PLANAR LIGHTWAVE CIRCUITS ENABLE NEXT-GENERATION 40G/100G NETWORKS

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ABSTRACT

Next-generation 40G/100G networks have begun to rely heavily on Planar Lightwave Circuits (PLCs) for delivering the small size, low cost, and complex functionality they require. The goal of transmitting 100G along a fiber infrastructure designed for 10G results in a myriad of challenges that must be resolved at the transmitter and receiver only, without altering the existing fiber plant. Advanced modulation formats like DQPSK make this possible, but traditional fiber optic components cannot readily achieve the performance and functionality that these new modulation formats demand. In this article we review how modern PLC technology is being leveraged to enable these very high-performance 40G/100G applications. We review the challenges that these advanced modulation formats create, the practical issues of using traditional optics in these advanced systems, and how PLCs are uniquely positioned to resolve those issues.

The availability of bandwidth intensive services such as Fiber-to-the-Home, along with bandwidth requirements in the commercial sector, have created a growing demand for the introduction of new 40G/100G optical networks. Many of these new systems rely on advanced modulation formats like Differential Phase Shift Keying (DPSK), and Differential Quadrature Phase Shift Keying (DPQSK), to complement more traditional architectures like Dense Wavelength Division Multiplexing (DWDM). Each of these methods presents substantial optical, mechanical, and electronic complexity. Traditional bulk-optic assemblies can in some cases achieve the required complexity in relatively low volumes, but have substantial problems meeting the additional requirements of volume manufacturability, compactness, ruggedness, and low-cost.

Advanced Planar Lightwave Circuits (PLCs) can achieve the desired level of sophistication in a small, rugged package. These optical chips, similar in many ways to their electronic counterparts, are fabricated using wafer-level processing techniques and use optical waveguides to route photons, the same way that metal traces are used to route electrons in an electronic chip.

Typical PLC modules for 40G/100G applications require the following sub-components: a fiber interface, wavelength filter or combiners, precise phase-delayed optical interferometers, polarization control and polarization based splitting/combining, optical isolators, laser sources, and detectors.

Over the last several decades, PLCs have established themselves as an ideal way to create wavelength filters, and stable interferometric structures. PLCs are mass producible using the same general techniques as used in the semiconductor industry. A packaged PLC device consists of a planar chip with passive optical filters and a fiber pigtail. With standard etching and metallization techniques, the planar chip can also serve as a platform for active elements. Recently, successful hybridization methods have been introduced onto the PLC platform to efficiently couple lasers and detectors to waveguides using passive automation.

In a bulk optic assembly, lasers are coupled to fibers using one or more bulk-optic lens assemblies. In that configuration, changes in mechanical positioning can occur due to temperature drift or stress, which in turn leads to variations of the optical signal due to temperature and stress. In contrast, lasers can be soldered directly in front of a mode-matched optical waveguide on a PLC. In this configuration, there is little mechanical stress, and no distance over which thermal drift can accumulate. Tracking error can be held to less than 0.2 dB quite easily, over a 120^{o}C temperature range.

Optical receivers are fabricated by integrating photodiodes onto the PLC chip itself. In a bulk optic device, a lens is used to focus the incoming light into the narrow aperture of the photodetector. In a PLC, the detector chip can be placed within a few microns of the waveguide carrying the light, allowing the use of narrow aperture (low capacitance) photodiodes without the need for active alignment. Between the high-speed photodetector and the external electronics there is usually a transimpedance amplifier (TIA). The PLC platform allows these TIAs to be mounted on the optical chip platform, directly adjacent to the photodetector, thereby ensuring optimal signal integrity at high data rates.

In WDM systems, data is created as pulses where the signal level is turned on or off to indicate ones and zeros. This method of modulation, sometimes called On-Off Keying (OOK) suffers from fiber non-linearity and signal-to-noise problems at high data rates of 40G per channel. In order to increase bandwidth, multiple wavelengths are used to pack more signals onto the same optical fiber. In this regime, PLCs have already proven to be advantageous from a cost and size standpoint, especially for systems with four or more wavelength channels.

To reach higher per-channel bandwidths, sophisticated 40G/100G architectures are being developed that make use of phase-based multiplexing. This is called Phase Shift Keying (PSK). DPSK consists of a single stream of data at a defined bit-rate. Through an optical delay line interferometer, data bits are interfered with preceding bits in order to create an intensity-keyed signal. This interference based demodulation technique improves signal to noise, and for a variety of reasons reduces fiber non-linearity effects. Since PLCs are manufactured using processes similar to those used in electronic wafers, they afford the possibility of stable delay lines that can be fabricated with photolithographic precision. Polarization effects in the network can be corrected using polarization diversity strategies implemented on the optical chip itself.

Phase shift keying capacity can be increased further using DQPSK. With this method, information is coded into two quadratures of optical phase, leading to a four-fold increase in effective data rate. An optical wave can be subdivided into a set of constituent waves that do not mutually interfere. While an OOK pulse can only represent two states (0 or 1), a DQPSK pulse can represent four possible states (00, 01, 10, or 11). DQPSK starts with the bandwidth advantages of DPSK, but also multiplies the bandwidth by accessing different quadratures (or phases) of light. The optical quadratures must be implemented on the scale of the wavelength of light itself, and involve a phase difference equivalent to a few hundred nanometers, which can be extremely difficult to control using anything less than photolithographic precision.

To correctly demodulate a DQPSK signal, two delay lines similar to the ones used in DPSK are needed, but these must be delayed between themselves in phase by only one optical quadrature. This secondary delay must be held to a precision of tens of nanometers. The photolithographic precision of a PLC circuit is ideally suited to DQPSK. Finally, TIAs, electrical traces (possibly impedance matched), decoupling capacitors, and an assortment of small electronic components can be bonded close to the optical circuit, indeed even immediately above optical waveguides and filters, leading to a high degree of compactness and signal integrity.

A typical hybrid PLC device consists of small optoelectronic chips and sub-components integrated onto a larger optical chip, which typically the optical filtering elements and other passive structures. This hybridized sub-assembly is then placed in a planar package, wirebonded, pigtailed, lidded, and tested for final use. All of the processes involved in the manufacturing of such a component, from optical fabrication to final assembly, are suited to automated bonding and testing methods. The semiconductor and electronic chip industries have developed pick-and-place and flip-chip bonding processes that are well suited to PLC manufacturing. Wirebonding and post packaging can be carried over from the electronics industry with little modification.

As customers demand more bandwidth, volume requirements will increase. And as is often the case, costs will continue to decrease despite the added functionality. Meanwhile, with so much deployment underway, ruggedness and reliability become mandatory requirements for any optical component. Increasing system functionality imposes size restrictions on all components, but collapsing that functionality onto a single integrated optical chip presents an opportunity for meeting the needs of new 40G/100G systems, both now and as their requirements continue to evolve. Hybrid PLCs represent an ideal choice for low cost, rugged, compact optoelectronic components for a high volume market.

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