Title: PROGRAMMABLE DEMULTIPLEXER USING ELECTRO-OPTICALLY MODULATED POLYMERIC GRATING ARRAY

Abstract

A programmable optical demultiplexer (or switch) employing index-modulated electro-optical (or thermo-optical) polymeric grating-coupler array in conjunction with substrate guided wave is proposed. These modulated grating-couplers are produced by a modulating signal (voltage) applied to electrodes with grating patterns. Different electro-optic grating-couplers in the grating-coupler array have different coupling wavelengths so that each of them can couple a selected wavelength out from the substrate guided waves. This architecture can be used as a programmable demultiplexer to implement reconfigurable wavelength-division-multiplexed (WDM) optical systems.
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PROGRAMMABLE DEMULTIPLEXER USING ELECTRO-OPTICALLY
MODULATED POLYMERIC GRATING ARRAY

FIELD OF THE INVENTION

This invention relates to electro-optical demultiplexing devices for
reconfigurable wavelength-division-multiplexing (WDM) systems in fiber-optic communication.

BACKGROUND OF THE INVENTION

A WDM system provides optical communication in wavelength multiplex
mode. This approach allows modulated radiation from several light
sources having clearly distinct wavelengths to be transmitted
simultaneously over a single fiber and is a most promising approach to
increase the number of communication channels and improve capacity in
fiber-optic communication. The use of WDM has the potential of
improving the performance of fourth generation fiber systems by a
factor of more than one thousand. The commercialization of high
capacity WDM lightwave systems requires high performance channel
multiplexers and demultiplexers with add/drop capacity.

Recently, research on devices and techniques for high capacity WDM
systems and dense wavelength division multiplexing (DWDM) systems
having effective network restoration capability, i.e. reconfigurable
WDM systems, has received more attention. Most of the currently
available demultiplexers are passive devices, so they cannot satisfy
the requirements of reconfigurable WDM systems. In future high-capacity WDM systems or DWDM systems, the routing of optical signals
will be performed in optical cross-connects (OXC). The functions and applications of WDM systems will be extended by reconfigurable structures.

Reconfigurable WDM networks would facilitate transmission of large bandwidths. The switching nodes in this kind of WDM networks could be directly connected to each other without electronic processing. This relaxes the capacity requirements for electronic switching systems when all links may all be optically traversed. A dynamic reconfigurable WDM network layer could set up such direct, optical, links. This could be used to adapt the network to structural changes in traffic load.

Certain polymers, a new kind of organic nonlinear electro-optical (EO) materials, have high EO nonlinearity and high thermo-optical (TO) effect. Polymers generally have potentially both large EO and TO coefficients, low dielectric constants, improved thermal and temporal stability, and easy fabrication conditions. These physical properties of polymers are useful in constructing waveguide-type optical devices. A variety of polymer-based devices aimed at providing feasible structures have been reported. The technologies associated with packaging and interfacing with other devices are also important considerations.

An optical intensity modulator in organic nonlinear optical polymers was reported in "Travelling-wave polymeric optical intensity modulator with more than 40 GHz of 3-dB electrical bandwidth" by C.C. Teng in Appl. Phys. Lett., Vol. 60, No. 13, 30 March 1992, pp. 1538-1540.

A "Polymeric Digital Optical Switch using Fluorinated Polyimide" was reported by T. Ido in Proceedings of Optical Fiber Communication Conference (OFC 199), pp. 29-30. This digital optical switch utilizes the large thermo-optical effect of the polyimide waveguide.

**SUMMARY OF THE INVENTION**

The present invention provides a programmable demultiplexer based on electro-optically, or thermo-optically, modulated polymeric grating-coupler array in conjunction with a substrate guided wave. These EO or TO modulated polymeric grating-couplers in the array are designed to have different coupling wavelengths and are formed by applying modulation effects to grating-electrodes fabricated on a high-index substrate. When a selected grating electrode is activated by an appropriate modulation effect (electrical or thermal), the modulated grating-coupler is activated and then couples an optical beam having the selected wavelength out from the substrate guided waves. Hence, different grating-couplers can be used to couple different wavelength beams from the substrate guided waves. The electro-optically programmable optical interconnect devices according to the present invention may be used as demultiplexers to implement reconfigurable WDM systems for fiber-optic communication.
The structure of the grating-couplers must meet two conditions. One condition is total internal reflection (TIR) for optical beams propagating within the substrate, when no modulating signal is applied to the grating-electrodes. The other condition is the momentum matching at the expected wavelength for grating coupling when the modulated grating-coupler is activated by a modulation effect applied to the grating-electrode. Theoretical study shows that perfect momentum matching of the structures according to the present invention cannot always be implemented, so that compensation for the existing mismatch is required. The design of a grating structure directly impacts coupling efficiency of the grating-coupler and the bandwidth of the coupled beam at the expected wavelength.

**BRIEF DESCRIPTION OF THE DRAWINGS**

Example embodiments of the invention are described with reference to the accompanying drawings, in which:

Figure 1 shows in perspective a programmable demultiplexer using EO modulated polymeric grating-coupler array in conjunction with substrate guided waves according to the present invention;

Figure 2 illustrates the principle of operation of the programmable demultiplexer of Figure 1 (in cross-section along A-A);

Figure 3 shows a top view of one of the electrodes of the grating coupler array in Figure 1; and
Figure 4 shows a top view of one of the electrodes of a grating coupler array but for a TO modulated polymeric grating-coupler array.

DETAILED DESCRIPTION

Referring to figures 1 and 2 of the drawings, the first being a perspective view and the second a vertical cross-section along the axis A-A, a demultiplexer according to the present invention comprises a high refractive-index substrate 10 having a transparent electrode layer 11 on top. On top of the layer 11 there is an electro-optical (OE) polymeric layer 12.

A plurality of upper electrodes, for example eight, G1 to G8, which induce index-modulated grating-couplers in the polymer layer 12 when activated, and which are modulated (activated) by applying a voltage to therewith connected contact pads P1 to P8. Both the electrodes G1 to G8 and the pads P1 to P8 are formed on top of the EO polymeric layer 12 and may be shaped as shown in Figure 3. A prism 13 is used as shown to launch a WDM signal beam 14 to propagate in the wave-guiding high-index substrate 10. Of course, other means for launching the WDM beam may also be used.

The operation of the demultiplexer is explained with reference to figure 2. The beam 14 is launched into the substrate 10 via the prism 13 and propagates by total-internal-reflexion (TIR) as indicated by arrows 15 from left to right. When an appropriate modulating signal (voltage) is applied between the electrode 11 and one or more of the
electrodes G1 to G8, the corresponding pads P1 to P8 being the other electrode, the refractive index of the polymer 12 underneath the electrode is "modulated" to provide a grating-coupler and couple-out the respective, predetermined wavelength (~1 to ~4) signal or beam (being a component of the WDM beam propagating in the substrate 10) through the respective grating-coupler electrode Gi. The first condition necessary for operation of the demultiplexer is that the WDM beam in the substrate 10 experiences TIR at all locations of the grating-couplers G1 to G8 as long as no index modulating signal is applied to any of the pads P1 to P8. If we designate \( n_p \), \( n_L \) and \( n_s \) to be the refractive indices of the polymer layer 12, the transparent lower electrode 11 material and the substrate 10, respectively, and the bouncing angle of the bouncing beam within the substrate 10 to be \( \theta_b \), the basic TIR condition can be expressed as

\[
\theta_b > \sin\left(\frac{n_L}{n_s}\right)
\]

The second condition is the momentum matching for coupling an optical beam having the expected wavelength with a high efficiency. For a given grating spot, if the modulated grating-coupler having \( \Lambda \) period is produced to couple the optical beam having \( \lambda \) wavelength out, the momentum-matching condition for this operation can be defined by

\[
\frac{n_s \sin(\theta_b) - \sin(\theta_c)}{\lambda} = \frac{m}{\Lambda}
\]
\[
\frac{n_s \cos(\theta_s) - \cos(\theta_c)}{\lambda} = \frac{m}{\Lambda}
\]  

(2b)

where \( \theta_s \) is the coupling angle of the modulated grating-coupler and \( m \) indicates the \( m^{th} \) diffraction order. When the second condition is met to perform the second operation, the first condition, i.e. the TIR condition is broken. If \( d \) and \( \Delta n \) stand for the thickness and index modulation of the polymer film, respectively, the coupling efficiency of the modulated grating-couplers can be expressed as

\[
\eta = \sin^2(k_c \cdot d)
\] 

(3)

where \( k_c \) is the coupling constant and strongly depends on the index modulation \( \Delta n \).

If the second condition, i.e., the momentum matching, cannot be completely met in this structure, a compensation for the mismatch of the momentum need to be made to improve the coupling efficiency of the modulated polymeric grating-couplers. For more detailed information about the momentum matching for this structure and the compensation for the mismatch of the momentum, see "Intraplane to interplane optical interconnects with a high diffraction efficiency electro-optic grating" by D. Sun et al., (1997), *Applied Optics* Vol. 63, No. 3, pp. 629-634.
Should the polymeric layer 12 be a TO or polymide layer, then the electrode layer 11 is no longer required. A suitable grating inducing electrode would then be that shown in Figure 4, where the modulating voltage is applied between the pads Pi and P'i to heat the electrode "fingers" 16 and the corresponding volume in the polymer layer 12 underneath.

Finally, the device as shown in Figures 1 to 4 for a WDM demultiplexer for a WDM signal centered about a wavelength of 1.55 micrometer would typically have the following characteristics:

a) The optical substrate 10
   - thickness appr. 2mm
   - length 20-30 mm
   - width 6-8 mm
   it may be a polymer or other suitable optical material layer supported by a suitable carrier surface;

b) The transparent electrode 11
   - thickness less than 0.5 micrometer of evaporated indium-thin-oxide (ITO) (the electrode 11 must be no thicker than is required for photons of the WDM signal to tunnel through);

c) The EO polymer layer 12
   - thickness 4-6 micrometer;
The grating-coupler electrodes Gi
- thickness appr. 0.5 micrometer
- width 1-1.5 mm
- number of grating "ribs" appr. 500
- grating pitch or period 1-2 micrometer
- the change in pitch from G1 to G9 would be a few nanometres
- a suitable method for forming the grating electrodes
  would be to use direct electron beam

The potential difference between the electrodes Gi and 11
for inducing the grating-coupler underneath the electrode
Gi in the polymer layer 12 is 10-12 V.

The device shown, when reduced to a single grating-coupler electrode G
or more, may also be used to switch a light beam or beams of the
appropriate wavelength, which have been launched into the substrate 10
(e.g. by means of an optical waveguide or fiber 17 at one end thereof)
between an output waveguide 18 and the electrode G output. Moreover,
it is possible to provide several arrays as shown in Figure 2 in
parallel, thereby creating a unidirectional switching matrix for
optical signals. And by combining two such matrices, a bidirectional
switching matrix may be provided.
WHAT IS CLAIMED IS:

1. An optical switch, comprising:

   (a) a substrate for guiding an optical signal along a dimension thereof;

   (b) an electro-optical (EO) or thermo-optical (TO) polymer layer on top of said substrate; and

   (c) a grating-coupler inducing electrode on top of said EO or TO layer adopted to induce a grating-coupler therein for diverting said optical signal from said substrate to said electrode.

2. An optical switch as defined in claim 1, wherein an EO polymer layer is utilized, and further comprising a transparent electrode formed on top of said substrate between it and said grating-coupler inducing electrode.

3. An optical switching array, comprising a plurality of optical switches as defined in claim 2.

4. An optical switching matrix, comprising a plurality of switching arrays as defined in claim 3.
5. An optical wave-division multiplexed (WDM) signal demultiplexer, comprising:

(a) a substrate for guiding an optical signal along a dimension thereof;

5 (b) an electro-optical (EO) or thermo-optical (TO) polymer layer on top of said substrate; and

(b) a plurality of grating-coupler including electrodes forming an array along said dimension on top of said EO or TO layer, said electrodes adapted to have a refractive-index modulating signal applied thereto.

10 6. The optical WDM demultiplexer of claim 5, further comprising means for launching said optical signal into said substrate.

7. The optical WDM demultiplexer of claim 5, wherein the grating-coupler electrodes are made of one of: aluminum, gold, chromium and other metals.

15 8. An optical wave-division multiplexed (WDM) signal demultiplexer, comprising:
12

(a) a substrate for guiding an optical signal along a dimension thereof;

(b) a transparent electrode formed on top of said substrate;

(c) an electro-optical polymer layer on top of said transparent electrode; and

(d) a plurality of grating-coupler inducing electrodes forming an array along said dimension on top of said electro-optical polymer layer, said electrodes adapted to have a refractive-index modulating signal applied between a selected one thereof and said transparent electrode.

9. The optical WDM demultiplexer of claim 8, further comprising means for launching said optical signal into said substrate.

10. The optical WDM demultiplexer of claim 8, wherein the grating-coupler electrodes are made of one of: aluminum, gold, chromium and other metals.
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC 7 G02F1/065

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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**Patent family members are listed in annex.**

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Date of the actual completion of the International search

31 May 2000

Date of mailing of the International search report

15/06/2000

Name and mailing address of the ISA

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