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INDUSTRY

Incumbents favored in RBOC GPON derby

By STEPHEN HARDY

While the deadline for responses to the request for proposals from AT&T, BellSouth, and Verizon for GPON equipment has passed, the speculation surrounding which companies will earn contracts continues. Most touts say the three incumbent BPON suppliers—Tellabs and Motorola at Verizon and Alcatel at AT&T—begin the race with a lap up on the rest of the field. However, the final order of finish, particularly for Verizon's business, and the criteria that will determine which suppliers gain or maintain roles as sources remain a subject of debate.

The three RBOCs once again have bound the tongues of potential suppliers with nondisclosure agreements, so all sources contacted by *Lightwave* say that information about which firms were asked to respond to the RFP, which firms submitted proposals, and what the RFP contained has been hard to find. Contacted directly, AT&T declined comment, as did Verizon—except to say that the latter expects to deploy GPON equipment by the end of this year, according to Mark Marchand, Verizon's director of media relations.

The consensus among analyst sources is that responses were due in mid-December, although it is believed that some players, particularly companies based outside of the U.S. or responding as partnerships, may have received extensions.

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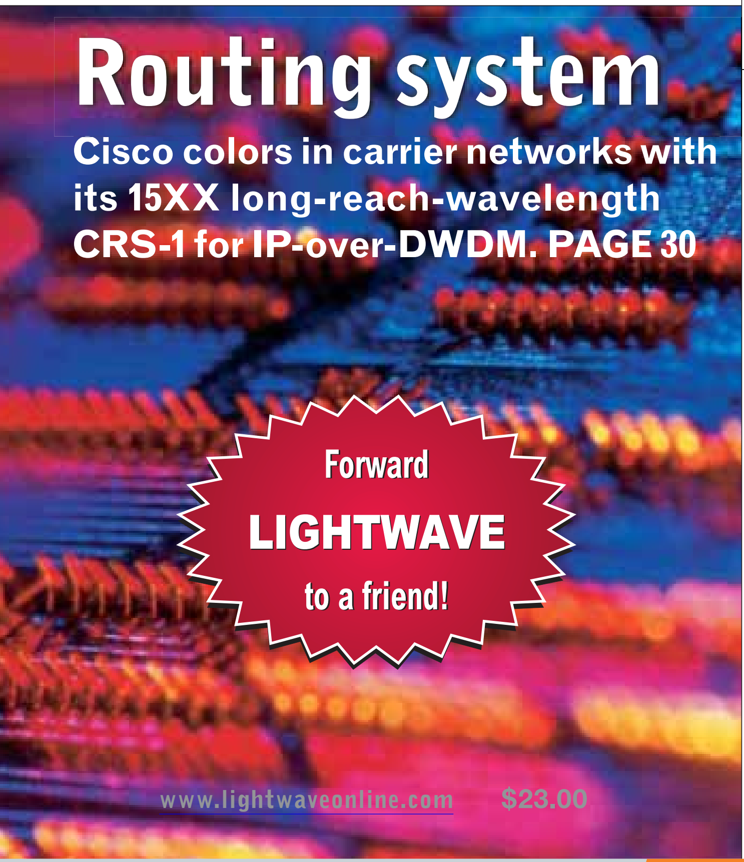

Routing system

Cisco colors in carrier networks with its 15XX long-reach-wavelength CRS-1 for IP-over-DWDM. PAGE 30

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TECHNOLOGY

PLCs poised to displace bulk-optics in FTTH

By DR. MATT PEARSON

Focus on

Last-mile optical access has always been recognized as a fundamental requirement for efficient high-bandwidth deployment. In recent years, true fiber-to-the-home (FTTH) installations have finally been realized in many parts of Asia, and the technology is now spurring new markets in North America and Europe.

Along with this widespread deployment has also come a fundamental change in the optical components marketplace. With FTTH transceiver prices now entrenched below $100 and volumes exceeding several million units per year, the business of optical components has moved from a low-volume/high-margin arena to one of very low cost/high volumes. Concurrently, the incumbent thin-film filter technology, which relies on TO-can components, now faces serious competition from new advanced technologies based on highly integrated planar lightwave circuits (PLCs) and automated assembly.

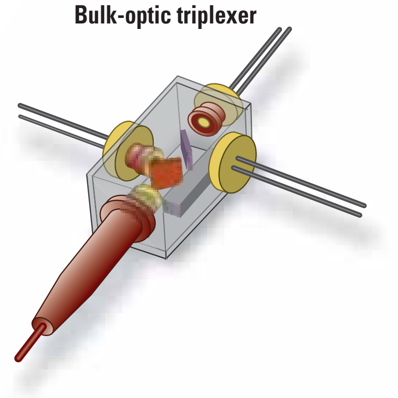

Figure 1. The common bulk-optic triplexer is based on thin-film filters and TO-cans.

Differing approaches

FTTH deployment has increased steadily in Asia for several years now. It is reported that there are more than 70,000 new FTTH subscribers every month in Japan alone. Now the push for FTTH has reached

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APPLICATIONS

Muni networking largely mirrors RBOCs

By MEGHAN FULLER

The RBOC trio of Verizon, BellSouth, and AT&T (formerly SBC) has made no secret of its affinity for Gigabit PON (GPON) technology, particularly following the recent release of its jointly developed GPON RFP. In fact, Verizon spokesman Mark Marchand confirms that Verizon will begin deploying some GPON this year. For the municipalities and municipal utility companies who have deployed or are deploying their own fiber-to-the-home (FTTH) networks, this is good news. They are closely monitoring the RBOC's FTTH activities and welcome the economies of scale those deployments will bring.

"The biggest thing that's happened—and it's changed our financial outlook—has been Verizon's entry into the business," contends John Smith, telecommunications director of the Chelan County Public Utility District (PUD) in Washington State. "We've seen the cost of equipment go down dramatically as a result of what they are doing. We absolutely watch the bigger guys. Whatever technology choices they make, we want to kind of stay in sync with them because we want to continue to take advantage of the price breaks and other things their decisions help generate."

Video service delivery

According to Mike O'Malley, group marketing manager at Tellabs (Naperville, IL), municipalities and utilities face the same three critical questions that the RBOCs must answer when considering an FTTX deployment. "First, how do I achieve

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Technology

Advances in research, development, engineering, and standards

Pushing the technology boundary from compact CWDM to compact DWDM

By Daoyi Wang and Yao Li

Thin-film filters (TFFs) and arrayed waveguide gratings (AWGs) are the two major optical platforms for DWDM multiplexer/demultiplexers. AWGs have the advantage of semiconductor batch processing and thus offer cost advantages at the chip level. However, the technology's fundamental temperature sensitivity means a higher packaging complexity than TFFs for temperature stability. Although athermal packaging technologies recently have become available, they have a higher cost unless the multiplexer/demultiplexer channel count is higher than 16 channels. For these reasons, as well as the fact that AWG insertion loss typically is independent of channel count, most long-haul transport applications featuring 32, 40, or more channels use AWG technology.

TFF technology, on the other hand, offers modular flexibility, lower insertion loss, and lower cost if the multiplexer/demultiplexer channel counts are small. Today's metro DWDM applications that are typically eight channels grouped and expandable in future to 32 or 40 channels prefer the TFF technology. Since many current metro WDM applications started with CWDM and are amplifier-free, as bandwidth expansion continues, the need to upgrade to DWDM by vacating one or two CWDM channels becomes increasingly visible. Thus, technologies need to be developed to continue to improve optical performance and lower cost.

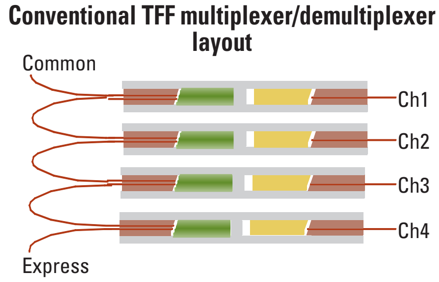

Figure 1. The TFF-based multiplexer/demultiplexer module design has a pair of flaws: increased insertion loss and a relatively bulky design.

For metro CWDM multiplexer/demultiplexer applications, it has been previously shown that pushing the integration of TFF solutions down to the substrate level provides more compact module dimensions, about 1-dB lower insertion loss, lower overall per-channel device cost, and better device stability measured by temperature-dependent loss (TDL), versus the

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PLCs poised to displace bulk-optics in FTTH

North America and most other parts of the world. Two factors drive this broadband network revolution. First, subscribers want the exceedingly high-speed data and video on demand that FTTH can provide. Second, in recent years passive optical network (PON) technology has enabled carriers to deploy last-mile optical access economically on a massive scale, offering fewer truck-rolls and lower operating expenses.

Typical PONs use up to three wavelengths: 1490 nm for voice and data and 1550 nm for RF video downstream to each home, and 1310 nm transmitted upstream. In some cases, particularly in Asia, only two wavelengths are used, one upstream and one downstream. In every subscriber home there is a triplexer or diplexer transceiver to manage these optical functions.

The incumbent technology used for these transceivers is based on thin-film filters (TFFs) and TO-can technology (see Figure 1). This bulk-optic assembly technology has been used for many years in other applications, and has been adapted to support recent FTTH requirements. But in a market where transceiver prices are now well below $100, this technology is on the verge of being replaced by new, lower-cost technologies that have been specifically designed to address the high-volume, low-cost arena of FTTH.

PLCs, the subject of much R&D over the past decade, have now emerged as the technology of choice for replacing bulk-optic components in diplexers and triplexers. These PLCs are fabricated with the same processing technology used for making electronic ICs. Unlike traditional bulk-optic assemblies, where light is guided through a series of lenses and filters and free space, in a PLC approach the optical signals pass through waveguides on the chip, much in the same

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TECH TRENDS

WDM-PON gains notice in the U.S.

By Meghan Fuller

During the Optoelectronics Industry Development Association's (OIDA) Annual Forum, held late last year in Washington, DC, keynote speaker Mark Wegleitner, senior vice president and CTO of Verizon (New York), revealed that the carrier expects to migrate its fiber-to-the-premises (FTTP) network "from BPON to GPON to eventually become WDM-PON." This statement is significant as it marks the first time Verizon, the FTTP leader in North America, has publicly positioned WDM-PON as a possible next step in the fiber access ladder.

There are few players in the nascent WDM-PON segment, but they are nevertheless making strides toward market acceptance. Korea Telecom is leading the charge on the carrier side, with field trials in 2004 and volume deployment in 2005. The carrier has deployed 50,000 lines to date with another 25,000 lines currently on order with startup Novera Optics (Palo Alto, CA), which has taken the lead on the vendor front.

Novera Optics sells its WDM-PON systems directly to Korea Telecom but also offers subsystems and modules, which it has sold to the likes of LG Electronics (Seoul, Korea). The vendor has begun talking to U.S. customers about the myriad benefits of WDM in the access network.

Benefits of WDM

Bernd Hesse, vice president of marketing and business development with Novera Optics, believes that a passive optical network, in which fiber is shared among multiple end users, makes economic sense. "Sharing the fiber is not the issue," he says, "but sharing the bandwidth is a huge issue."

A BPON system, for example, supports 622 Mbits/sec downstream and 155 Mbits/sec upstream. If there are 32 subscribers on the system, that bandwidth is divided among the 32 subscribers—plus overhead. Upstream, a BPON system provides 3 to 5 Mbits/sec when fully loaded. "From our point of view, this is one of the major problems today with traditional PON networks," says Hess. "You've limited your applications on the edge at the customer premises. Nobody can predict what [bandwidth] we will need tomorrow."

WDM-PON systems, by contrast, allocate a separate wavelength to each subscriber, enabling the delivery of 100 Mbits/sec or more of dedicated bandwidth per subscriber or optical network unit

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Meghan Fuller
is the senior news editor at Lightwave.

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Pushing technology

traditional approach of three-port filter device-level integration. (See "Compact CWDM devices offer performance, economic advantages," *Lightwave,* March 2005, page 1.) The same concept can also be applied to certain types of DWDM multiplexers/demultiplexers. However, understanding the difference between CWDM and DWDM applications and the additional challenges a compact DWDM (CDWDM) implies are very important prerequisites.

Unique challenges to CDWDM

Naturally, there are differences between CWDM and DWDM. First, CWDM uses up to eight channels for current applications, and thus most multiplexer/demultiplexer modules provide either four or eight channels. On the other hand, DWDM systems typically have a lot more than eight channels, and their multiplexer/demultiplexer modules might start at eight channels as the minimum. CWDM has a much wider bandwidth for each channel, and its filter's dependence on the angle of incident (AOI) is much lower than its DWDM counterparts. A CWDM filter can be tuned so that its AOI is larger than 14° while still maintaining its optical performance specifications. On the other hand, DWDM's filter bandwidth margin is significantly lower, and thus its AOI has to be controlled in a tight range. Most CWDM applications do not suffer much chromatic dispersion (CD) and polarization-mode dispersion (PMD). On the other hand, CD and PMD are among the typical optical concerns for DWDM. In addition, due to bandwidth tolerance scale differences, DWDM filter manufacturing often requires a special monitoring of center wavelength change versus various environmental changes.

Further analysis of the issues reveals that to take advantages of the existing substrate-level integration demonstrated by CCWDM approaches, the following CDWDM technological challenges must be overcome first: 1) Find an effective method to accurately control the filter center wavelength during assembly and subsequent packaging processes; 2) use smaller AOI filter-cascade geometry than CCWDM to guarantee that filters will not have to be specially designed for this type of integration; and 3) cope with longer free-space propagation distance and its effects on device performance and stability. A rough calculation shows that reducing the filter AOI from 14° to 5° would result in about 300% longest-path optical beam propagation in free-space for the same eight-channel module and 50% device packaging-length increase. Such a long beam-propagation distance may increase packaging complexity.

Key layout changes

Figure 1 shows a typical current TFF multiplexer/demultiplexer module implementation where three-port TFF devices are first made and then integrated through fiber splicing and routing. The disadvantages are that the overall module insertion loss is compounded each time a device is cascaded due to unnecessary free-space-to-fiber conversion steps, and that the final module dimension has to include the space consumed by fiber routing, which makes a bulky package.

Figure 2 shows a CCWDM multiplexer/demultiplexer based on free-space cascade and substrate integration. Here, interchannel cascades are handled via reflected beams by each preceding filter. Both shortfalls mentioned in the Figure 1 design have been overcome. However, the Figure 2 design, which leaves filters and collimators as discrete components on the substrate, cannot address the aforementioned critical challenge of obtaining the needed center wavelength control of the DWDM filters.

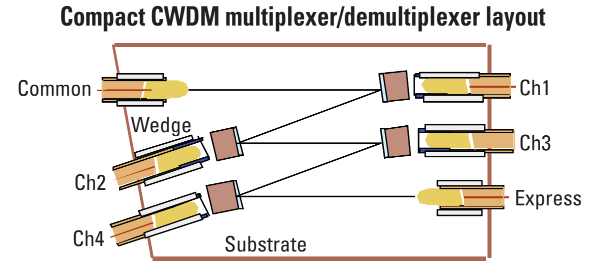

Figure 2. The compact CWDM multiplexer/demultiplexer design improves on the three-port TFF design, but isn't adequate for DWDM applications.

In Figure 3, a modified architecture for the CDWDM is presented where several key changes from the Figure 2 system can be noted. First, filters and collimating optics are integrated before this subassembly is integrated again on the substrate level for module formation. Second, the filters' AOI is arranged to be substantially smaller than in the CCWDM case. These changes enable an accurate wavelength control to about 0.03 nm or equivalently 0.15° of angular tuning and an overall packaging box dimension of 45×25×8 mm.

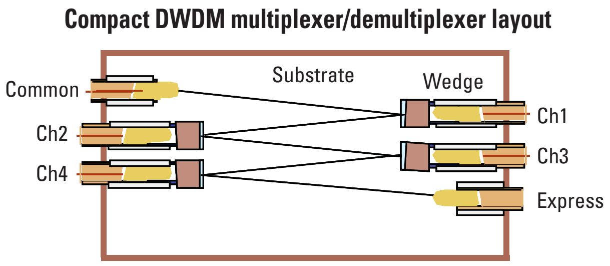

Figure 3. The compact DWDM multiplexer/demultiplexer design adapts the compact CWDM module design to meet DWDM requirements.

Filter and subassembly

For DWDM applications, two major factors require the accurate wavelength control of multiplexer/demultiplexer devices. The first is the narrow channel spacing: 1.6 nm for 200 GHz and 0.8 nm for 100 GHz. The second is the coating yield: Without a central AOI tuning mechanism, the central wavelength of coating should be controlled accurately, which is very difficult for DWDM dielectric coatings. Usually, within a coating wafer, the resultant central wavelengths vary due to fluctuations in the thin-film layer thickness. Thus, only a small central area has the right wavelength for a specified DWDM channel. A good tuning method enables the use of a range of wavelengths, thus enlarging the usable area of the filter wafer.

For 100 GHz, the central wavelength control accuracy must be within 0.05 nm, which means 0.15° of incidence angle control at a nominal AOI of 1.8°. It is not practical to use the conventional method, i.e., directly rotating a filter by hand, to achieve this target. Additionally, after getting the right wavelength, securing the wavelength throughout the device lifetime is most critical. These issues have been successfully solved by the filter-collimator subassembly design. As shown in Figure 4, the filter is bonded to a tube end-face. The other end of the tube is polished to fit the polish angles (8°) of the lens and the dual-fiber pigtail. The distance between two fibers in the pigtail is set to tilt the out beam from the collimator to the specified AOI. To compensate for possible manufacturing errors of fiber distance and coating wavelength, the pigtail can be displaced laterally. After both the central wavelength of the filter and the minimum loss of the collimator have been obtained, the pigtail is secured to the tube. The angle tuning relationship is $d\theta = dx/f$, where $d\theta$, dx, and f denote angle change, lateral offset, and collimator focal length, respectively. For f = 1.93 mm, to meet a 0.02-nm wavelength adjustment, a maximum 2 μm of offset dx is required.

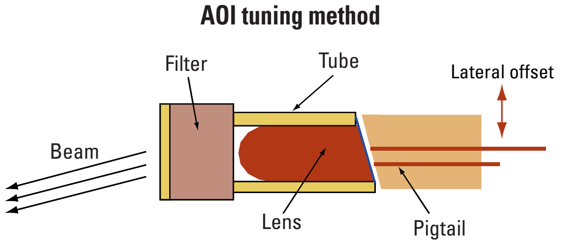

Figure 4. A robust AOI tuning method enables the compact DWDM module to provide a stable center wavelength frequency throughout the module's lifetime.

During device building, the in-process control of the center wavelength is set at 0.03 nm. More than 80% of center-wavelength errors of 100 channels fall within 0.02 nm.

Integration and overall module performance

As shown in Figure 3, a CDWDM device consists of multiple filter-collimator subassemblies bonded to a common substrate. Wedges are used to fill the gap between collimators and the substrate and are fixed by epoxy. This flexible structure performs excellently despite changes in ambient conditions.

The entire device works in a similar way as a CCWDM. The input multiplexed signals from the common port propagate to channel 1. The filter passband wavelength of this channel passes through; other wavelengths are reflected to channel 2 and are manipulated in the same manner, until all drop channels have been coupled out. Then the remaining signals exit from the express port.

The filter's AOI is configured so that CDWDM works at a middle range of AOI (about 4.5°) for which the coating performance and optical path lengths are optimally designed. Compared with regular three-port device filters, the central wavelength of a CDWDM subassembly offsets 1.6 nm, i.e., two channel grids for 100 GHz and one channel grid for 200 GHz. Due to the s-polarization and p-polarization splitting, the bandwidth shrinkage is about 0.05 nm, which is within the tolerable range.

To increase the transmission distance between two optical amplifiers, it is critical to minimize the insertion loss of multiplexer/demultiplexer devices. The root causes of device loss are collimator-to-collimator coupling loss and accumulated filter loss. The worst insertion loss among channels of an n-channel three-port DWDM and CDWDM can be estimated as $\Sigma(IL_{collimator})_n + \Sigma(IL_{filter,R})_{n-1} + IL_{filter,T}$ and $IL_{collimator} + \Sigma(IL_{filter,R})_{n-1} + IL_{filter,T}$, respectively. More specifically, the practical pair collimator loss is around 0.20 dB, filter reflection loss is typically below 0.005 dB to achieve transmission isolation requirements of 30 dB, and filter transmission loss is typically less than 0.25 dB.

By using the formula above, it can be seen that the three-port cascaded-filter approach can offer 1.1- and 1.9-dB worst insertion losses for four-channel and eight-channel modules, respectively. The CDWDM approach, however, can deliver 0.47 and 0.49 dB for the same two cases under the same assumptions, respectively. This loss estimation is based on the assumption that all collimator pairs are perfectly matched (0.20 dB). For practical devices, more coupling loss is seen due to nonperfect matching.

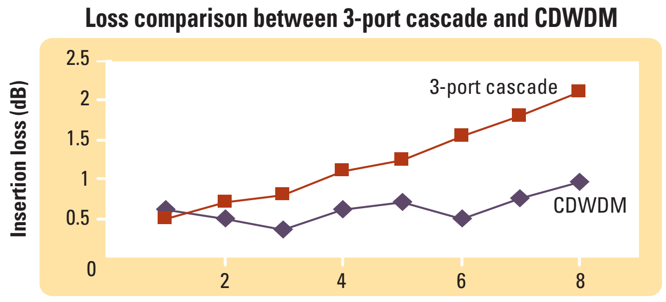

Figure 5. The CDWDM module clearly demonstrates better loss performance compared to a 3-port TFF design.

Figure 5 shows typical loss profiles of a three-port, cascaded-filter eight-channel 200-GHz multiplexer and its CDWDM counterpart at room temperature. A CDWDM-based device exhibits a loss of 1.0 dB, while its three-port counterparts have a typical loss of 2.0 dB. The loss variation over temperature −5 to ~65°C is about 0.33 dB.

The table shows a summary of CDWDM versus a conventional three-port cascaded filter multiplexer for an eight-channel application. It is clear that CDWDM offers better overall performance and cost advantages versus the currently available TFF multiplexer/demultiplexer approaches for up to eight-channel applications. Such applications are increasingly important due to strong growth in metro networking.

Comparing 8-channel CDWDM, CCWDM, and 3-port DWDM

Channel	1	2	3	4	5	6	7	8
CDWDM	0.6	0.5	0.35	0.6	0.7	0.5	0.75	0.95
CCWDM	0.5	0.4	0.4	0.6	0.7	0.5	0.7	0.8
3-port	0.5	0.7	0.8	1.1	1.25	1.55	1.8	2.1

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PLCs poised

way that electrical signals are routed through an electronic IC.

Traditionally relegated to niche applications and only high-channel-count systems, PLCs are now poised to dominate several areas of optical networking, including ROADM applications, channel monitoring, CWDM, and FTTH transceivers. Traditional PLC components have typically been based on arrayed waveguide grating (AWG) technology. Although AWGs have proved themselves in DWDM applications that require a large number of tightly spaced wavelengths, this technology has shown itself quite unsuitable for FTTH applications. The large chip size of an AWG makes it prohibitively expensive for FTTH applications, and the free-spectral range of an AWG is typically much too small to cover the full PON wavelength range (1260 to 1565 nm). These shortcomings have required the development of new PLC filter technologies, such as Dispersion Bridge gratings.

Divergent PLC paths

In generalized terms, there are two different types of PLC approaches now competing for the FTTH market: the external-filter PLCs, and the embedded-filter PLCs such as those that feature Dispersion Bridge gratings.

In the external-filter PLC, the chip contains waveguides only for routing light to different parts of the chip, and has no embedded wavelength-filtering capabilities (see Figure 2). Instead, deep pits are etched into the chip, into which TFFs are accurately dropped, aligned, and bonded in place. These TFFs perform all of the WDM functions of splitting/combining wavelengths. In essence, the PLC platform acts as a new packaging technology for simplifying the alignment and assembly of TFFs. This approach, coupled with an efficient means for mounting lasers and detectors onto the same chip, provides a high-volume approach to manufacturing FTTH transceiver chips.

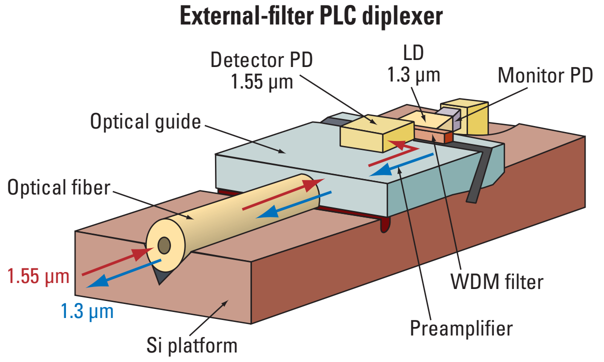


Figure 2. The external-filter PLC diplexer, with the thin-film filter inserted into the notch between laser and detector, provides improved economics versus bulk-optic approaches. However, assembly yield, and thus cost, continues to be a challenge with this technology.

This external-filter PLC technology has matured in recent years, and products based on the approach are now generally available. The main challenge in this architecture remains yield, and therefore cost.

The embedded-filter PLC takes integration to the next level by embedding the wavelength-filtering technology directly into the optical chip. Advanced WDM filtering technology, such as Dispersion Bridge gratings, can be fabricated on the chip itself, incorporated into the regular processing steps involved with manufacturing the wafers. This eliminates the need for any external TFFs, greatly simplifying the subsequent assembly and packaging steps. The result is a highly integrated PLC design that requires no external lenses or filters of any kind. The low cost and efficiency of this approach are greatly compounded by the fact that all chips are made in a wafer form, where a single 6-inch silicon wafer can contain more than 500 triplexers based

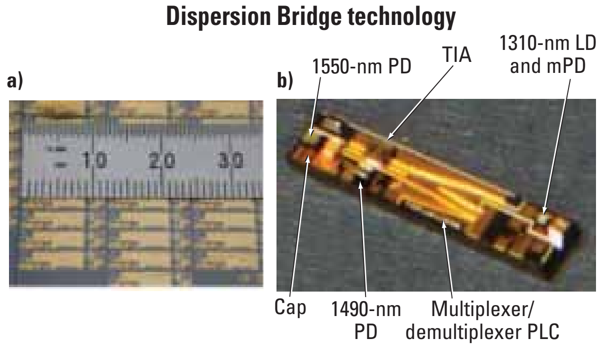
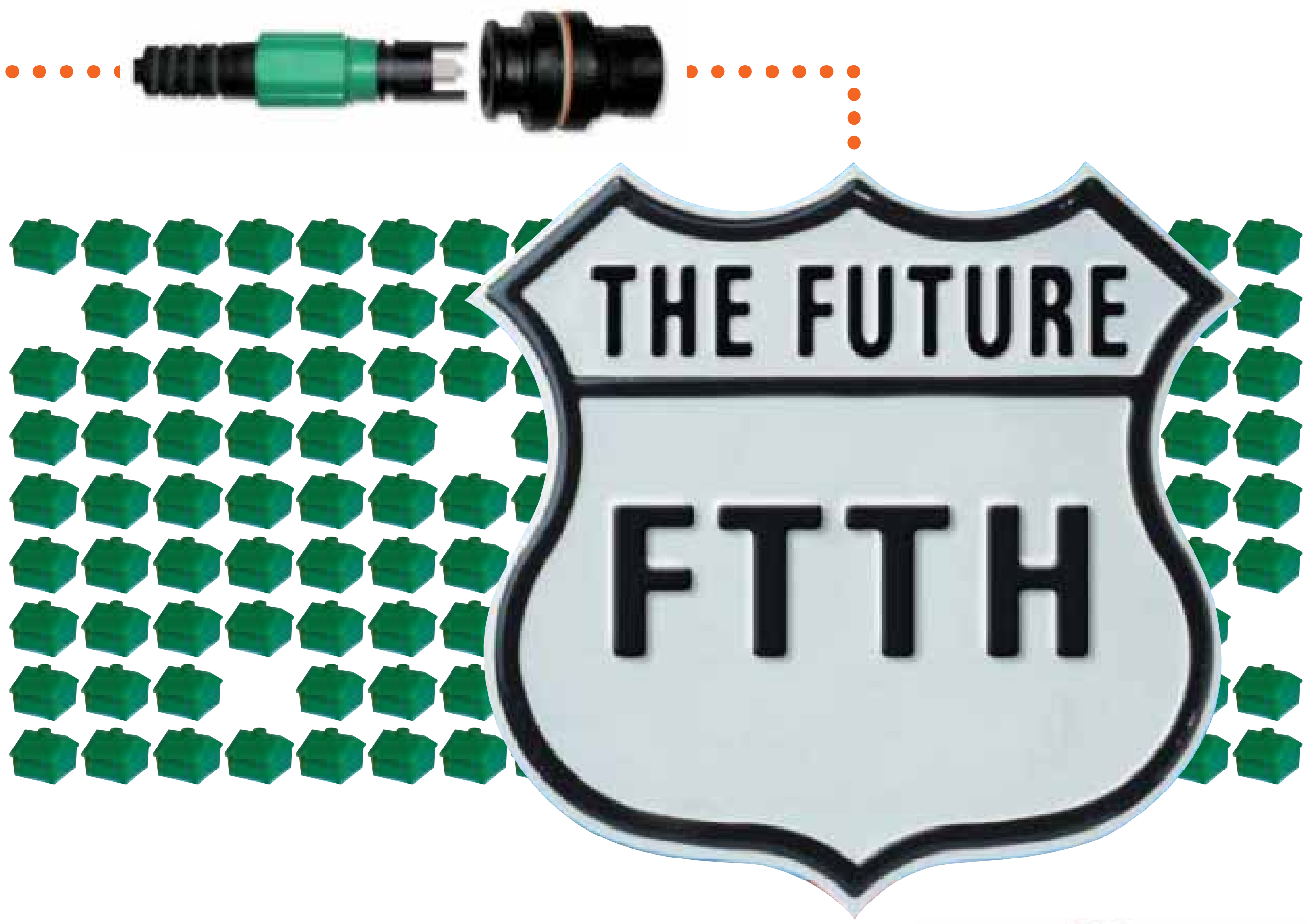


Figure 3. In the embedded-filter approach, a single wafer can contain more than 500 PLC-based transceiver chips.
(a) Part of a wafer composed of Dispersion Bridge filter chips; (b) the small hybrid chip is a self-contained, full-function FTTH triplexer.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