Market and Technology Trend of Integrated Fiberoptic Network Deployment

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Introduction

CIBC World Market [1] pointed out that one-third of all of the optical fiber market is occupied by long-haul fibers (see Fig. 1). In the mid 1990s the optical communication industry debated on the transition from OC-48 (2.5 Gb/s) to OC-192 (10 Gb/s). The biggest concern was the incremental cost of 10 Gb/s hardware compared to OC-48 systems already in service. Interestingly, OC-192 is now in service; a similar debate is ongoing for the transition to OC-768 (40 Gb/s) or even higher speed (160 Gb/s). If anything to learn from the past, we see that Nortel – being at the forefront of the first round debate pushing OC-192c – enjoyed a couple of years of market advantage over competitors like Lucent, NEC, Alcatel and Ciena. Another debate that is becoming prominent is the Photonic Integrated Circuit platform vs. present day discrete technology.

With the advent of modern smart gears, fiberoptics communication networks are expanding at a higher rate. For example, according to a new market study from ElectroniCast [2], 10 Gigabit datacom transceiver market will reach $9 billion by 2010, and the core optical transport market will grow to a net $2.5 billion by 2005 says a CIR report [3].

Other similar reports indicate that U.S. wavelength service market will reach $2 billion by 2007 [4]; optical cross-connect market will grow more than $6 billion by 2006 [5]; fiber to the home/office (FTTx) market will reach 2.9 billion by 2005 [6].

Needless to mention that, this growth is global. RHK reported that the Asia-Pacific optical transport market reached $6.2 billion in 2001 [7] and still growing, and the European transport market will grow to 14.8 billion by 2004 [8]. Table 1 summarizes growth potential in different segments of optical communications market as released by market research groups.

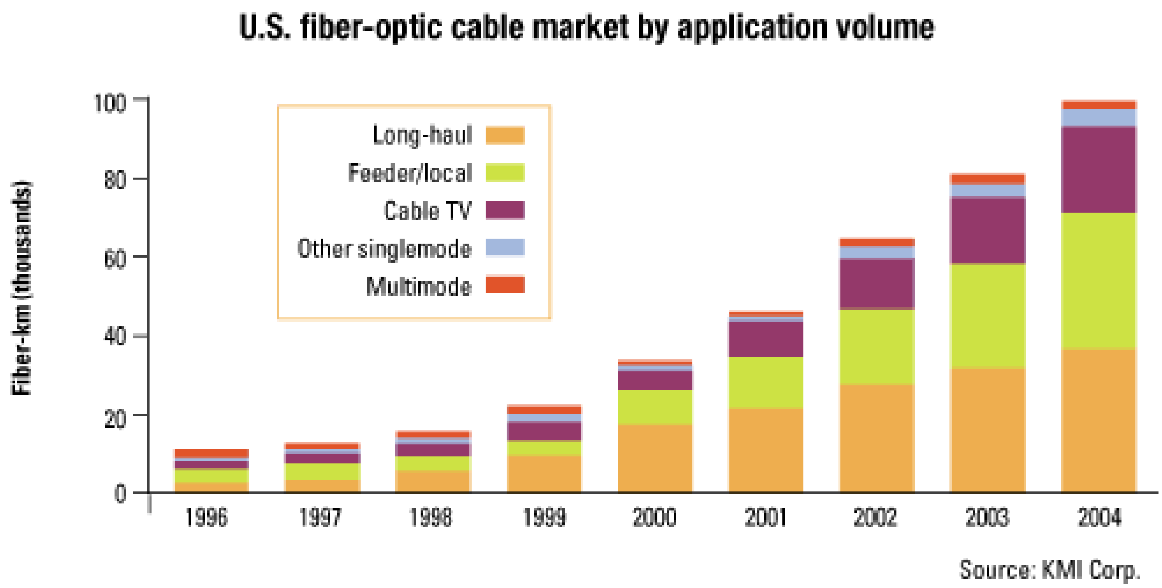

Figure 1. [from ref. 1].

Table 1. Summary from news release of Market Forecast from Different Market Research Groups.

Market Report Subject	Growth Potential	Target Year	Market Forecast Group
Fiber Optic Cable Usage	$24 billion	2000	ElectroniCast (San Mateo, CA)
Dispersion Management	One-third of long-haul fiber market	1996-2004 and onward	CIBC World Market (Denver, CO)
10 Gigabit datacom transceiver	$9 billion	2010	ElectroniCast (San Mateo, CA)
U.S. wavelength services	$2 billion	2007	Frost & Sullivan (San Antonio, TX)
Optical cross connect	$6 billion	2006	Frost & Sullivan (San Antonio, TX)
FTTx	$2.9 billion	2005	Chaffee Fiber Optics (Ellicott City, MD)
Asia-Pacific optical transport	$6.2 billion	2001	RHK Inc. (San Francisco, CA)
European transport	$14.8 billion	2004	RHK Inc. (San Francisco, CA)

Global OSS	$49.6 billion	2005	RHK Inc. (San Francisco, CA)
DWDM Long Haul Terrestrial	$6.4 billion	2006	Dell'Oro Group (Redwood City, CA)
Worldwide Optical Transport	$57.3 billion	2005	Dell'Oro Group (Redwood City, CA)

Photonic Integrated Circuit (PIC)

While there are several clever technologies exist to design and build networks and systems, the fundamental breakthrough required to meet dramatically reduced cost points is the introduction of viable photonic ICs (PICs). Although the physics of photons and electrons are different that make an exact comparison an area of moot point, the history of electronic IC's evolution does provide a positive outlook for the direction required for PICs. Paralleling the evolution of electrical circuits, the development of PICs promises to increase functionality, density and significantly reduced cost when compared to optical components assembled from discrete devices. The result will open more general systems and service applications for optical networks.

The main criteria of an integrated photonics technology must meet:

- The technology must be capable of creating a broad range of optical functions out of a single fab or process.
- The means must exist for it to be readily manufactured at low cost in high volume.
- The capability must be developed to aggregate individual optical functions into more complex arrangements within the technology and with other optical technologies.

The last criterion is a major hurdle in the present day approaches for the integrated technology. While investigation of many technologies is underway, ARP's efforts show that its proposal meets these challenges, suggesting clear first steps towards viable PICs.

Photonic Waveguides: the Building Block for PIC

Photonic waveguide is the fundamental element for photonic integrated circuits (PICs). In addition to PICs, photonic waveguides have a number of applications in sensors, spectrometry, and other devices where guided light in a narrow dimension plays a crucial role. For instance, future communication systems will exploit highly sophisticated guided wave optical networks. Future high bandwidth, high speed communication environments and the next generation of Internet will need ultracompact, lightweight, low-power, low-cost wavelength division multiplexer, demultiplexer, splitter, coupler, interleaver, optical amplifiers, modulators, and other photonic devices. Such technologies in turn require advances in design of ultracompact micro- and nano-photonic structures, with design and engineering of the electromagnetic properties of materials in the scales comparable to the wavelength of information carrying light. ARP's goal is to produce cost-effective, advanced, integrated photonics solutions for the next generation fiberoptic communication and computing by fabricating high quality, robust, photonic integrated circuits.

Photonic waveguides, the basic constituents of photonic integrated circuits (PICs), are somewhat analogous to the transistors in the electronic ICs. In the current practice, most photonic components are based on discrete technology where individual elements perform a single function; as a result they are bulky, lossy and performance limited. While recently the integrated approach is drawing significant interest, current integrated technologies also suffer from limitations of materials, processing, and performance. For instance, in glass based waveguides, refractive index variation is produced by doping glass with a suitable dopant. This doping is usually done by a diffusion controlled process. Such process is difficult, performance limited and the machineries dedicated to carry out these processes are expensive and not easily amenable for expansion. Other processes such as flame hydrolysis or chemical vapor deposition are also complicated, difficult to control, and enjoy only partial success. Thus, there is a tremendous need to find more efficient method to produce smarter, robust, and precise photonic waveguides.

The optical waveguides formed on a wafer can be designed to perform many important optical signal processing. A common application is optical multiplexing and demultiplexing on a chip that is commonly known as photonic integrated circuit (PIC) or Planar Lightwave Circuit (PLC). The most popular application of PICs is the arrayed waveguide grating (AWG). However, waveguides can be designed to perform other optical functionality such as amplification, switching, sensing, etc., thus allowing itself to be analogous to transistor that form forms the basis of electronic integrated circuit (IC). Also, using waveguides as the basic building block, a number of PICs can be constructed to carry out various photonic signal processing.

Triple-Phase Integration

The PICs are the basic building blocks for a number of modules and systems that are essential parts of fiberoptic based communication and computing. The dense wavelength division multiplexing and demultiplexing (DWDM and DWDD) are the most basic applications. In DWDM and DWDD, these chips function as the heart of the system by performing multiplexing (MUX) and demultiplexing (DMUX). In addition, used as a "building block," a number of systems and modules can be built around these chips by integrating over multiple tiers such as triple-phase integration described briefly below.

The DWDM is a first phase integration where the photonic waveguides are integrated on a substrate to perform passive functionalities. At the first phase of integration, multi-channel tunable optical add/drop multiplexer (TOADM) is another important application of these chips. Other common applications in the passive domain include multi-channel optical channel monitor, multi-channel tunable optical gain equalizer, multi-channel thermo-optic switch, multi-channel tunable optical attenuator, multi-channel sensors, etc.

At the second phase of integration, these chips can be combined with appropriate on-chip gain elements (e.g., Er^{3+} doped waveguide interconnect) to produce the above mentioned PICs with low-loss and/or with a gain. This is very important, because, optical transmission systems require frequent signal amplification and regeneration (also called repeater) that is expensive and adds complexity to system design. Ability to build systems with extremely low-loss and/or gain will simplify system design significantly. It will also eliminate the frequent need of repeaters, thus enabling significant cost savings and ease of deployment.

The third phase of integration will allow combining the low-loss PICs with active elements such as laser-diodes or VCSELS and detector arrays to produce a line of optronic modules and systems. Examples include modulators, receivers, transmitters, transceivers, transponders, switches, and fully built out DWDM systems.

Chip-scale Photonic Integrated Circuits

The objective of a chip-scale PIC is to produce a very concise device with multiple functionalities on a single substrate. Two different schemes are usually considered: (i) system-on-chip and (ii) chip-scale packaging; both of these schemes actually complement each other. Using the triple-phase integration as described above, a PIC such as a RAWG can be further integrated over several phases to produce denser functionality on the same substrate. For instance, a RAWG can be attached with amplifying waveguide elements to reduce the loss. Further, lasers and modulators can be added to the RAWGs to produce multi-channel transmitters. One can then add detectors to add more functionality enabling transceivers, transponders, and switching on a chip as well.

PIC manufacturing

Integrated photonic devices typically consist of nano-scale structures, with individual feature sizes controlled to dimensions ranging from few microns to few tens of nanometers. These devices are manufactured on a wafer scale in a semiconductor-like manufacturing process that results in optical chips in sizes from 1x1 mm to tens of millimeters. The first step in realizing a PIC device is to design the structure that yields the desired optical properties. That can be done through a combination of simulation and prototyping. Once a design is finalized, various lithography techniques, including e-beam lithography, can be used to fabricate the devices in batch.

Mode of Integration

Because of their physics and the manufacturing process may differ for different materials system, PIC structures can be integrated in multiple ways, both with themselves (monolithic integration) and with other materials and processes (hybrid integration) to produce a variety of integrated photonic devices. ARP's main thrust is on the monolithic integration; because, only this route is capable of producing highly reliable devices in the lowest possible geometry and cost bracket.

When processing a single beam of light (or multiple beams identically), the straightforward approach to monolithic integration is to sequence optical functions. In the PIC paradigm, that is achieved by creating intelligent design and mask to help simplify manufacturing process.

More complex configurations are possible, incorporating layers to achieve higher functional density. The benefit of layered PIC devices is the ability to combine adjacent optical functions into much smaller, denser devices that can either encompass the full function of an optical component or allow the optical component to be significantly reduced in size.

A second type of monolithic integration requires the processing of multiple parallel beams of light discretely in a single device. That's accomplished by using an array of differing optical functions on a single horizontal layer. An art-work consisting of an array of nano-optic functions is created by using masking and lithography steps. This is conveniently achieved by thin-film patterning processes.

In a broad range of optical components, the incident optical beams are split into constituent beams, which are differentially processed, passed through waveplates to compensate for introduced phase differences, and then recombined. For multiple parallel beams, that creates complexity in design and assembly because of the working size and alignment of individual elements. The resulting benefit is a compact, monolithically interconnected array of optical functions that can be packaged much more easily, resulting in increased density and reduced manufacturing costs.

Summary

In summary we note the following facts.

- Expansion of fiberoptics communication is essential to meet the tremendous growth in the national and global bandwidth demand.
- ARP's main thrust is on the monolithic integration of multiple functionality via volume manufacturing; because, only this route is capable of producing highly reliable devices in the lowest possible geometry and cost bracket.
- Even though the optical component market is experiencing temporary/apparent down turn, the PIC based gears have bright potential to find an immediate market share with the hardware manufacturers.

References

[1] J. Jungjohann, R. Schafer, A. Bezoza and K. Gallagher, "Will dispersion kill next-generation 40-Gbit/sec systems?" CIBC World Market, *Lightwave*, October 2001.

[2] ElectroniCast (San Mateo, CA): http://lw.pennwellnet.com/Articles/Article_Display.cfm?Section=Archives&Subsection=Display&ARTICLE_ID=102685.

[3] CIR Inc. (Charlottesville, VA): http://lw.pennwellnet.com/Articles/Article_Display.cfm?Section=Archives&Subsection=Display&ARTICLE_ID=130646.

[4] Frost & Sullivan (San Antonio, TX): U.S. wavelength services market to reach $2 billion by 2007.

[5] Frost & Sullivan (San Antonio, TX): Optical cross connect market to yield $6 billion by 2006.

[6] Chaffee Fiber Optics (Ellicott City, MD): FTTx market to reach $2.9 billion by 2005.

[7] RHK Inc. (San Francisco): Asia-Pacific optical transport market to grow to $6.2 billion in 2001.

[8] RHK Inc. (San Francisco): European transport market to net $14.8 billion by 2004.

<u>Note:</u>

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