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# Optical Packaging and Interconnection – A New Wave?

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**Abstract**
The market for optical communication equipment and components has grown significantly since the early 1980s with growth rates exceeding 50% annually in the late 1990s. Although demand has dropped significantly since 2000, the underlying drivers for demand are still operating.

This paper discusses the drivers for optoelectronic devices and optical PWBs, the major differences between IC packaging and optoelectronic device packaging, the emerging evolution of optical printed circuit board, and some of the opportunities for assembly and materials suppliers in these areas.

## Introduction

Optical cable was initially developed in the 1960s, however it was the refinement of fibre optic cable by Corning Fiber in the late 1970s that allowed the transmission of light over longer distances, enabling long distance optical communications. It was this that sparked the beginning of a new industry, requiring both the development of new electronic devices and packaging techniques and bringing changes to interconnection, including now the emergence of optical printed circuit boards.

The market for optical components has grown rapidly since, with market demand growth rates exceeding 40-50% per year in the late 1990s. During 2000, more than $7 billion was spent on components for the DWDM, SONET/SDH and CATV markets and as a result, there was almost a “gold-rush” mentality within the photonics component market. Many new companies have entered the market, especially within the last 2-3 years. This was aided by the ready availability of capital – more than $2 billion was invested in optoelectronic/photonic companies during 1999/2000.

The downturn in the market since mid 2000 has been severe, with many companies seeing drops in their share values of up to 95%. Many have needed to significantly change their operations, with billions of dollars in material and components inventories being written off. Multi-billion dollar losses have been recorded by companies, such as the $50 Billion+ plus loss recorded by JDS Uniphase. However these dramatic changes do not mean that the underlying drivers for photonic components have gone away.

## Drivers for Photonic Packaging

The key driving forces for photonic packaging are:

- Bandwidth Demand
- Technology
- Markets
- Application
- Cost

## Bandwidth Demand

Over the last 20 years there has been a continuous increase in the demand for the transmission for data. Estimates from DARPA (Defence Advanced Research Projects Agency) in the US give data transmission growth rates in the US of 20%-30% per year in the 1980s, increasing to 30%-40% per year in the early 1990s. Initially this was due to the development of private, mainly corporate networks, followed by the widespread use of email and the Internet from the mid 1990s.

Growth rates have increased significantly in the last two years. The US growth rate is currently around 400% per year (see Figure 1). Worldwide the current annual growth rate is estimated to be around 250%, but it is increasing as other areas catch up to US levels.

In comparison, voice traffic across fixed line networks is increasing at 5%-9% annually, with voice cellular traffic increasing at 30%-40% per year. The introduction of 2.5G and 3G cellular technology, with their ability to increase the data transmitted to handsets is expected to further increase the rate of growth of data traffic.

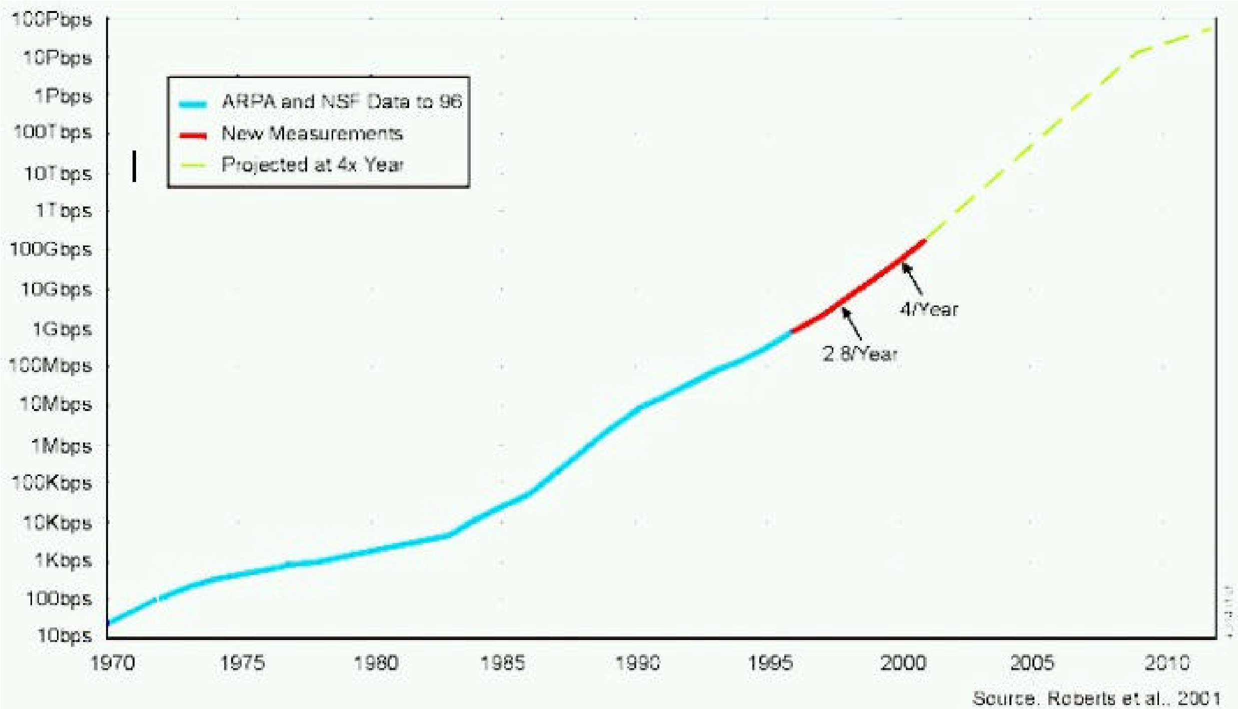


**Figure 1 – Internet Traffic Management**

**Technology**

The technologies used for optical communication also affect the packaging used for components and the number of components required. Examples are the transmission speeds used, the use of techniques such as DWDM (Dense Wavelength Division Multiplexing), and emergence of all-optical switching.

Transmission speeds for long-haul networks have been increasing rapidly since the 1980's, with OC-3 speeds of 155Mb/s becoming quickly replaced by OC-12 (622Mb/s), OC-48 (2.5Gb/s) and the now commonplace 10Gb/s network speeds. 40Gb/s components are now beginning to be available from suppliers, and field trials started in late 2000 by network carriers such as Deutsche Telekom. Research work is underway in a number of groups to understand the requirements for OC-3072 (160Gb/s) networks. However BPA expects that it will at least 3 years before OC-768 (40Gb/s) infrastructures will begin to be deployed.

DWDM is a method of increasing the bandwidth of an individual fibre optic cable. It works by combining (multiplexing) a number of data signals at slightly different wavelengths through a fibre. In this way a single fibre is turned into a number of "virtual" fibres, with each "virtual" fibre carrying a data stream at a different frequency. At the receiver end of the fibre, a demultiplexer is used to split out each of the individual data streams.

The use of this technology can result in an enormous amount of bandwidth being available on a single fibre. An individual fibre cable using 40Gbps DWDM technology with 160 channels would provide 6.4Terabits of bandwidth.

The use of DWDM technology drives the use of more transmitters and receivers per installed fibre, as well as requiring the use of additional multiplex/ demultiplexer components.

The move to more advanced DWDM architectures is also driving the requirement for very high speed, reliable and cost-effective switching technologies. Currently 95%+ of switching is completed by an optical-electrical-optical switch where the data signal passes through an electrical stage. All optical switching would eliminate the need for this electrical conversion stage. Additional benefits would include the ability to scale systems more easily as the switching system would be independent of the transmission speed, reduce the impact of EMC, and potentially shrink the size of the switching equipment.

Significant investments have been made in the technology, and it is also proving a driver for future component packaging design, particularly in the area of MEMs packaging, and for the use of tuneable lasers.

However there are still some issues to be solved, such the increasing the speed of the optical switch devices to match current electrical switches. It will be several years before all the key components have reached a stage where they can be used commercially. BPA expects that all optical networks will be in use by 2007/8.

**Markets**

The markets for optoelectronic components can be classified into three main groups, long-haul, metro, and last mile/residential/enterprise.

The long haul/submarine market covers the links required to provide the backbone infrastructure to networks, and which are used as high speed, high volume conduits. They run at the highest transmission speeds, typically at 2.5Gbps or 10Gbps. This is currently the largest market for high-end, high-cost optoelectronic components.

Long-haul networks have stringent reliability requirements (defined by Telcordia standards) and so require hermetically sealed packaging to enable the use of components within a wide range of environmental tolerances.

The metropolitan or "metro" market defines the networks that are deployed in city/urban areas. Up to 200km in length, these networks interconnect users and smaller networks within the same geographical area and act as the bridge between access/"last mile" networks and the long-haul networks.

In the metro market bandwidth and reliability are drivers, but package size, power consumption and heat dissipation are also important. This is because network operators usually have to rent the space they require for their equipment and in city locations this can be expensive.

The "last mile"/residential/enterprise market cover the very short distance links, from individual circuit boards to the local metro networks. Although FTTx (fibre to the X, where X = home, office, curb, etc.) projects have begun in some countries, for example the ONE (One Network for Everyone) network project in Singapore, they are still at early stages in most countries. Cost is the key driver in this market, as components need to be inexpensive to make equipment commercially viable. It is potentially the largest market long term, but will not be a volume market for at least five years.

**Application**

The application an optoelectronic component needs to perform also has an effect on the packaging required for it. The three types of component used in optical communications can classified into:

- Active, e.g., lasers, photo detectors, modulators.
- Passive, e.g., multiplexers/demultiplers, filters
- Modules, e.g., transceivers, transponders, amplifiers, and switches.

**Cost**

Cost is now the most significant factor for components in all market sectors. During 1999 and 2000, optoelectronic component supply constraints meant that prices were kept high. The key drivers for sales (apart from availability) were innovation, size, power consumption, etc.

However the downturn in the market has meant that components have dropped in price significantly since Q3 2000, with filter prices dropping particularly fast. AWG (array waveguide grating) filters have halved in price per port since Q3 2000 to $200-$400 per port.

**Differences between IC Packaging and Optoelectronic Packaging**

The optoelectronic component industry is often described as being 10-20 years behind other more mature and established industries such as semiconductor packaging and SMT assembly. Although there are some similarities between IC packaging and optoelectronic component packaging, there are a number of significant differences between them, with the features of the optoelectronic component market including:

- A much wider range of custom/non-standard packages
- Much greater alignment and dimensional accuracy required
- Inclusion of an optical fibre in the package construction
- Often low volume/high product mix
- Widespread use of manual assembly/limited automation
- A wide range of materials used
- A lack of standardisation in both package types and assembly equipment
- The need for optical as well as electrical testing

**Optical Printed Circuit Boards**

High-speed data transmission is also important over shorter distances, and the ability to send signals further over an optical interconnect is one of the major driving forces for the use of optical backplanes. Transmission speeds are now beginning to reach a level where the transmission of data within a rack and between boards is becoming difficult using electrical wiring technology (see Figure 2). BPA has identified that the breakpoint range for the use of optical interconnection at the backplane level occurs where the transmission speeds are between 3-5 Gb/s.

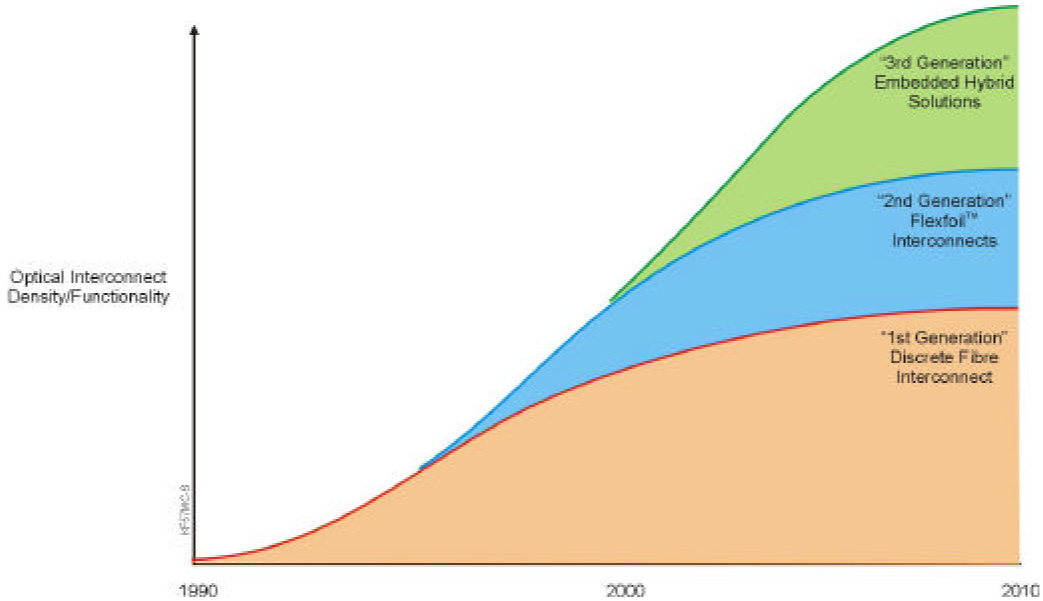


**Figure 2 – The Three Generations of Optical Backplane Technology**

Some of the major applications requiring optical printed circuit boards include:

- Telecom switches
- Telecom transmission equipment
- High-end datacom switches and servers
- Aerospace and avionic communications
- UMTS mobile telephone base stations
- High-end enterprise computer servers
- Mainframe/supercomputers

**Optical Backplane Technology**

BPA's research has identified that there are three product/technology generations relating to optical backplane technology as shown in the technology roadmap in figure 2.

The first generation is discrete optical fibre interconnection, which is currently the most common method of interconnection between boards within a rack. It uses discrete optical fibres and separable optical connectors to interconnect modules and components on one daughter card to another within a rack connection. Figure 3 illustrates a typical configuration using this approach.

These "First Generation" optical interconnect approaches are simple, relatively low cost and offer high performance "point to point" interconnection for critical transmission lines within a rack system.

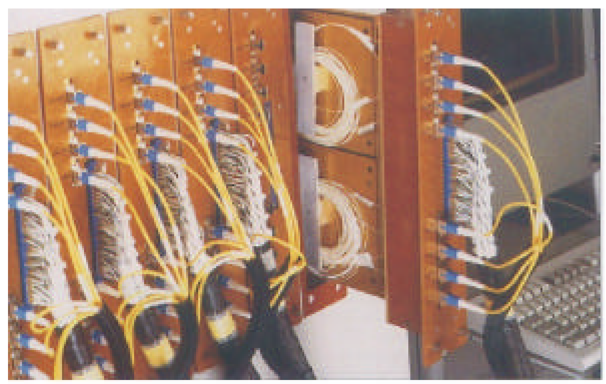

**Figure 3 – Discrete Optical Fibre Interconnect**

**Second Generation –Optical Interconnection Using Flexible Circuitry**

Advanced Interconnection Technology Incorporated of Islip, New York, USA was one of the first companies to develop "optical interconnect technology on flexible circuitry (Figure 4).

Their filament-embedding equipment technology allows continuous lengths of optical fiber to be bonded to a substrate in precise, pre-determined path locations

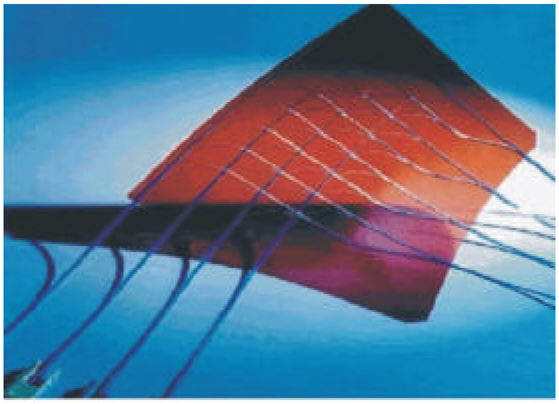

**Figure 4 – Flexible Circuitry Optical Interconnection**

**Third Generation – Embedded Optical and Electrical Interconnects**

The third generation technology, which has only recently emerged, provides optical waveguides embedded into conventional printed circuit board technology. An example is shown in Figure 5. We have identified that there are four main approaches that are in development worldwide by a variety of different companies and organisations. These include:

- Embedded polymer optical waveguides.
- Overlaid polymer optical waveguides.
- Embedded optical fibre technology.
- Embedded glass optical waveguides.

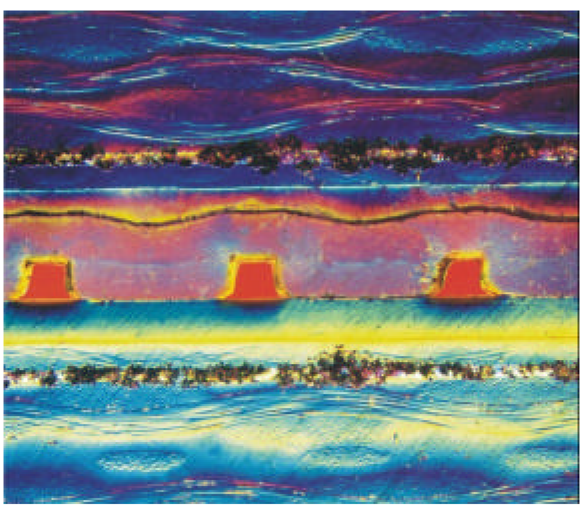

**Figure 5 Third Generation – Embedded Optical Waveguide Structure**

**Optical Backplane Technologies And Players**

Some of the major players active in each region include:

*European Players*

- C-LAB
- Daimler Chrysler Research
- Fraunhofer IZM
- PPC
- BAe Systems
- Heriot-Watt University
- EOCB Joint Development Project

*North American Players*

- Litton Interconnect Technologies
- Teradyne Connection Systems
- Tyco
- Coretec

*Asian Players*

- Fuji Xerox
- ASET
- Hitachi Chemical
- NEC.
- Asahi Glass

**Opportunities for Assembly Equipment and Material Manufacturers**

There are many opportunities for materials and assembly equipment suppliers in the areas of optoelectronic packaging and optical PWB construction and assembly.

**Photonic Packaging**

Automated package assembly and test equipment is going to be key in ensuring the reduction of the assembly cost component within optoelectronic packaging. Currently assembly and test can comprise up to 80% of the total cost of a component. There are several areas within the assembly process where automation will both reduce assembly costs and help to improve process yields. These include:

- Fibre alignment (even where passive alignment techniques are employed)
- Automated adhesive and epoxy dispense
- In-process curing
- Materials handling

Thermal management techniques and materials will continue to be important. As a result of the need to reduce both the package size and also the cost of the packaging there has been the introduction of more uncooled active laser modules. Agere Systems, Lucent, Fitel (Furakawa Electric), and others have developed uncooled source and pump laser modules. The power output is reduced in these modules. For example the uncooled Fitel laser pump laser is only rated at 80W compared to 100W for the cooled version. However this will be acceptable for Metro applications. BPA forecasts that suppliers will continue to develop packages using passive cooling where possible for metro applications. For FTTx applications all modules will be uncooled. Appropriate materials will be required.

As transmission speeds increase, the use of high speed, low induction assembly processes will be required for the driver electronics within packages. Wirebonding will continue to be used for devices up to 10Gb/s. At 40Gb/s there may be some use of ribbon bonding, but BPA forecasts that manufacturers will move to flip chip technology for the placement of semiconductor devices. This would be to reduce interconnection distances and minimise the effect of any inductive and resistive electrical effects that can occur at high operating frequencies.

**Photonic PWB and Interconnect**

There are clearly opportunities for manufacturers of PWBs in the optical PWB market. BPA's research has indicated that the demand is actually for hybrid optical boards, which contain both embedded optical and electrical interconnections.

The boards require improved physical characteristics compared to FR4 board materials. This includes high thermal stability/low shrinkage, reduced dielectric constant (ideally <3) and reduced dissipative factor (ideally <0.003).

In addition the boards require new constructions to be used. Optical via structures are necessary to allow optical signals to be passed down to the optical waveguide layers within the board. The high operating frequencies mean that techniques used in microwave products such as microvia technology and exotic laminate materials could be required. The use of these constructions will also require improvements in board processing techniques, particularly the board lamination processes.

The use of optical interconnection on PWBs will require accurate alignment of components and features on the boards. This will drive improvements in the areas of efficient coupling and PWB alignment technologies.

Materials are beginning to become available from PWB suppliers such as Isola, Gore, Matsushita, Rogers, and Taconic with improved properties. However they are currently significantly more expensive than FR4, ranging from 1.5 to 10 times the cost.

**Photonic Materials**

In the area of photonic materials there are opportunities in a number of areas.

Clearly materials for optical waveguides are key, with waveguides currently being produced from a number of different materials, including:

- Silica
- Polymers
- Glass
- SiON
- InP

Stable adhesives with good hysteresis properties are necessary. Optical system designers can cope with some degree of movement of materials during operation, but it is important that adhesives do return to the same position after a temperature excursion.

Finally there is the need for many optical components for use within the boards, including lenses, mirrors and grating technologies for alignment and coupling.

**Conclusions**

Although the drop in demand for optical networking equipment has been significant in 2001, with an average drop of 40%, the drivers for data transmission are still in effect, driving an eventual resumption of demand.

Optical backplane technology is still in an early embryonic development phase, with most of the activity in embedded hybrid solutions still at a research and development/prototyping stage. There are still many technical challenges that need to be overcome, including reducing the optical loss characteristics of the waveguide materials used, improving the manufacturing yield, and reducing costs. Key challenges include the availability of low loss, low cost waveguide materials that can withstand the temperatures used in PWB lamination processes, and the development of low cost, accurate alignment and coupling technology for the optical interconnection.

Within the areas of materials and assembly/test equipment there are currently opportunities for suppliers in both optical PWBs and optoelectronic packaging. Cost reduction is now the key driver for photonic packaging and manufacturers will consider any technically acceptable solution that contributes to this. BPA expects that there will be considerable activity in the area of materials evaluation for both optical boards and devices as packages become standardised, and more automated equipment begins to be utilised.

**Reference**

1. US Internet Traffic Growth, Lawrence Roberts, Caspian Networks, August 2001.