ensure that the fiber acceptance area is as large as possible compared to the active area and Numerical Aperture (NA) of the LED or Laser. For the fiber to laser coupling, the

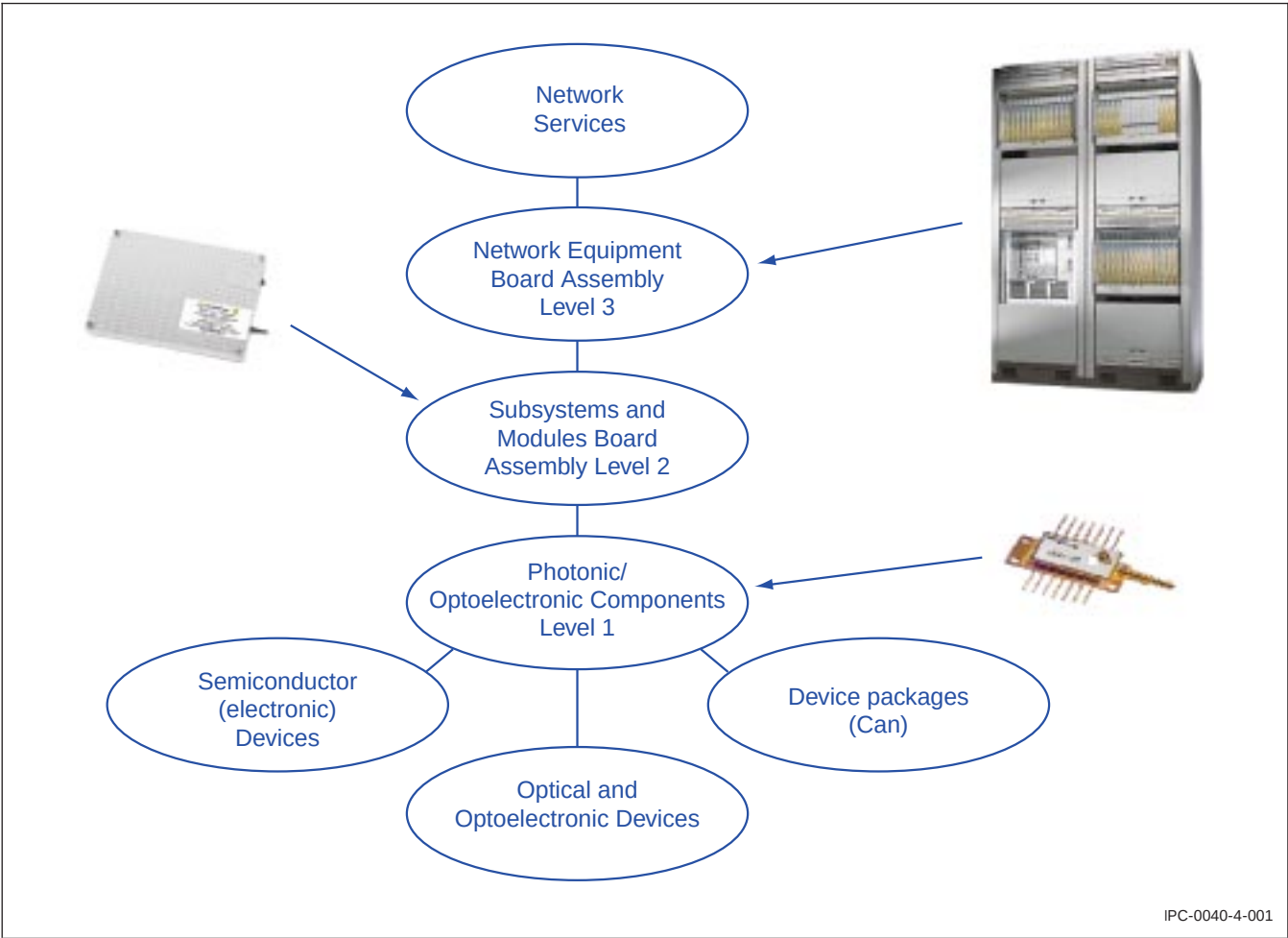


Figure 4-1 Design Configuration Hierarchy

Table 4-1 Physical Characteristics of Optoelectronic Packages

Characteristic	1996	1998	2000	2005
Pin Centerlines mm	2.54	2.0	1.5	<1.5
Signals/Inch (25 mm)	80	100	150	>150
Data Rates (Gbs/channel)	0.622	1.0	2.4	25
Connector Type (Copper)	HM/8R FB	HM12R HS3	HS4	HSIS
Connector Type (Fiber)	SC	HM/MPX	HS/MPS	Wave guide
B/P Construction	FR-4d/ Cyanate Ester	Getek FR-4m/f	4350/25N PPE	PPE/PTFE Optical Polymer
Via Holes	Plated Hole → (Compliant Pin)		THS & Microvia → (Combination)	Microvia

pling the goal is to insure that all of the light emerging from the fiber falls in the active region of the detector.

Waveguides and optical components may be characterized by a set of parameters and examples. The values used for this characterization are shown below in Table 4-3. These values are important and need to be known when coupling differing optical elements in a single package.

4.1.2 Coupling Between Lensed Fiber and Laser Waveguide There are several characteristics for the fiber

tip used to couple lasers with a waveguide or optical fiber. Table 4-4 provides the capability and expense for several fiber tip conditions.

4.1.2.1 One Lens System Usually a lens is used to decrease the divergence of the laser light output in order to focus it and to couple the light more efficiently into the waveguide or other optical item in the light path, or optical train (see Figure 4-2).

Table 4-2 Optical Communication Technology Roadmap

Technology/Components Commercial Availability	1998	2000	2003	2005	2011
Laser Sources: edge-emitters VCSELs	Single λ DFBs 850 nm discrete	40 channels (tunable) 850 nm arrays	100 channels (tunable)	1000 channels	
Optical Detectors		WDM detector w/ filter Lower cost APDs Organic Photodetectors			
Transceivers: packaging Lan price	Discrete Components	Hybrid Integration (with CMOS VLSI) \$25 LED datacom \$75 VCSEL datacom \$700 ONU	\$15 LED datacom \$45 VCSEL datacom \$175 ONU	Lower Cost, LSI OEICs \$100 ONU?	\$1 T/R for board to board links
Optical Amplifiers		<80 nm EDFA/Raman hybrid	100 nm	Ultra-wideband OAs, 80-345 nm Channel Gain Compens. Price <\$1000?	
Optical Switches	16 x 16	128 x 128	1024 x 1024	4096x4096 Optical Packet Switching	
Dispersion Compensators	Disp. comp.fiber	Bragg grating devices Slope management Dynamic dispersion compensation? Dynamic PMD compensation			
Wavelength Converters		Optoelectronic (transducers)	all-optical		
Connectors	Single-mode Multimode & POF	very low cost (Access and Datacom) Array large array (for ~100 channel DWDM, Routers, Switches) very low cost for premises networks			
Optical Fibers		Dispersion flattened large core for DWDM ultra wideband (no OH peak @1385 nm) ultra low loss, low cost/high speed plastic optical fiber			
Optical Packages & Assembly		Low cost packaging and fiber coupling Automated surface mount assembly			

Table 4-3 Spot Size for Various Optoelectronic Components

	Numerical Aperture	Guiding/Active Area
Single Mode Fiber	0.1 - 0.15	8 - 11 μm
Multimode Fiber Large Core Step Index	>0.3	50 - 110 μm
Multimode Fiber Graded Index	0.2 - 0.3	50 - 62.5 μm
Laser Diode	0.3 - 1.0 often asymmetric	1 - 3 μm
VCSEL	0.1 - 0.3	3 - 20 μm
2.5 Gb/s PIN receiver	—	40 - 80 μm
10 Gb/s PIN receiver	—	15 - 40 μm
40 Gb/s PIN receiver	—	2 - 15 μm

Table 4-4 Fiber Tip Characteristics

Fiber Tip	Description
Flat cleave	Cheap
Angle cleave	Cheap, no issue with back reflection
Conical fiber	High coupling efficiency
Edge fiber	High coupling efficiency for asymmetric beam

4.1.2.2 Two-Lens System In a two-lens system, a first lens is used to collimate the light beam; a second is used to focus the light into the fiber (see Figure 4-3).

The main advantage of using multiple lenses is to split the tolerances. The displacement of each component can be larger than using a single optical component.

4.1.3 Passive Alignment Passive alignment is a technique used for assembling optical or optoelectronic components in which piece parts are positioned relative to each other, or known positions within the package. Since most piece parts are assembled this way, it almost always refers to the positioning of the waveguide (fiber, etc.) relative to the active device (laser, detector, SOA). This technique does not use the performance of the system to determine the optimal position for any of the parts in the assembly but, instead, attempts to place all parts accurately enough so that after assembly, the device will function correctly. The extreme accuracies required to couple light into the waveguides used in optical communications generally prevent this technique from being used in applications that require high coupling efficiencies.

Most components that are assembled using passive alignment utilize silicon v-groove (Si-V) or silicon optical

bench (SiOB) technology and have very stringent requirements for part placement accuracy (within 3 microns, 3 sigma).

4.1.4 Active Alignment For single-mode fiber, the alignment requires a sub-micron positioning accuracy. The main advantage of this method is the relaxation of the tight mechanical tolerance required for passive alignment.

The principle of this method is as follows.

- The laser diode is biased during the alignment.
- The optical output power coupled into the waveguide or optical device is continuously monitored and provides a feedback for the optimization of the alignment process.
- When the target power has been reached the optical device is locked in place.

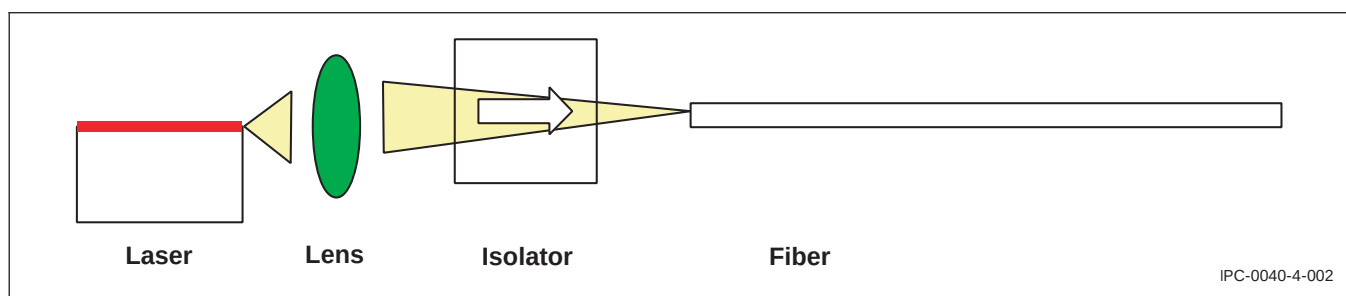
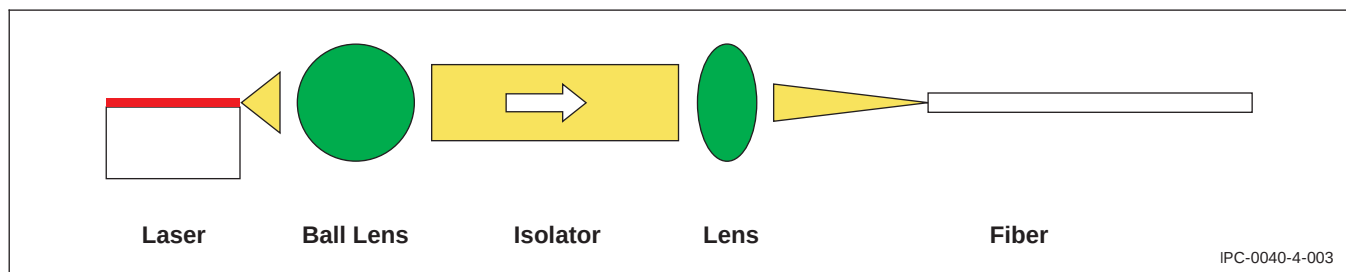
The algorithm and the locking of the fiber in place can be achieved with various means and are usually proprietary processes.

4.1.5 Optical Microsubmounts

4.1.5.1 Design for Waferprocessing In several applications the optical part must be prepared in a wafer format. Processing can thus become more automated and the manner in which the devices are assembled becomes very cost effective with high yield potential. Figure 4-4 shows an example of the technique of combining optical and electronic components at the silicon wafer stage.

The Process consists of

- Die-Bonding on Si or Glass-Wafer
- Wirebonding

**Figure 4-2 One Lens Coupling System Diagram****Figure 4-3 Two Lens Coupling System Diagram**

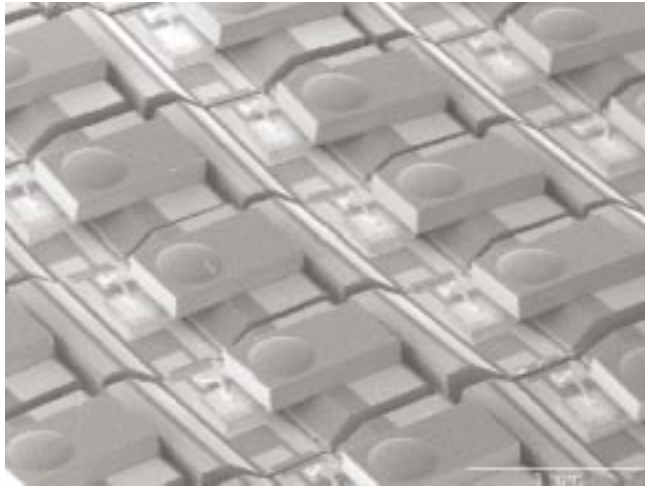


Figure 4-4 Wafer Optical/Electronic Combination

- Active or Passive Alignment of Si-Lens
- Electro-Optical Test
- Burn-In (a few thousand simultaneously)
- Electro-Optical Test
- Depanelization by Wafersaw

4.1.5.2 Example of Laser Diode - Microsubmount on TO-Header At the next assembly level the laser diode is mounted to a TO header so that it can be handled and packaged properly. Figure 4-5 shows the details of the mounting process.

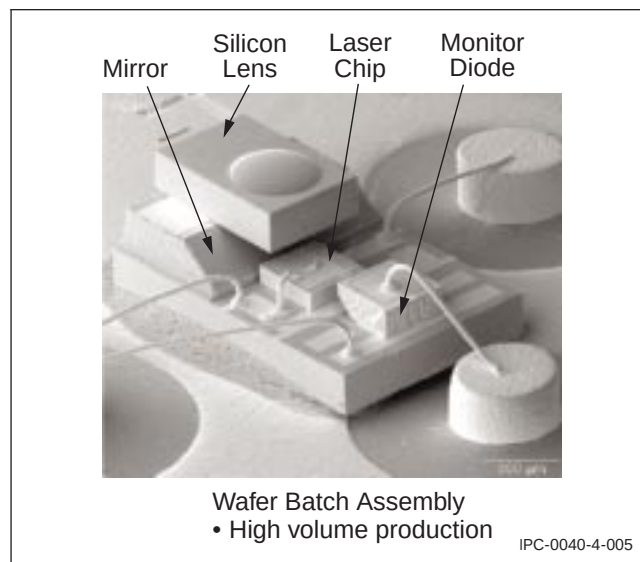


Figure 4-5 Mirror and Lens Alignment

4.1.6 Alignment Technology Here are several examples of alignment techniques used in the industry (see Appendix A references 1 to 9 for more details).

The principle of high accuracy alignment is as follows:

1. The least sensitive degrees of freedom are locked first either by design, by passive alignment or by a rough active alignment.

2. Then the most sensitive degrees of freedom are locked in place using a much finer alignment method.

4.1.6.1 TO Can Alignment - Newport Technology The following characteristics, shown in Figure 4-6, highlight the processing steps to align the laser to the coaxial cable (see Appendix A ref. 8).

4.1.6.2 TO Can Alignment for Module The laser alignment process is a critical step in producing the detector Module. The concept can be applied using other than the TO can shown, however it must be stable in order to provide the necessary focus at the next assembly level (see Figure 4-7).

4.1.6.3 Two-Lens System Using a Lens in the Wall of the Butterfly Can Figure 4-8 shows the steps and characteristics for alignment of the two-lens system in the wall of a butterfly can.

The Alignment-Process consists of the following steps:

- Active Alignment of TO-Laser.
- Active Alignment of Fiber.
- Active Alignment of TO-Detector.

4.1.6.4 Use of Clips or Flexure for Alignment Figure 4-9 depicts the optical module assembly principle. The module is assembled on a ceramic substrate with a metal platform. Optical chips (laser, photodiodes...) and electronic components (RF matching circuitry, drivers, amplifiers...) are mounted on the ceramic by pick and place techniques commonly used in the electronic industry, using fluxless soldering processes, and within an accuracy of about 10 microns. Pick and place automation using machine vision is greatly facilitated by the quasi-planar design.

Optical components such as lenses and fibers are mounted on micro-machined flexible metallic elements (flexures). Micro-optical components such as fibers, lenses, isolators, and filters are preassembled on the flexure. This preassembly is then picked and placed in coarse optical alignment on the metallic platform using machine vision. Fine active alignment is obtained by an automated process which slightly deforms the flexure. After alignment, the flexure is then rigidly laser welded to the metallic platform (see Figure 4-10).

Figure 4-11 provides the process step information to hold the micromachined flexure in alignment prior to welding.

Similar methods are used in the industry for this alignment process. Figure 4-12 shows two different clips used in the industry for high accuracy alignment process.

4.1.6.5 Alignment of AWG with Fiber Array Arrayed Waveguide Gratings (AWG) are passive components (see Appendix A, ref. 10). Multi wavelength signal multiplexing

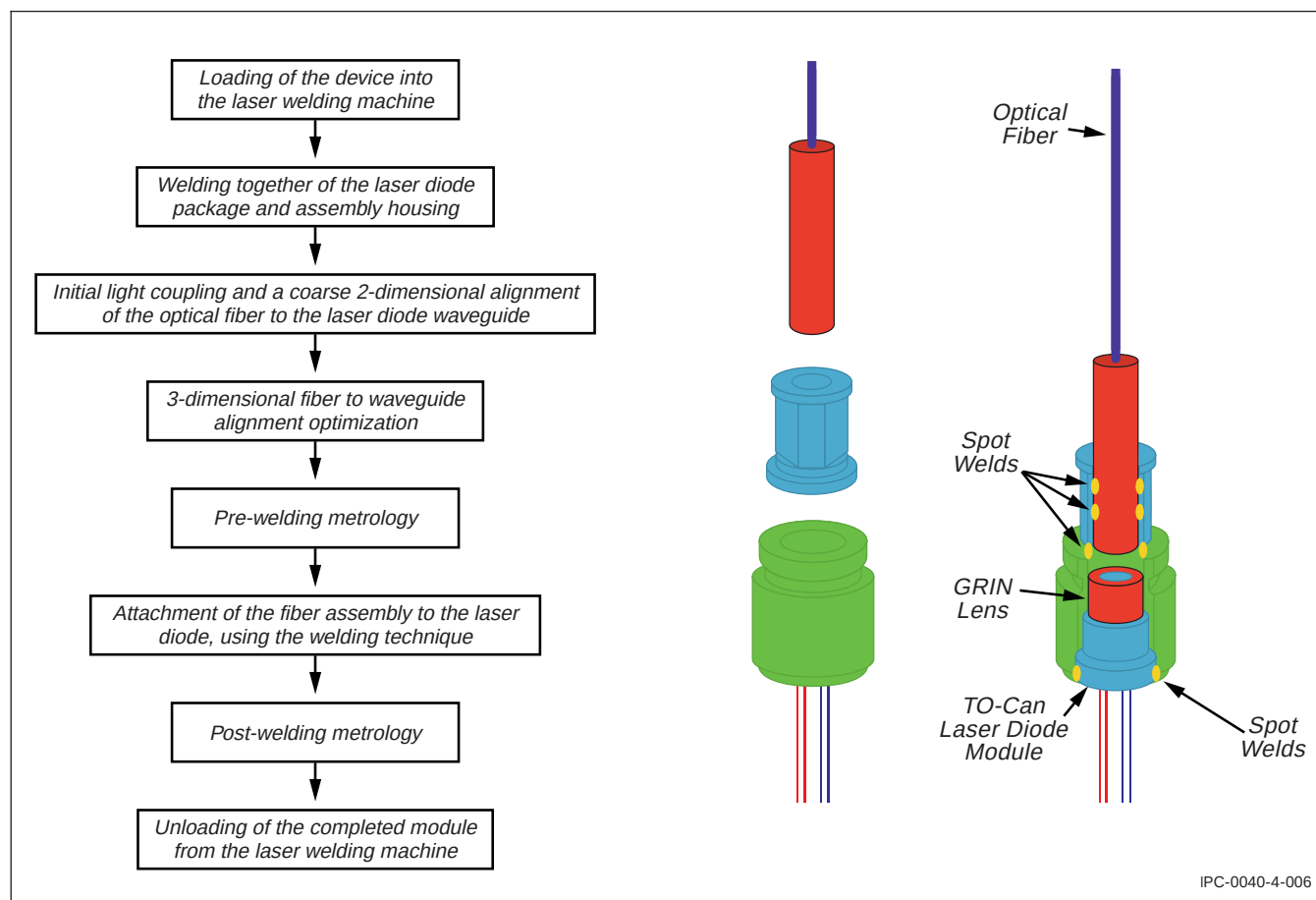


Figure 4-6 Coaxial Module Assembly

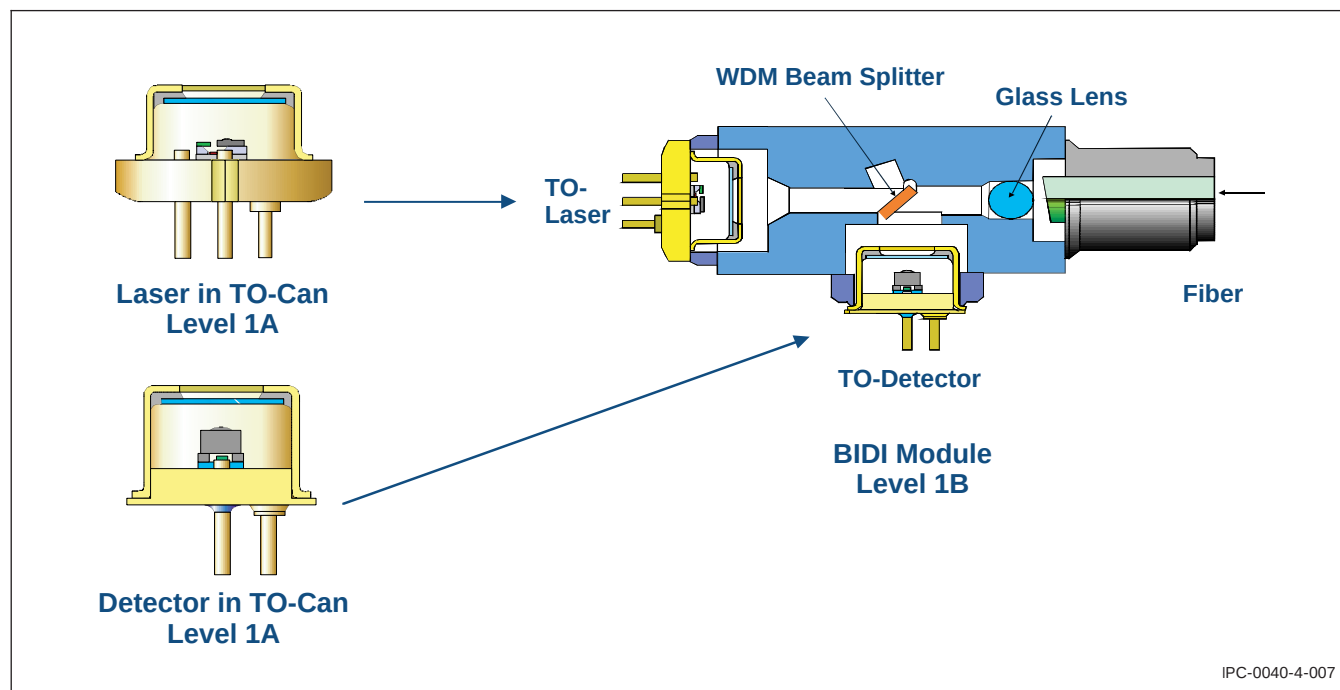


Figure 4-7 TO-Can Alignment

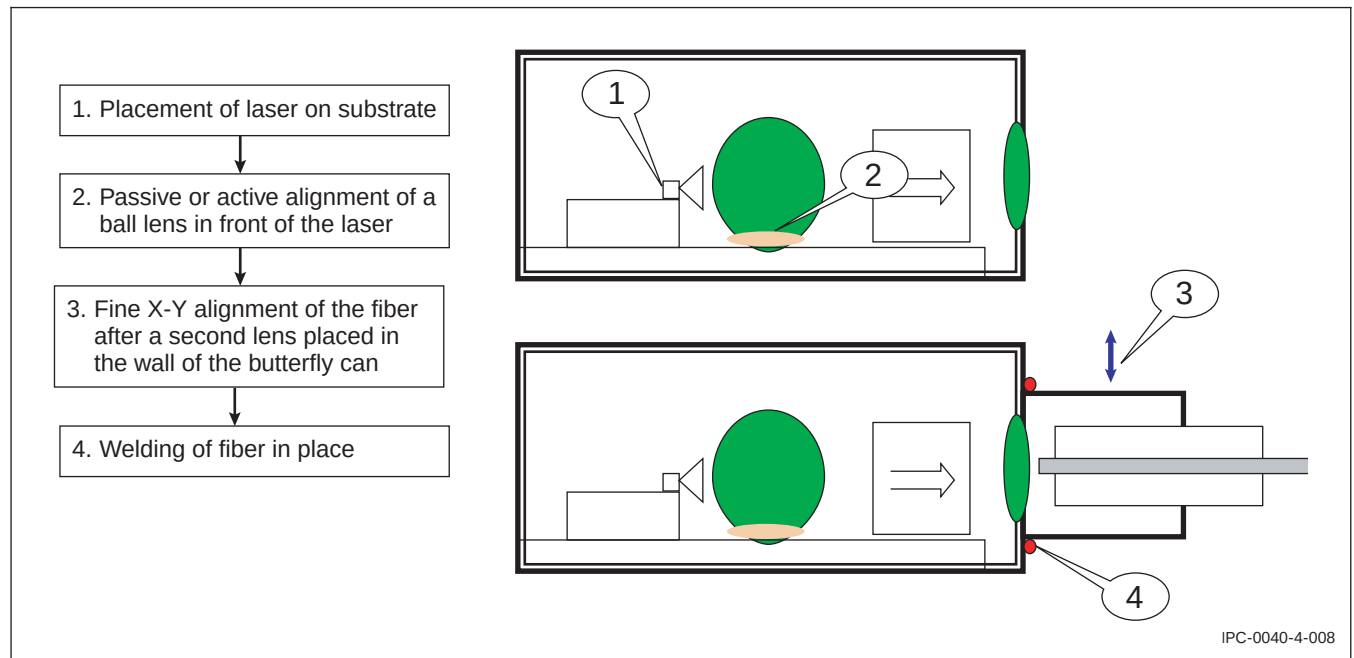


Figure 4-8 Two Lens System Alignment

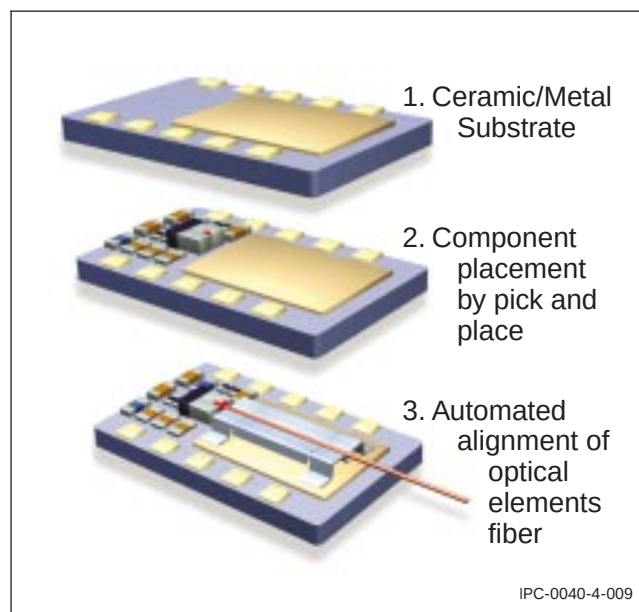


Figure 4-9 Quasi-Planar Optoelectronic Package Assembly Principle

side are distributed on separated waveguides on the output side of the AWG. The fiber alignment on the input side of the AWG requires detection of light from the output side of the AWG by aid of a magnifying lens and an infrared camera (see Figure 4-13).

If a fiber array is connected to the input side of the AWG, then the alignment system should have five axes of movement, at a minimum. The desired output channel is selected by a tunable laser source. For exact balancing of the light intensities between different waveguides on the output side of the AWG, two detectors are used in place of the camera.

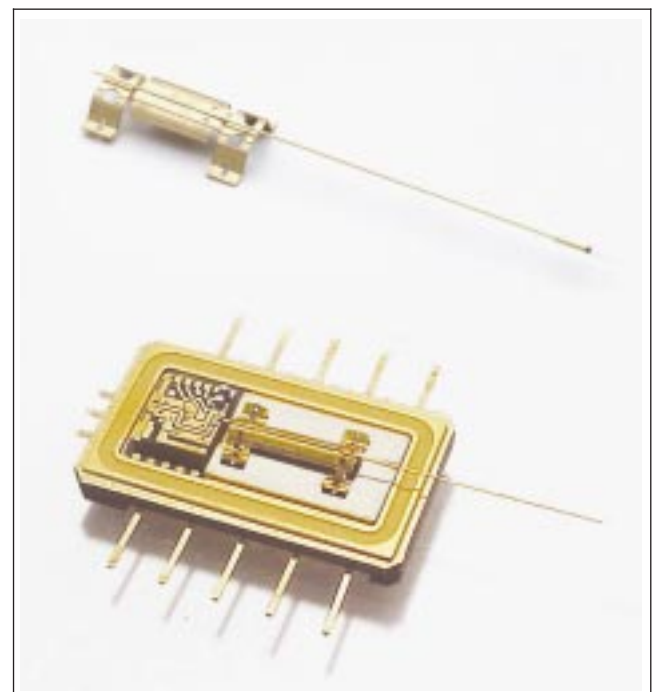


Figure 4-10 Micromachined Flexures and Mini-Module Platform with Aligned Fiber

After alignment, the fiber array will be fixed by gluing with UV curing epoxy and the aid of a glass lid (see Figure 4-14).

If there are lensed fibers in the array, the fixing will be done with two glass lids at the sides of the array giving an air gap between fiber tip and AWG front facet (see Figure 4-15). The final packaged AWG configuration is shown in Figure 4-16.

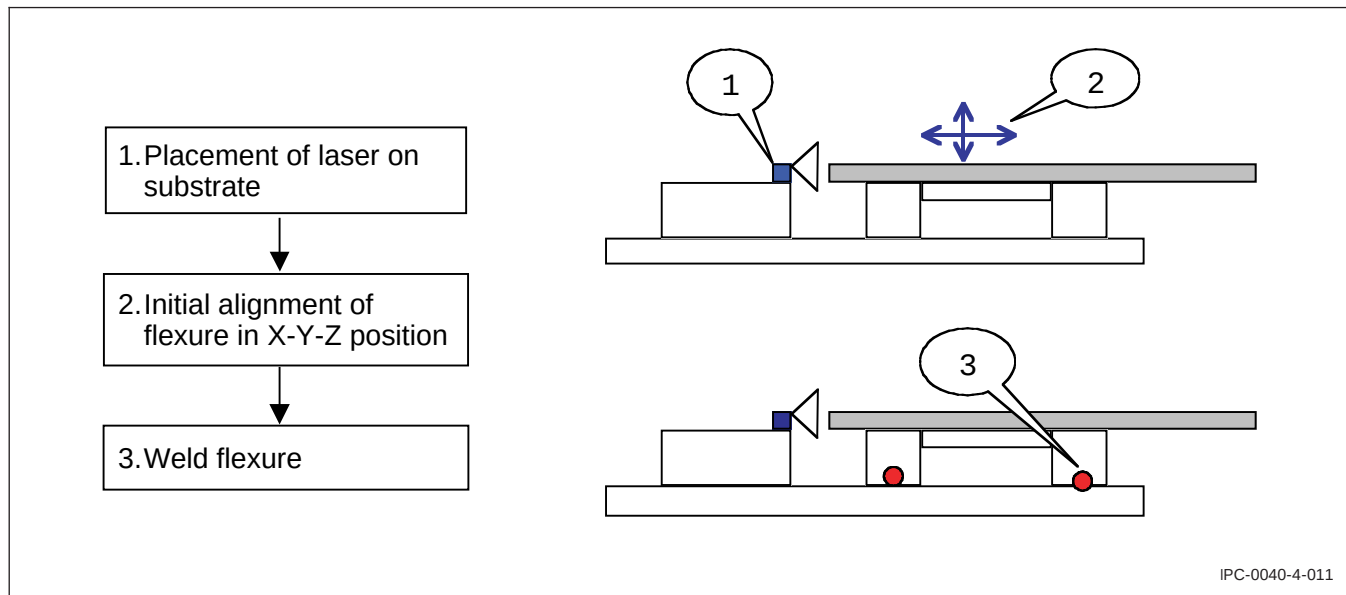


Figure 4-11 Flexure Alignment Process Steps

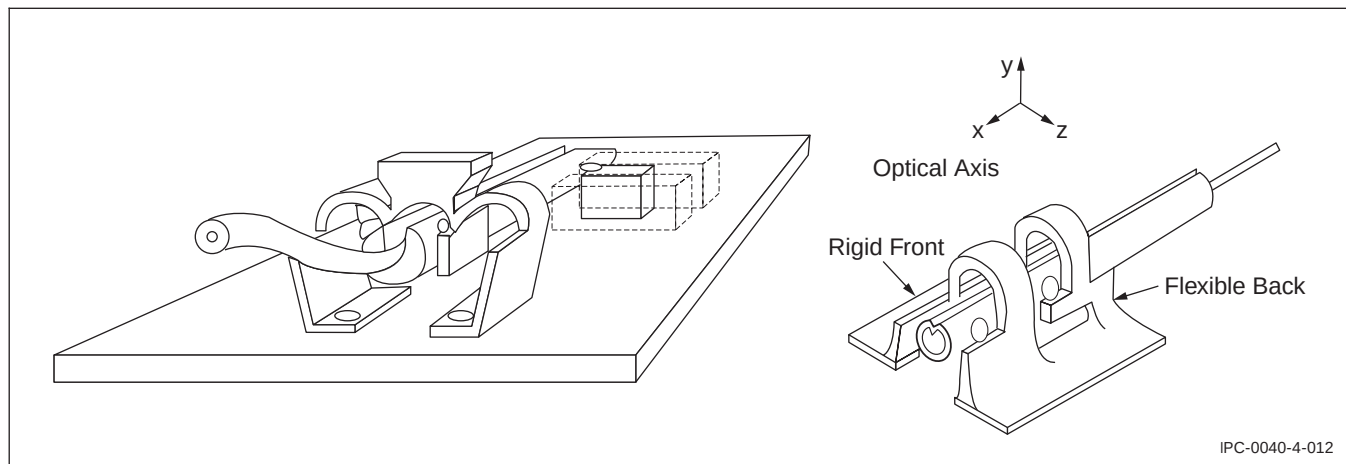


Figure 4-12 Example of Industry Alignment Clips

4.1.7 Design/Process for Rework Generally, the alignment can shift during the subsequent process step. It is then required to rework the alignment to gain back the loss of coupling efficiency. This is commonly done in welding using a “hammering” method. The hammering method consists of firing the laser at specific locations to induce deformation and alignment change.

4.1.7.1 Attachment Methods After the alignment process, the optical component is fixed in place using various methods. The main requirements of these process methods are as follows:

1. During the attachment, the mechanical shift has to be minimized in order to maintain the alignment.
2. The temperature of the attachment process has to be low enough or very localized in order to avoid overstress on other optical components placed previously and to prevent displacement induced by thermal expansion mis-

match when cooling down the components to room temperature.

3. Impact of potential contaminants needs to be considered when selecting solders, fluxes, cleaners, and other materials.
4. The joint needs to be reliable to prevent any displacement shift during the environmental stress tests and during the life of the product.

The following is a brief list of materials and processes used to attach optical components in optoelectronic packages:

- Epoxy (UV cured or thermal cure)
- Solders
- Frit and Low Temperature Glass
- Welding
- Mechanical Screws
- Brazing Process

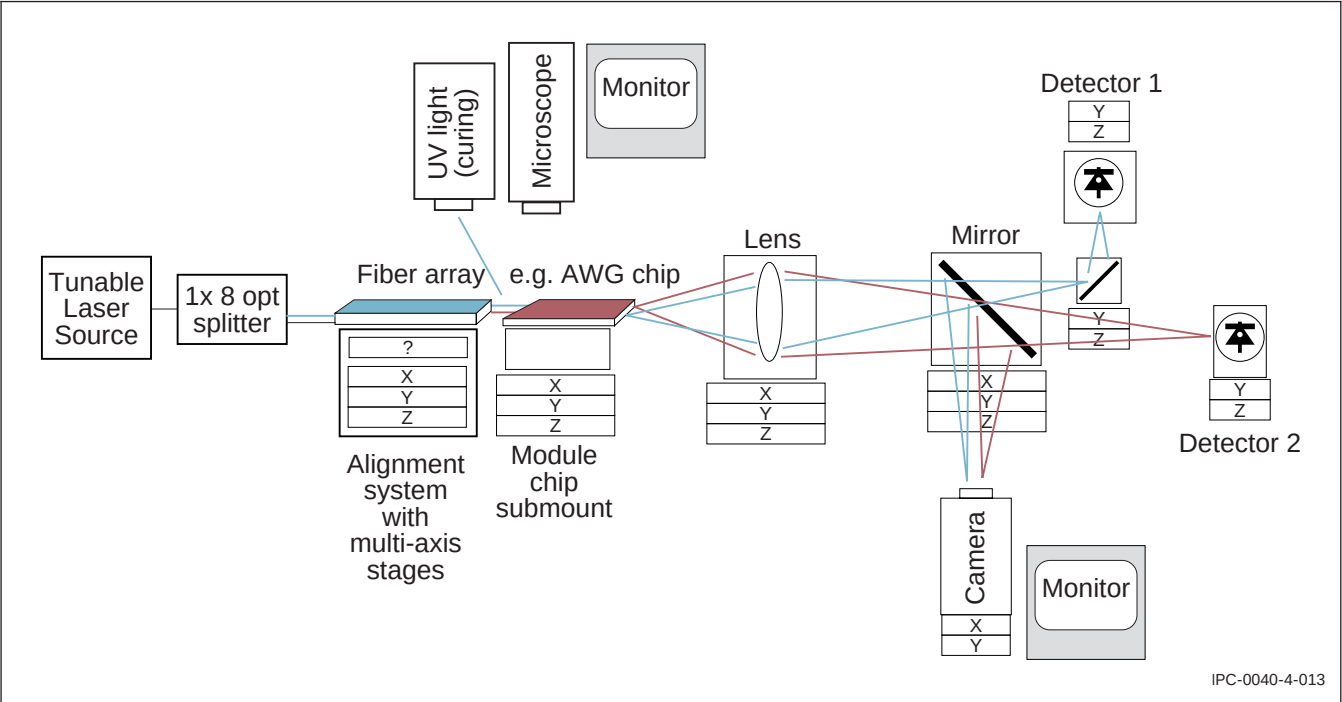


Figure 4-13 Magnifying Lens and Infrared Camera Relationship

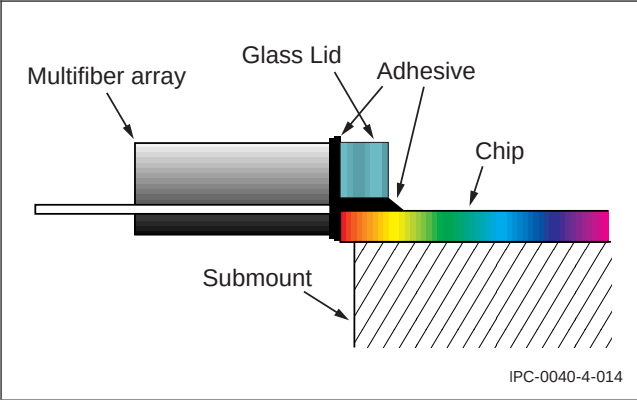


Figure 4-14 Multifiber Array Attachment

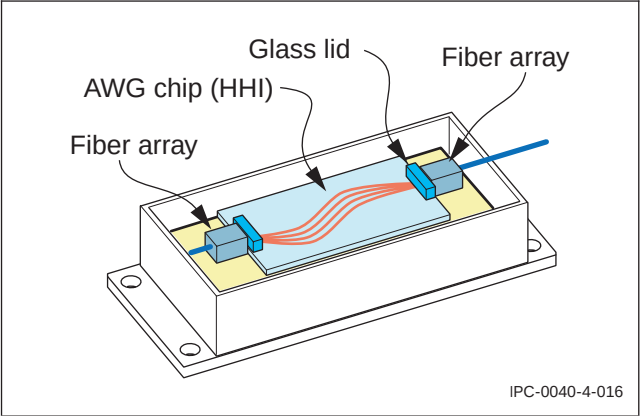


Figure 4-16 Example of AWG Package

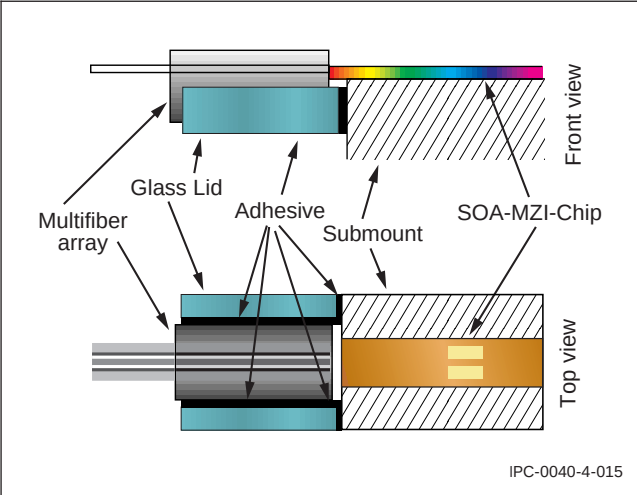


Figure 4-15 Glass Lid to Handle Lensed Fibers

4.1.7.2 Solder The advantage of solder attachment technology is the wide range of process temperatures, the reliability of the joint and the organic free material. Table 4-5 shows a list of commonly used solder in opto-electronic industry.

Table 4-5 Commonly Used Solder With Melting Temperature	
Solder	Melting Temperature (°C)
Au-12Ge	356
Au-10Sn	295
Au-20Sn	280
Sn-37Pb	183
Sn-58Bi	138
Sn-52In	118
In	157

4.1.7.3 Frits or Low Temperature Glass This attachment method requires special metallization to bond ceramic, glass, or metal. The method is mainly used to attach glass to Kovar for hermetic packages. It offers excellent hermetic seals and does not require the metallization of the glass. The material used for this method is called a frit; it has a relatively low softening point of glass composition (melting temperature 330°C and above).

4.1.7.4 Brazing Process Brazing materials and processes offer a high temperature range. Table 4-6 shows a list of Cu and Ag based brazing materials.

Table 4-6 Common Brazing Materials and Melting Temperature Range °C

Brazing Composition	Melting Temperature °C
Cu-40Zn	890-900
Cu-40Zn-10Ni	890-920
Cu-15Ag-5P	650-800
Ag-Cu-Zn-Cd	620-760

4.1.8 Single Fiber Most of the traditional optoelectronic components interface with a single optical fiber. These components include such devices as laser diodes and photo-detectors. The optical train for such components may be designed for direct coupling between the device and the fiber, or it may incorporate additional optical elements, such as lenses and isolators. The selection of the particular optical train design depends on the performance requirements for the component.

4.1.8.1 Direct Coupling Direct coupling may be executed using a cleaved (flat end) or tapered fiber. Cleaved fiber is significantly cheaper, and exhibits lower insertion loss variability than a tapered fiber. However, cleaved fiber suffers a greater nominal insertion loss, and it also produces greater reflections.

In the case of direct coupling, the fiber tip is located in very close proximity to the optical device. Therefore, the fiber must enter the component package, and, if the component needs to be located in the hermetic environment, the fiber has to be metallized to allow for hermetic sealing at the package wall.

A cleaved fiber tip is produced by cleaving the bare fiber. When coupling to a laser diode, a cleaved fiber produces a high insertion loss, typically 9-12 dB. This is due to the fact that the laser diode output beam suffers from two asymmetries: astigmatism and an elliptical beam profile, while the fiber beam profile is round.

Tapered fiber incorporates a lens at the fiber tip, and it can be formed by two primary methods:

- **Melting and pulling the glass tip** - this produces a taper in both the cladding and core of the fiber. In this method, the heat is applied by an electric arc or by dipping the fiber tip into molten glass. The resulting lens is rotation-

ally symmetric with a radius that can be controlled by process variables. A typical insertion loss for a tapered fiber coupled to a laser diode is in the range of 2-3 dB.

- **Removal of excess glass** - this produces a lens at the fiber tip, but leaves the fiber core diameter unchanged (the taper is produced in fiber cladding only). In this method the glass is removed by etching or polishing, and the resulting lens may have other than spherical profiles, for example parabolic. Such fibers produce better coupling - the insertion loss can be as low as 0.2-0.4 dB when coupled to a laser diode.

4.1.8.2 Lensed Coupling Lensed coupling may be done by single or multiple lenses. The distance between the optical device and the fiber tip is governed by the radii of the front and back facets of the lens when using a single lens. In the case of multiple lenses, the light beam is usually collimated by the first lens and focused by the second lens. This makes it possible to place an isolator in the collimated portion of the beam when a tight control of reflections is required.

Lensed coupling provides a possibility to locate one of the lenses at the package wall, in which case the optical fiber may not have to enter the component package, and the fiber does not need to be metallized.

When lensed coupling is used, the resulting insertion loss will depend on the optical characteristics of the lenses. It is, therefore, possible to tailor the optical train to the requirements of the particular product. Typically, the optical train designed for lower insertion loss, will exhibit greater insertion loss variability.

4.1.9 Fiber Ribbon Cable New optical components include such devices as optical switches, AWG (Array Waveguide Gratings), and optical MUX / DeMUX devices. A single optical device of this type contains multiple optical waveguides, and the pitch of these waveguides directly affects the size of the device. Since these devices interface with multiple fibers, packaged in a ribbon configuration, the waveguide pitch must be equal to the pitch of fibers in the fiber array. The beam profile for these devices is governed by the dimensions of the optical waveguides in the devices, and this makes it possible to obtain acceptable insertion losses when interfacing them with cleaved fibers.

The fiber pitch in a standard fiber ribbon cable is 0.25 mm, as shown in Figure 4-17. Therefore, it is not feasible to align each fiber individually to the respective waveguide - there is no space for fiber grippers in a 0.25 mm pitch. Even if the space problem could be resolved, the amount of time required to align 8, 16, or 32 fibers makes this approach economically unattractive. Consequently, the fiber ribbon cable is typically terminated in a V-groove block. This creates a fiber array assembly that allows it to be handled as one unit. Optical alignment is accomplished

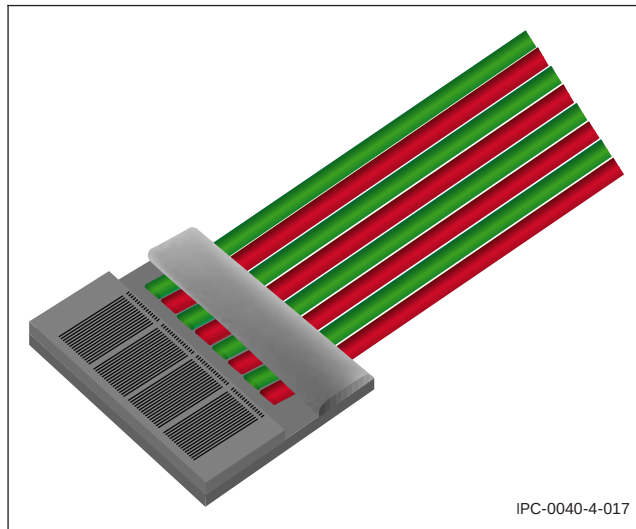


Figure 4-17 Multiple Fiber Ribbon Terminated in a V-Groove Block

two of the fibers in the array, usually the outermost ones. Clearly, the alignment of all other fibers to their respective waveguides depends on the deviation of the fiber from its nominal position, and this, in turn, depends on the precision of the V-groove block.

These blocks are manufactured in silicon using wafer FAB technology, and this results in the fiber position being within 0.5 micrometers or better from its nominal position. Figure 4-18 shows such a V-groove substrate. Such a substrate has V-shaped grooves that are etched in silicon. Silicon is used because the angle of the groove is precisely controlled by the material crystalline structure, and this provides a tight control of the fiber position in the vertical direction. The grooves are designed to house bare fibers (125 micrometers in diameter). The organic fiber coating (buffer) is stripped down to the bare fiber, and the array of fibers is positioned in the grooves and sandwiched between the substrate and lid (glass or silicon). The substrate, fibers, and lid are assembled using adhesive, and the face of the assembly is polished. The typical polish is flat but, if necessary, angled polish can be used to reduce reflections. The organic fiber coating is additionally attached to the substrate using structural adhesive to provide mechanical strength. The fiber array assembly is then aligned and attached to the optical device using UV cured adhesive.

4.1.10 Axis Change Coupling of Multifiber In some applications the multifiber is coupled to the next assembly using the concept of bending the photons through the use of a reflective mirror. This alternate method to direct coupling requires a special coupling unit that ensures the accurate alignment of the photonic elements. Figure 4-19 provides an illustration of the process.

4.1.11 Multifiber Termination Using Cost-Efficient Plastic Parts, Suitable for MT-Connector In order to keep cost to a minimum, plastic encapsulation is used as

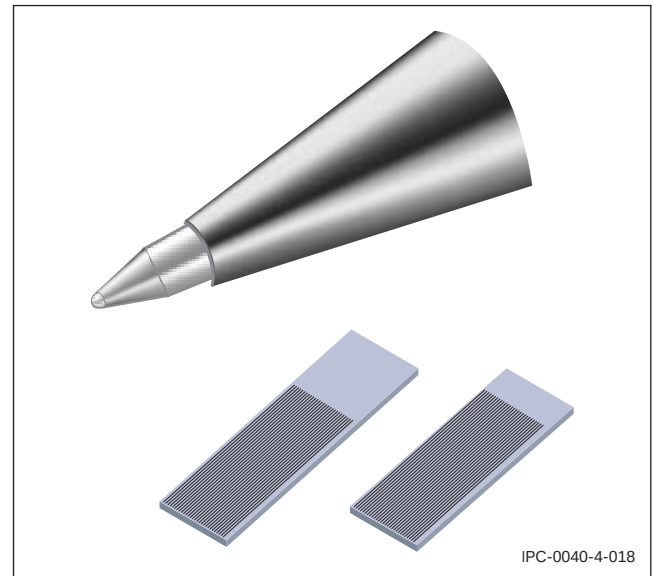


Figure 4-18 V-Groove Substrate

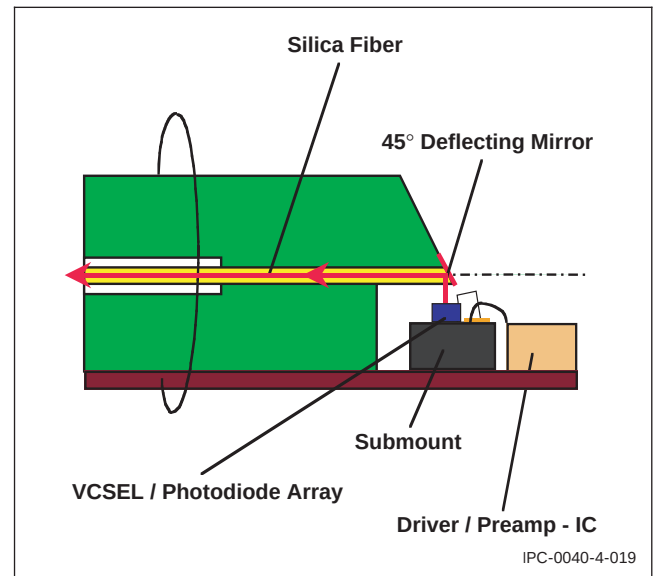


Figure 4-19 Example of Couple Axis Change

the medium for making the connections between various optical elements. Figure 4-20 shows an example of these designs.

4.1.12 Package Interconnection The optical connection of the package to the next element in the system is made by means of a fiber pigtail or a connector interface.

4.1.12.1 Pigtail Interface A pigtail interface involves having a fiber pigtail as part of the packaged optical device. The end of the fiber pigtail is usually terminated with a required type of an optical connector. At the point of exit from the package, the fiber jacket is attached to the pipe of the package, and in addition a strain relief boot is used to control the bend radius of the fiber pigtail.

The length of the fiber pigtail affects the magnitude of signal reflections that will reach the optical device.

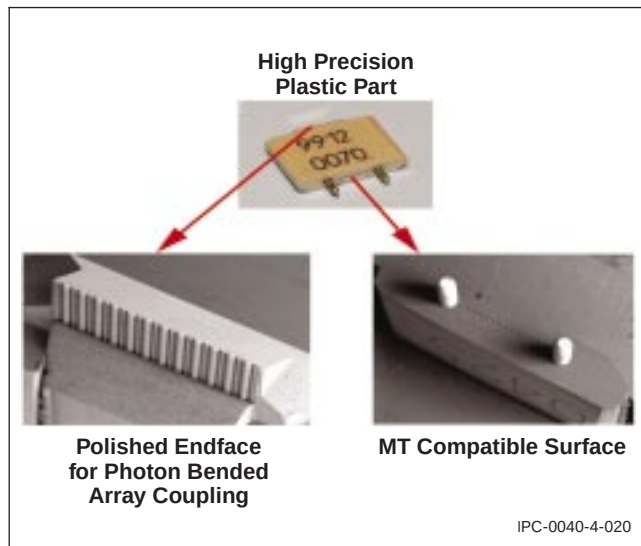


Figure 4-20 Examples of Plastic Encapsulation

of the signal gets reflected at the connector interface. In most cases, the length of 1 meter is sufficient to eliminate most of the signal reflections. This length of fiber is also needed to manage the fiber cable on the board where the packaged component is mounted.

Figure 4-21 shows an example of an optical component in the package with a single fiber pigtail prior to the lid sealing.

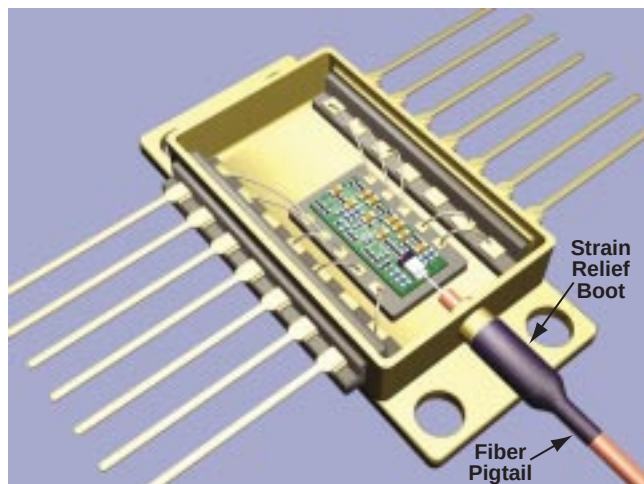


Figure 4-21 Single Fiber Pigtail

4.1.12.2 Connector Interface Clearly, a component with a fiber pigtail cannot be used in the same way as all the other SMT components. This increases the system cost and serves as an incentive to use the connector interface instead of the fiber pigtail wherever possible.

An optical component with a connector interface does not require a fiber outside of the component package. Instead, the optical connector is built into the package wall. The optical train may have a lens that focuses the light at a point where the mating connector is located. Alternatively,

a connector ferrule with a short length of fiber may be mounted into the package wall.

4.1.13 Package Interconnect There are quite a few different Interconnect packages for Optoelectronics modules in the industry. Mainly they can be subdivided in 2 different families: The transmitter or receiver modules and the transceiver modules (Transmitter and Receiver in the same module).

Several optoelectronic component suppliers have entered into multisource agreements (MSAs) in an attempt to provide assurance that customers are able to purchase parts from several suppliers. Although not quite the same as a specification or standard that can be referenced in a purchase order, the MSA concepts provide a certain degree of procurement flexibility provided the proper safeguards are in effect, such as dimensional tolerancing, performance, finish, etc.

4.1.13.1 Transmitter and Receiver Modules Transmitter and/or receiver modules are provided as independent functioning modules. Their design functions are dedicated to one or the other functions and provide additional performance of either receiving or transmitting capability.

4.1.13.2 Transceiver Modules The transceiver modules include both the transmitter and the receiver in the same package. The electronic interconnection between the PCB board and the optoelectronic device is subdivided in five different families called pin-out family or footprint family.

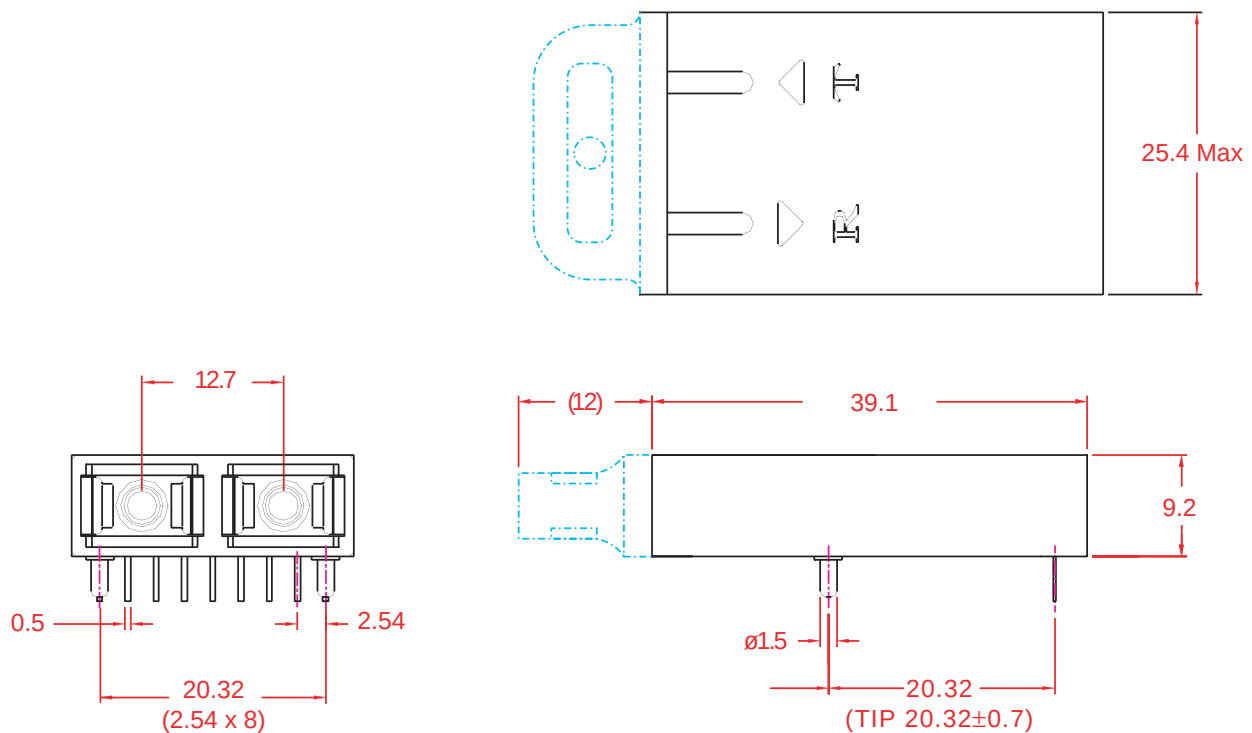
4.1.13.3 1x9 Footprint The 1x9 footprint transceivers have a 9 pin through-hole electrical connection to the host board. These 1x9 transceivers are basically duplex-SC transceivers (it can also use FC, ST or any other standard optical connector). They operate with a single +5V or +3.3V power supply. They can be AC or DC coupled (see Figure 4-22).

4.1.13.4 2x9 Footprint The 2x9 footprint transceivers have 2 rows of 9 pin through hole electrical connections to the host board. These 2x9 transceivers are basically duplex-SC transceivers (they can also use FC, ST or any other standard optical connector). Each 2x9 footprint transceiver consists of a transmitter optical subassembly, a receiver optical subassembly and an electrical subassembly. All are housed within a plastic/metal package. They operate with a single +5V or +3.3V power supply. They can be AC or DC coupled (see Figure 4-23).

Compared to the 1x9 footprint, the 2x9 has additional features such as Clock and Data Recovery.

4.1.13.5 GBIC Transceiver The Gigabit Interface Converter (GBIC) is a Hot Pluggable SC Duplex transceiver. GBIC conforms to the Gigabit Interface Converter (GBIC) standard.

Pin	Function	1x9 Pin Out Description
1	VEER	Receiver Signal Ground
2	RD+	Receiver Data Out
3	RD-	Receiver Data Out Bar
4	SD	Signal Detect
5	VCCR	Receiver Power Supply Filter Circuit
6	VCCT	Transmitter Power Supply Filter
7	TD-	Transmitter Data In Bar
8	TD+	Transmitter Data In
9	VEET	Transmitter Signal Ground



Mounting Studs: The mounting studs are provided for mechanical attachment to the host board.

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Figure 4-22 Typical 1x9 SC Duplex Transceiver Footprint

specification and usually meets the height requirement of 9.8 mm (see Figure 4-24).

They operate with a single 5V or +3.3V power supply and are AC coupled to the host board. Each GBIC transceiver consists of a transmitter optical subassembly, a receiver optical subassembly and an electrical subassembly. All are housed within a plastic/metal package.

GBIC transceivers use a card edge style electrical connection (20-pin SCA Electrical Connector) to the host board allowing sequential plug-ins. This transceiver includes an EPROM for transceiver information access.

4.1.13.6 Small Form Factor (SFF) Small Form Factor transceivers are housed in a package style that can be the

multisource 2x5 Small Form Factor (SFF) (see Figure 4-25) or the multisource 2x10 SFF (see Figure 4-26).

The 2x5 SFF has 2 rows of 5 pins whereas the 2x10 SFF has 2 rows of 10 pins.

SFF transceivers have an LC Duplex or an MTRJ optical interface.

This SFF transceiver is about half the size of a duplex SC 1x9 transceiver. Thus it allows a higher port density for a given product.

They operate with a single 5V or +3.3V power supply and are AC or DC coupled to the host board. Each SFF transceiver consists of a transmitter optical subassembly and a receiver optical subassembly.

Pin	Function	2X9 Pin Out Description
1	N/C	Not Connected
2	N/C	Not Connected
3	Clock -	Received Recovered Clock Out Bar CLK-
4	Clock +	Received Recovered Clock Out CLK+
5	BM- (Bias Monitor -)	Laser Bias Monitor Bar LMON-
6	BM+ (Bias Monitor +)	Laser Bias Monitor LMON+
7	Tx Disable	Transmitter Disable Txdis
8	FM+ (Facet Monitor+)	Power Monitor PMON+
9	FM- (Facet Monitor-)	Power Monitor PMON+
10	Tx Ground	Transmitter Signal Ground VEET
11	Tx Data In +	Transmitter Data In TD+
12	Tx Data In -	Transmitter Data In Bar TD-
13	Tx Vcc	Transmitter Power Supply
14	Rx Vcc	Receiver Power Supply
15	Flag (Signal Detect)	Signal Detection Flag
16	Rx Data Out-	Receiver Data Out RD-
17	Rx Data Out+	Receiver Data Out RD+
18	Rx Ground	Receiver Ground

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Figure 4-23 Typical 2x9 SC Duplex Transceiver Footprint

receiver optical subassembly and an electrical subassembly. All are housed within a plastic/metal package. The transceiver should meet the height requirement of 9.8 mm.

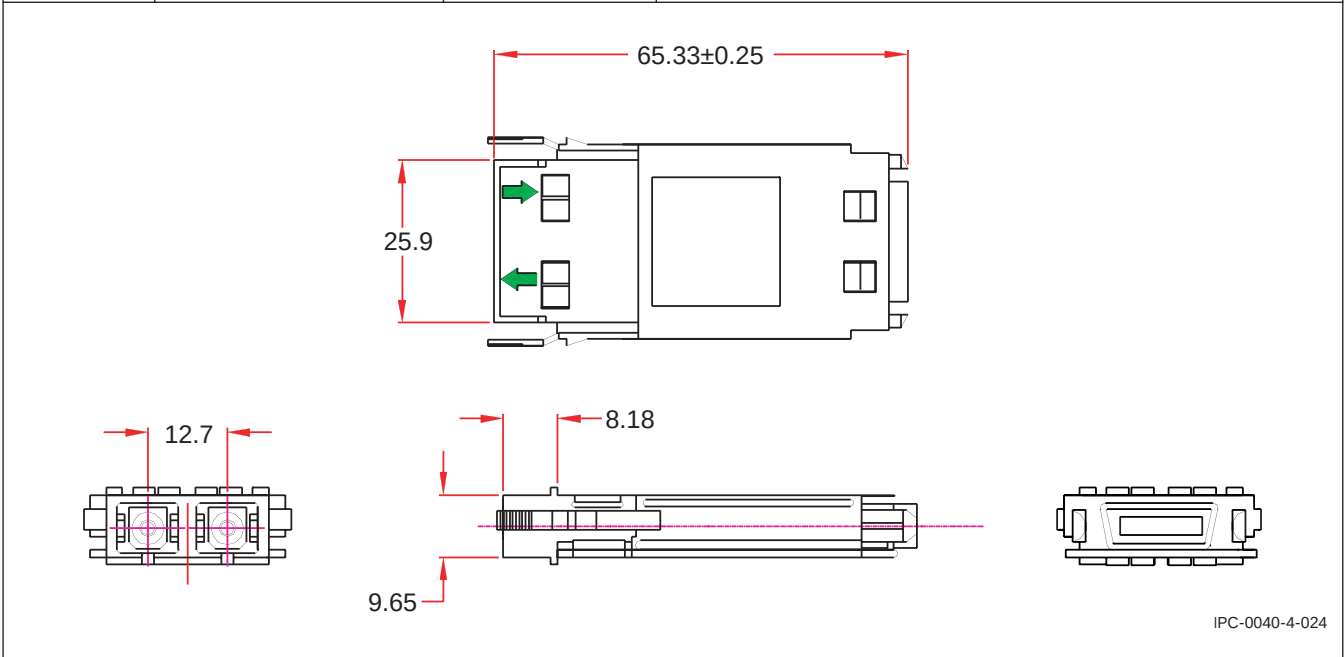
4.1.13.7 Small Form Factor Pluggable (SFP) The pluggable small form factor transceiver is a “Hot Pluggable” transceiver. They operate with a single +3.3V power supply. Each SFP transceiver consists of a transmitter optical subassembly, a receiver optical subassembly and an electrical subassembly. All are housed within a plastic/metal package. The package style is the multisource SFP with an integrated LC or MTRJ optical interface. This SFP trans-

ceiver is about half the size of a duplex SC 1x9 transceiver (see Figure 4-27). Thus it allows a higher port density for a given product.

The SFP transceivers use a card edge style electrical connection to the host board allowing sequential plug-ins. This transceiver includes an EPROM for transceiver information access.

4.2 Level 1 Components The characteristics of level 1 components vary starting with a relatively simple component assembly (level 1A) to a very complex assembly of optical and electronic parts (level 1C). Design of level 1 components

Pin	Function	Sequence	GBIC Card Edge Pin Out Description:
1	RX-LOS	2	Receiver Loss of Signal LOS
2	VeeR	2	Receiver Signal Ground VEER
3	VeeR	2	Receiver Signal Ground VEER
4	MOD_DEF(0)	2	Module Definition and Presence MOD DEF(0)
5	MOD_DEF(1)	2	Module Definition and Presence MOD DEF(1)
6	MOD_DEF(2)	2	Module Definition and Presence MOD DEF(2)
7	Tx-DIS	2	Transmitter Disable Txdis
8	VeeT	2	Transmitter Signal Ground VEET
9	VeeT	2	Transmitter Signal Ground VEER
10	Tx-FAULT	2	Transmitter Fault Tx Fault
11	VeeR	1	Receiver Signal Ground VEER
12	RD-	1	Receiver Data Inverted RD-
13	RD+	1	Receiver Data Non-Inverted RD+
14	VeeR	1	Receiver Signal Ground VEER
15	VccR	2	Receiver Power Supply Filter VCCT
16	VeeT	2	Transmitter Power Supply Filter VCCT
17	VccT	1	Transmitter Signal Ground VEET
18	TD+	1	Transmitter Data Non-Inverted Input TD+
19	TD-	1	Transmitter Data Inverted Input TD-
20	VeeT	1	Transmitter Signal Ground VEET



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Figure 4-24 Typical GBIC Transceiver Footprint

products have the same issues except that level 1C components are usually more complex and perform more functions.

4.2.1 Component Housings Optical component housing provides a number of functions:

- Mechanical and environmental protection.
- Heat transfer from the component to the outside of component housing.

- Optical train stability.
- Electrical feedthrough.
- Optical feedthrough.

Typical housings (shown in Figure 4-28) are constructed of aluminum, die cast alloys or plastics. Fiber and packaged components can be mounted within the housings using fasteners, welds or adhesives. Optical fiber is joined to the housing using external strain relief or connectors. Housings

Pin	Symbols	Function	SFF 2x5 Pin Out Description
1	VEER	Receiver Signal Ground	Receiver Signal Ground VEER
2	VCCR	Receiver Power Supply	Receiver Power Supply VCCR
3	SD	Signal Detect	Signal Detect SD
4	RD-	Receiver Data Inverted Differential Output	Receiver Data Out Bar RD
5	RD+	Receiver Data Non-Inverted Differential Output	Receiver Data Out RD
6	VCCR	Transmitter Power Supply	Transmitter Power Supply Filter VCCT
7	VEER	Transmitter Signal Ground	Transmitter Signal Ground VEET
8	Txdis	Transmitter Disable	Transmitter Disable TXdis
9	TD+	Transmitter Data Non-Inverted Differential Input	Transmitter Data In TD
10	TC-	Transmitter Data Inverted Differential Input	Transmitter Data In Bar TD

The diagram shows a top view of the SFF 2x5 Transceiver Footprint. It is a rectangular component with 10 pins along one edge. The pins are numbered 1 through 10. Pin 1 is labeled VEER, Pin 2 is VCCR, Pin 3 is SD, Pin 4 is RD-, Pin 5 is RD+, Pin 6 is VCCR, Pin 7 is VEER, Pin 8 is Txdis, Pin 9 is TD+, and Pin 10 is TC-. The component has a central area with two circular features labeled RX and TX. The text 'TOP VIEW' is written vertically on the right side of the component.

Mounting Studs: The mounting studs are provided for mechanical attachment to the circuit board.

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Figure 4-25 Typical SFF 2x5 Transceiver Footprint

provide environmental immunity and methods for supporting components in their final applications. Free-space optical assemblies may require thermal expansion matched ceramic, metal or composite materials to prevent unwanted motion of internal elements. Kovar, a nickel and cobalt rich iron alloy, is often used because of the excellent thermal expansion match to optical fiber. Copper-Tungsten compositions are often used to provide comparable thermal expansion but higher thermal conductivity than can be achieved with Kovar housings. Device carriers, fiber components, waveguides, filters, lenses, mirrors, prisms and other components can be secured to metal or metallized ceramic housings. Heat is often transferred directly to the housing, requiring mechanically flat and stable surfaces. The housing base often mates to thermally dissipative elements and carries threaded connections for stable bolt-down attachments. Housings must not significantly deform when bolted into final enclosures.

4.2.2 Mechanical and Environmental Protection The application or environment for which a component is intended, often dictates the type of housing construction needed to provide the necessary mechanical and environmental protection.

In some instances, components use hermetically sealed housings. These typically consist of a base, seal ring, electrical feedthrough and fiber feedthrough. All of these parts

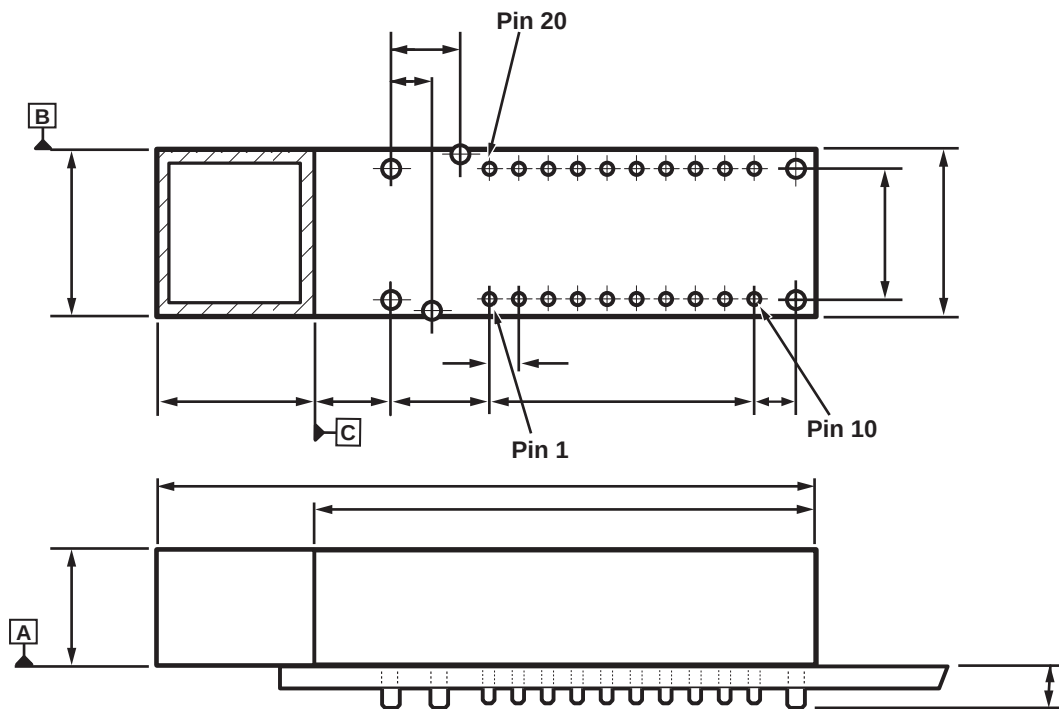
must have matching CTE in order to maintain a reliable hermetic seal through the full operating temperature range.

4.2.3 Heat Transfer from the Component to the Outside of Component Housing For components that dissipate a large amount of heat and/or require a stable operating temperature, the housings often contain thermo-electric coolers. In such cases the housing base is made of copper-tungsten composites.

4.2.4 Optical Train Stability The individual optical paths comprising the optical train must remain physically immobile or signal loss will result. As a result, for some components that generate a significant amount of heat or operate in an elevated temperature environment, the method chosen for attachment must be carefully considered. Position shifts on the order of 1 μ m during cycling may not be allowed.

4.2.5 Electrical Feedthrough Component Housing To achieve true package hermeticity, the electrical feedthrough dielectrics may only be made of non-organic materials - glass or ceramic. Figure 4-29 shows an example with glass sealed pins emanating from 2 sides of the package. Because of this, the seal ring and fiber pipe are typically made from Kovar. The base is also Kovar, except for components that require low thermal resistance, in which case copper-tungsten composites are used. Sometimes the housing is made from a multilayer ceramic.

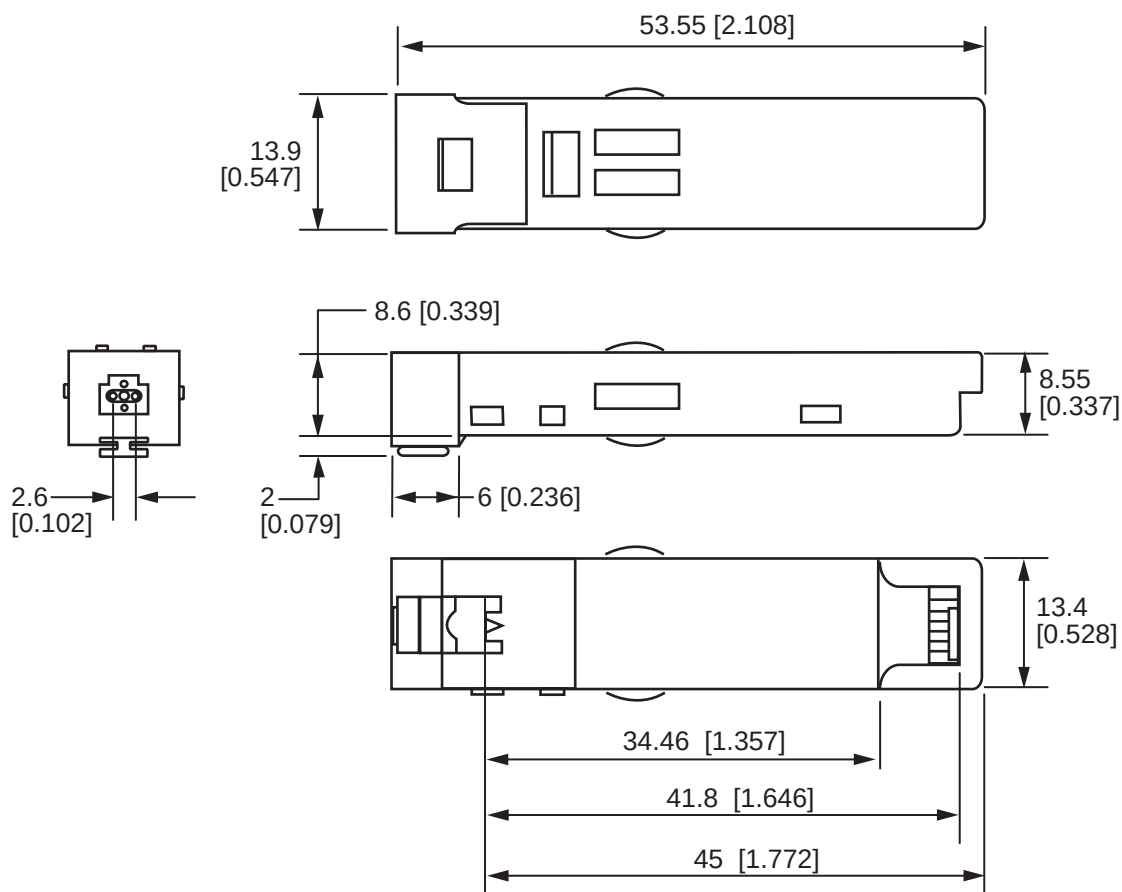
Pin	Symbols	Function	SFF 2x10 Pin Out Description
1		Photodetector Bias	Photodetector Bias
2	VEER	Receiver Signal Ground	Receiver Signal Ground (VEER)
3	VEER	Receiver Signal Ground	Receiver Signal Ground (VEER)
4	Clk-	Receiver Recover Clock Out Bar	Receiver Recover Clock Out Bar (Clk-)
5	Clk+	Receiver Signal Clock Out	Receiver Recover Clock Out (Clk+)
6	VEER	Receiver Signal Ground	Receiver Signal Ground (VEER)
7	VCCR	Receiver Power Supply	Receiver Power Supply (VCCR)
8	SD	Signal Detect	Signal Detect (SD)
9	RD-	Receiver Data Inverted Differential Output	Receiver Data Inverted Differential Output (RD-)
10	RD+	Receiver Data Non-Inverted Differential Output	Receiver Data Non-Inverted Differential Output (RD+)
11	VCCT	Transmitter Power Supply	Transmitter Power Supply (VCCT)
12	VEET	Transmitter Signal Ground	Transmitter Signal Ground (VEET)
13	Tdis	Transmitter Disable	Transmitter Disable (Tdis)
14	TD+	Transmitter Data Non-Inverted Differential Input	Transmitter Data Non-Inverted Differential Input (TD+)
15	TC-	Transmitter Signal Ground	Transmitter Data Inverted Differential Input (TD-)
16	VEET	Laser Data Bias Current Monitor Inverted Differential Input	Transmitter Signal Ground (VEET)
17	Bmon-	Laser Diode Bias Current Monitor Inverted Differential Input	Laser Diode Bias Current Monitor Inverted Differential Input (Bmon-)
18	Bmon+	Laser Diode Bias Current Monitor Non-Inverted Differential Input	Laser Diode Bias Current Monitor Non-Inverted Differential Input (Bmon+)
19	Pmon-	Laser Diode Optical Power Monitor Inverted Differential Input	Laser Diode Optical Power Monitor Inverted Differential Input (Pmon-)
20	Pmon+	Laser Diode Optical Power Monitor Non-Inverted Differential Input	Laser Diode Optical Power Monitor Non-Inverted Differential Input (Pmon+)



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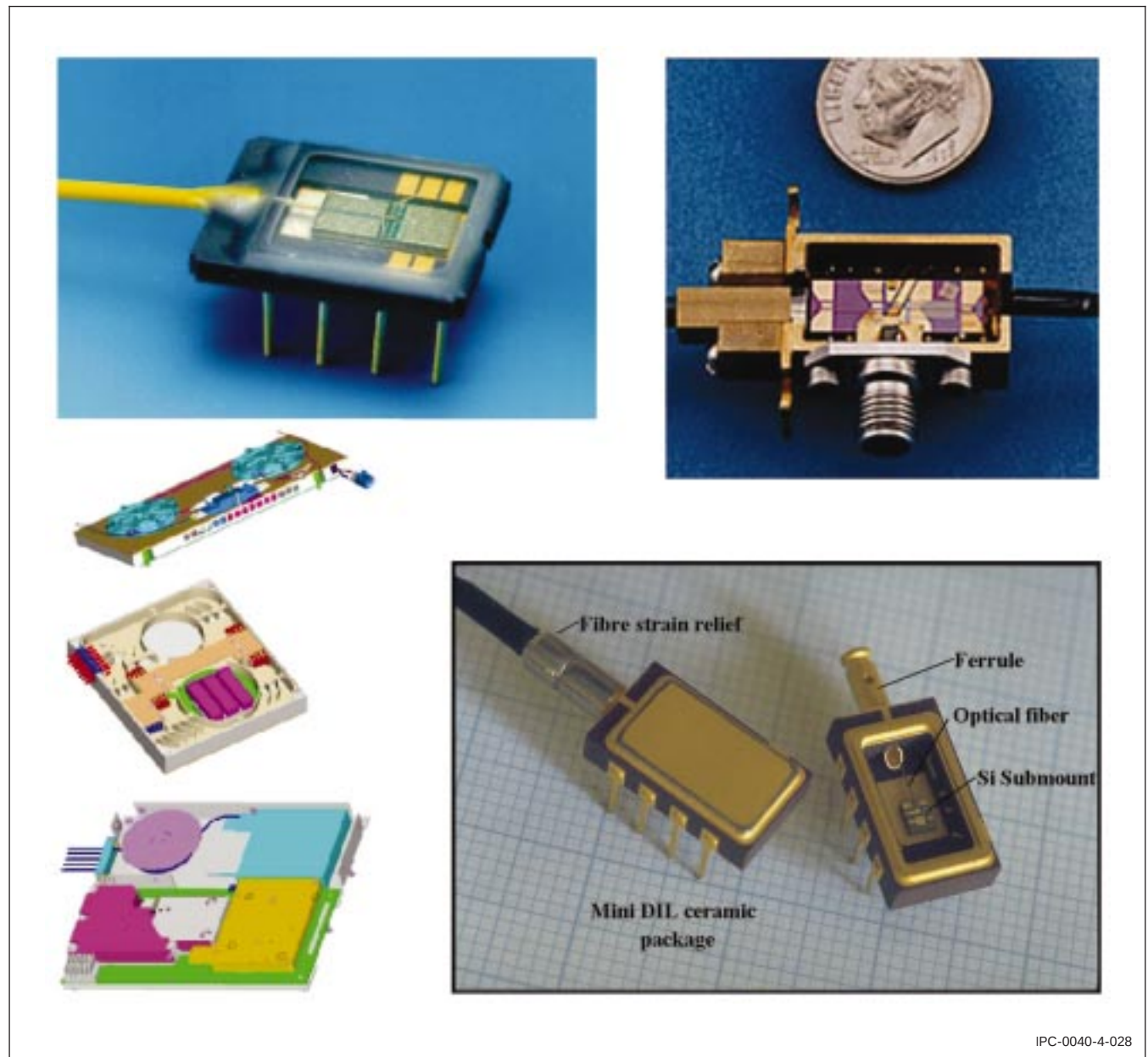
Figure 4-26 Typical SFF 2x10 Transceiver Footprint

Pin	Function	Sequence	Function
1	VEET	1	Transmitter Signal Ground VEET
2	Tx Fault	3	Transmitter Fault Tx Fault
3	Tx Disable	3	Transmitter Disable Txdis
4	MOD DEF (2)	3	Module Definition and Presence MOD DEF(2): SDA (Serial Data Signal)
5	MOD_DEF (1)	3	Module Definition and Presence MOD DEF(1): SCL (Serial Clock Signal)
6	MOD_DEF (0)	3	Module Definition and Presence MOD DEF(0): Transmitter Signal Ground
7	Rate Select	3	Rate Select
8	LOS	3	Receiver Loss of Signal LOS
9	VEER	1	Receiver Signal Ground VeeR
10	VEER	1	Receiver Signal Ground VEER
11	VEER	1	Receiver Signal Ground VEER
12	RD-	3	Receiver Data Inverted RD-
13	RD+	3	Receiver Data Non-Inverted RD+
14	VEER	1	Receiver Signal Ground VeeR
15	VCCR	2	Receiver power supply filter VCCT
16	VCCT	2	Transmitter power supply filter VCCT
17	VEET	1	Transmitter Signal Ground VEET
18	TD+	3	Transmitter Data Non-Inverted Input TD+
19	TD-	3	Transmitter Data Inverted Input TD-
20	VEET	1	Transmitter Signal Ground VEET



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Figure 4-27 Typical SFP Transceiver



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Figure 4-28 Housings - Application Specific

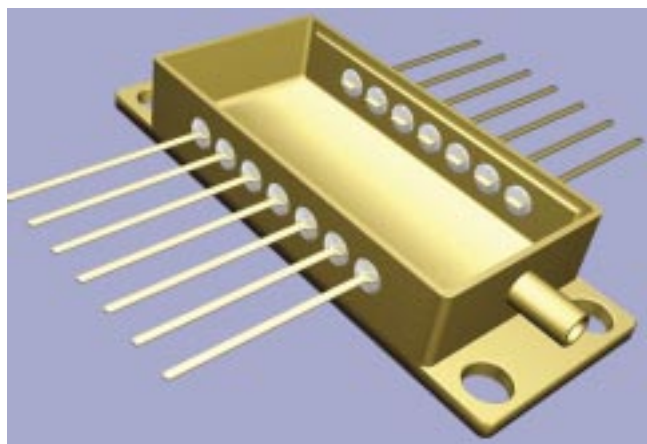


Figure 4-29 Glass Seal Pins

Depending on the electrical signal speed, the electrical feedthrough can be structured as:

- Glass-Seal Pins
- Single-Layer Ceramic
- Multilayer Ceramic
- Coaxial Connector

4.2.5.1 Glass-Seal Pins The glass-seal pins shown in Figure 4-29 are made by sealing the electrical pins in a glass dielectric within the holes drilled in the package seal-ring. The pins protrude into the housing, and the electrical connections are completed by wirebonding from the optical device to the tips of the package pins. This is the lowest cost feedthrough, but it is not suitable for electrical signals over 500-800 MHz.

4.2.5.2 Single Layer Ceramic The single layer ceramic feedthrough has the electrical pins brazed in a ceramic substrate. Just like in the glass-seal feedthrough, the pins protrude into the housing. Because of the superior electrical properties of the ceramic, this type of feedthrough can be used for up to 2 GHz electrical signals. Figure 4-30 shows a housing with a single layer ceramic feedthrough.

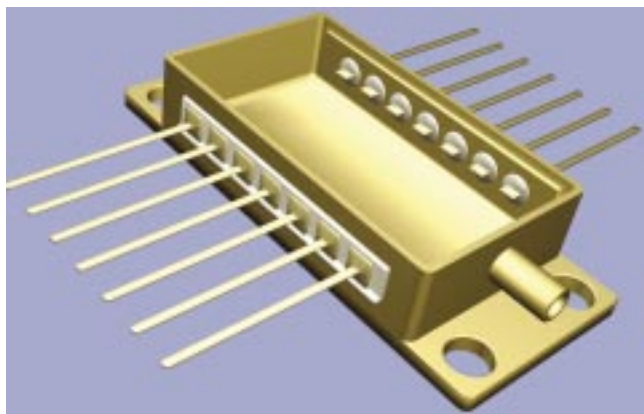


Figure 4-30 Single Layer Ceramic Feedthrough

4.2.5.3 Multilayer Ceramic In the multilayer ceramic feedthrough, the electrical connection from the outside to the inside of the housing is created by metallized tracks that are sandwiched between layers of ceramic. The electrical pins are brazed to the external pads on the ceramic, and the electrical connection to the optical device is made by wirebonding to the internal pads on the ceramic (see Figure 4-31). When using this approach, the metallization tracks can be designed to provide a true controlled impedance transition. This type of feedthrough can be used in a differential signal configuration to obtain satisfactory performance up to 10 GB/sec. Figure 4-32 shows such a transition.

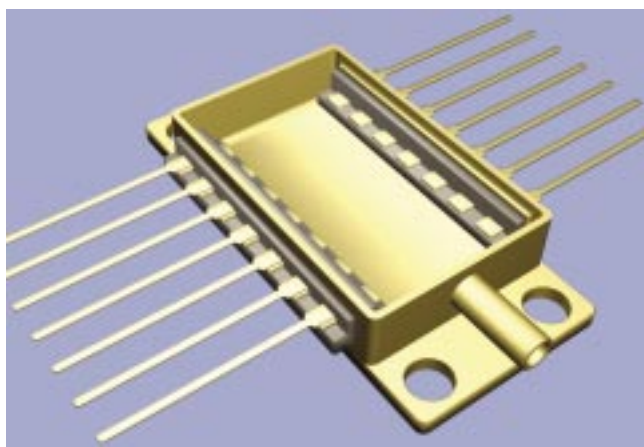


Figure 4-31 Wire Bondable Pads

In all previous configurations, the electrical leads are designed for through-hole or SMT attachment to the circuit board. However, current PCB materials and structures cannot support signals at data rates higher than 3-5 GB/sec.

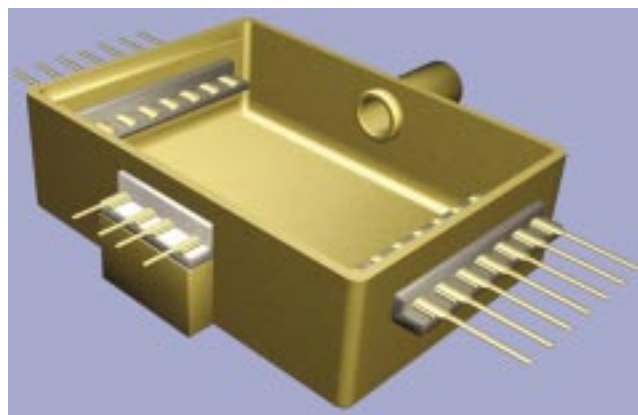


Figure 4-32 Differential Signal Configuration

Therefore, for high data rates the electrical interconnect is made by means of coaxial cables. For such cases, the component housings can incorporate coaxial connectors. (see Figure 4-33) “V” and “K” type connectors are used, and the signal pin of the connector is soldered into the housing.

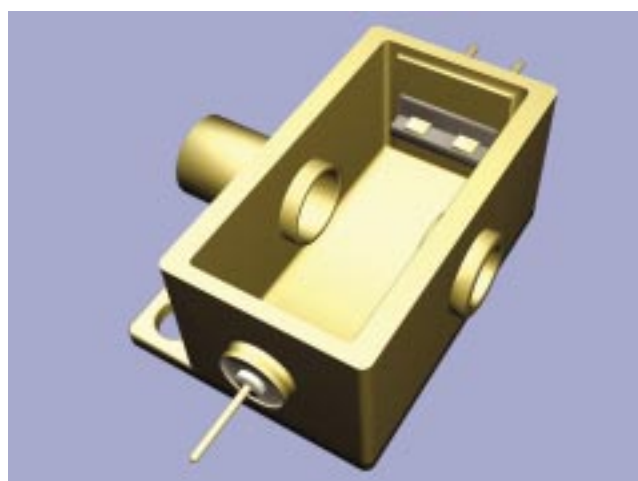


Figure 4-33 Coax Connector

4.2.5.4 Optical Feedthrough Where the optical train consists of direct fiber coupling to the optical device, the optical feedthrough for single fibers consists of a Kovar pipe that is hermetically brazed to the component housing (see Figures 4-29 through 4-33). The fiber is metallized and then soldered directly into the fiber pipe. The fiber jacket is attached by adhesive to the fiber pipe in order to provide mechanical integrity to the fiber feedthrough. Because of this the hermetic seal to the metallized fiber has to cover a large clearance between the fiber and fiber pipe, and this requires a large volume of solder. Sometimes the metallized fiber is soldered into a metal sleeve, and then this sleeve is soldered into the fiber pipe. This decreases the volume of solder used, but in this approach two soldering operations are required, and the solder hierarchy becomes more complex (two solders with different melting points are required).