Silica waveguide device enables high-speed optical communication

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A novel optical circuit provides the precise and stable functions required for receivers used in next-generation, coherent optical-fiber transmission systems.

Optical signal processing and detection methods for data transmission have been attracting considerable attention. In particular, advanced modulation formats and coherent detection—i.e., sensing of light modulated in both phase and amplitude—are of interest for fast 40Gb/s and 100Gb/s modulation schemes, as well as potential next-generation systems for over 100Gb/s. The techniques involved allow high spectral efficiency, receiver sensitivity, and are robust to signal impairments. However, such high-performance data transmission systems require receivers with sophisticated configurations (see Figure 1), which may result in higher cost and larger size.

A typical receiver configuration comprises passive devices (such as a polarization splitter, a polarization-maintaining power splitter, a polarization rotator, and 90° hybrids or wave mixers) in addition to active devices (such as a local oscillator and balanced photodiodes). Silica-waveguide-based planar lightwave circuit (PLC) technology is a promising way to integrate passive optical parts and thus reduce the receiver cost and size. The integrated passive components (colored yellow in Figure 1) are referred to as a dual-polarization optical hybrid (DPOH). The DPOH works as an interferometric mixer of the signal and reference light, which is required before electrical signal processing is implemented to analyze and retrieve the polarization state, phase, and amplitude of the signal light.

We have been working with silica-waveguide-based PLC technology with a view to developing receivers with improved performance for high-speed optical communication. Our device consists of a germanium-doped silica waveguide core embedded in a silica glass layer on a silicon substrate. The core-cladding index difference is low (1.5%), and the core is kept away from the atmosphere. The result is good long-term stability and a high level of control over the propagation constant. These waveguide features have a number of advantages: they are highly reliable, mass producible, and inexpensive; they have low propagation and fiber coupling loss; they have low polarization and temperature dependence; and due to their weak birefringence properties, they are capable of accommodating polarization-managing elements such as splitters, combiners, and rotators. These characteristics have been proven in a range of commercial products, such as arrayed-waveguide-grating wavelength multiplexers for dense wavelength division multiplexing, splitters for FTTH (fiber to the home, a broadband network architecture that uses optical fiber to replace all or part of the usual metal local loop), and delay-line interferometers for various types of high-speed differential demodulators.

Figure 2 shows the configuration of the Mach-Zehnder (MZ)-interferometer-based polarization splitter used in the DPOH. Glass-etched grooves along one of the MZ arm waveguides induce a birefringence change in the waveguide and a 180° phase shift between the transverse electric and magnetic (TE and TM)
modes, thus realizing a polarization-splitting function; it outputs TE light to the cross-port and TM to the through-port. The insertion loss for this element is less than 1dB and the polarization extinction ratio is larger than 27dB over a range as wide as 100nm, thanks to a special wideband coupler design.\(^3\)

The 90° hybrid component of the DPOH is composed of four 2 × 2 multimode interference (MMI) couplers connected as shown in Figure 3. The optical lengths of three of the waveguides connecting the MMI couplers are the same, and that of the remaining one is λ/4 (i.e., 90° in optical phase) longer than the others. This configuration appears complex compared with that of a single 2 × 4 MMI coupler-based 90° hybrid, which is commonly used in indium phosphide-based coherent receivers.

However, in our design, it is possible to reduce the wavelength dependence of the phase (which otherwise means that a λ/4 path length is no longer λ/4 when the wavelength is changed). We can balance out the wavelength-dependent phase shift with the wavelength dependence of the 2 × 2 MMI coupler.\(^4\) The measured phase difference between in-phase (I) and quadrature (Q, 90° out of phase) ports of the 90° hybrid has a flat spectrum with a phase difference of 90° ± 0.7° over a 100nm wavelength range for both polarizations. This value of phase uncertainty is lower than that for the 2 × 4 MMI-based 90° hybrid.

By integrating a polarization splitter, two 90° hybrids, and a polarization rotator, we obtain a one-chip DPOH for a coherent receiver (see Figure 4). Additional polarization splitters are located in the free area to act as polarizers and increase the polarization extinction ratio. A polyimide film waveplate is inserted in a groove crossing the waveguide to act as a polarization rotator. Despite the complicated layout, the excess optical loss of this chip is only 2dB owing to the low propagation loss of the silica waveguide.

Figure 5 shows a packaged coherent receiver frontend module including the DPOH chip, balanced photodiodes, and trans-impedance amplifiers. The optical output from the DPOH is coupled into the photodiodes through a microlens array.\(^5\) An 112Gb/s dual-polarization fast-modulated signal was successfully received with this module as shown in the constellation (complex plane plot of signals) in Figure 5. The mechanical size and optical and electrical specifications of the module are based on the Optical Internetworking Forum implementation agreement on coherent receivers.\(^6\)

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In summary, silica waveguide-based PLC technology is promising for fabricating coherent receivers for use in future systems transmitting at 100Gb/s and above. Further downsizing is possible using waveguides with a higher core-cladding index difference, and hybrid-integrating photodiodes and trans-impedance amplifiers on the surface of a silica waveguide chip. Such optimizing techniques are among the studies we will be engaging in during the next steps of our research in this field.

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Hiroshi Takahashi has been involved in research on silica waveguide integrated-optic devices such as arrayed-waveguide-grating wavelength multiplexers and optical switches since 1988. He now leads a research group focusing on lightwave circuit design for coherent transmission and optical signal processing.

References