Code Division Multiple Access (CDMA) with MMI Mineral-Organic Circuits

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ABSTRACT:

The optical fiber, which offers a large bandwidth (about five TeraHertz per telecommunication window), can be fully used only if the techniques of multiple access are sufficiently effective. Our technology based on an organic-inorganic material offers a solution for the realization of the coupling and the decoupling of transmitted channels : in addition to the multiplexer with division by wavelength (WDM) based on multimode interference couplers, we present here a system of multiple access with division by code (CDMA) using multimode interference couplers as well.

Keywords: Multiple access, Optical circuits, WDM, CDMA, organic-inorganic, multimode interference.

1. INTRODUCTION

Three schemes of access are possible to share the large bandwidth of the optical communication link:- the time sharing (TDMA) which authorizes a great number of users but request a fast synchronization,- the wavelength sharing (WDM), which basically requires precise adjustments, and – the sharing with code division (CDMA) which allows a great flexibility in the management of the multiple accesses. Naturally the techniques can be combined.

Among the various designs of the necessary devices, the implementation in integrated optics is a promising solution. Since a decade, the organic-mineral materials are investigated for applications in integrated optics[1,2] . These materials combine the advantages of the mineral networks - thermal stability, mechanical resistance, transparency ...and of organic materials – low cost, process at low temperature, change of index by simple polymerization. The single mode (at 1.55 µm) basic guide structure has a 6 µm x 6 µm section, this is compatible with the dimensions of single mode fibers ensuring a good coupling.

This technology (organic-mineral) can be used to make various optical circuits[3] : gratings[4], couplers[5], power splitters. We present here wavelength division multiple access (WDMA) circuits based on MMI devices as well as recent investigations on code division multiple access (CDMA) .

2. ORGANIC-MINERAL TECHNOLOGY

The guiding structure consists of three layers deposited on a silicon substrate : buffer layer, guiding layer and protective coating. The basic material is synthesized by hydrolysis and polycondensation of methacryloxypropyl trimethoxysilane(I). Methacrylic acid and zirconium n-propoxide are combined with II) in a molar ratio 2.5:1:1[6]

Each layer fabrication needs only four steps: synthesis, deposition, UV exposure (for the guiding layer only), thermal treatment. All depositions are made by dip-coating. A <100> silicon substrate is used as mechanical stand, whose advantage is to be a crystalline material. This enables to obtain a perfect end of guide by simple cleaving when coupling with optical fibers.

A photosensitizer is added to the sol for the guiding layer only. This enables the drawing of optical circuits through a local refractive index increase caused by UV- polymerization. A quasi-symmetric guiding structure is obtained, thanks to the deposition of a protective coating whose refractive index is close to the one of the buffer layer. The circuits are

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imprinted in the guiding layer through the protective coating, through a mask or by direct writing using a He-Cd laser emitting at a wavelength of 325 nm. The writing system utilizes a truncated TEM_{01}* beam laser with a "doughnut" irradiance distribution. It is configured to deliver 80 µW onto the sample in a 5.0 µm diameter spot[7]. The circuits are written at a scan velocity of 0.8 mm/sec. The multimode regions (large guides) are defined using a pocket mode spiral trajectory with an overlap of 2.0 µm between passes. A 30 minutes final heating at 120°C stabilizes the structure building a solid mineral network. This process enables to reach a refractive index change of 0.015 between the core of guide and the buffer. Such a 5µm x 5µm waveguide is single mode around 1.55µm wavelength.

3. MULTIPLE ACCESS BY WAVELENGTH DIVISION

The optical circuit based on an array of guides between two star couplers is the most popular approach to make WDMs in integrated optics. An alternative is to use multimode interference (MMI) couplers. The theoretical performance of MMI couplers have been largely studied, but presently few experimental results are proposed in the literature. These devices may be chosen because they have advantages such as low theoretical insertion loss, compact size, large optical bandwidth and high fabrication tolerance[8]. But they are studied and fabricated here because they can be used also as spectrum synthesizers in our novel approach of optical CDMA (see below).

A NxN MMI-PHASAR is composed of three main elements : a NxN MMI power splitter, an array of N single mode waveguides and a NxN MMI combiner. Two identical MMI-couplers are used as input and output, making the device symmetric and reversible. The first NxN coupler consists of a multimode waveguide connected to N incoming and N outgoing single mode waveguides distributed with a uniform spacing along the transverse axis. Because of the different propagation speeds of the modes in the large section, the power is not uniformly distributed in the cross section but at certain distances from the input, it presents peaks which can be exploited by placing output guides at the location of the peaks. The design can be done in such a way that peaks have equal magnitudes but different phases. Moreover the phase differences are an integer number of π/N if N is the number of outputs in the considered section plane.

The array of waveguides induce a combination of phase delays depending on the wavelength. These differences of optical paths are designed to adjust the phases at the inputs of the second MMI-coupler which is used as a combiner. The combinations of phases at the input of the combiner have to be built so that constructive interference occurs at a different output for each wavelength[9,10].

The MMI couplers are only slightly sensitive to wavelength. This enables to design the circuit for a central wavelength and to consider that the MMI device itself keeps the same behavior in the wavelength range of use.
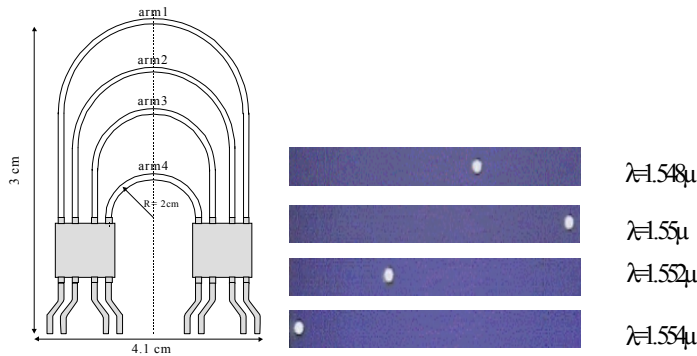

Fig. 1 : *Four channels WDM based on MMI devices in organic-mineral technology.*

A 4x4 MMI-coupler element is designed for use at 1.55 µm. All geometric parameters are given in figure 1. It is imprinted by laser direct writing onto the organic-mineral guiding structure presented above. A photograph of the top view of the end part of a 4x4 MMI-coupler with its 4 output guides is shown in figure 1.

This basic part alone (MMI splitter) of the WDM device, when excited by a laser diode at a wavelength of 1.55µm showed in a first experiment a maximum difference of power between two outputs of 1.5dB.

The theoretical values, calculated at 1.55µm wavelength, are respectively 0.2dB and 0,1dB. A better accuracy on the refractive index change obtained by adjusting the UV exposure time, the thermal treatment and the layer compositions could greatly improve the device. The present technology has given propagation losses in the order of 0.2 dB/cm.

Mainly because the diameter of the fiber core is close to the width of the guide, the coupling losses are limited to 3 dB with simple face to face arrangement : the fiber is placed in front of the guide input at a Fabry-Perot distance maximizing the coupling.

The 4 channel MMI-PHASAR with a 2 nm selectivity for use in this wavelength range has been made using two 4x4 MMI-devices, one as a splitter in input and the other as a combiner in output. A schematic description giving the dimensions of the device is presented in figure 1. The phase states of outputs of the first MMI device (splitter) and of inputs of the second one (combiner) are computed with theoretical formulae[11] as well as simulations might be performed with our home made software which can be run on our web-site[12]. The differences of optical paths between each guide of the array are then adjusted relatively to the shortest arm : the relative length of the other arms are respectively Ll-L4=1205.4 µm, L2-L4=1005.1 µm and L3-L4=603.1 µm. These difference in arms lengths ensure correct phase states at the inputs of the combiner to get one and only one output excited, different for each wavelength.

The device is designed to filter 1.548µm, 1.550 µm, 1.552µm and 1.554 µm, but the behavior is theoretically cyclic : it works for four consecutive wavelengths with 2 nm increment, provided that the MMI couplers give a homogeneous division. For the proper wavelength, the theoretical cross-talk varies between -25dB and -45dB according to the outputs.

The complete WDM circuit is imprinted in the guiding structure according to the organic-inorganic technology presented above. A curvature radius of 2 cm is used to ensure negligible bending losses. Present calculations show that a radius of 2 mm leads to bending loss about 0.1 dB/cm.

The device is tested with a tunable laser diode and an infrared camera. When scanning the wavelengths over a wider range, a cycle of 8 nm is observed for each output, this corresponds to the theory. Figure 1 presents the output answers of the circuit excited from the input guide 1 at the wavelengths chosen for the design: 1.548, 1.550, 1.552 and 1.554 µm. Each wavelength is clearly connected to a predefined output guide. Measured levels at other outputs varies from -8 dB to –13dB (versus 0dB) in our experimental realization: This indicates a reasonable cross-talk for a WDM based on multimode interference made in this low cost technology. These promising results can be improved by an optimization of the homogeneity of the division, and a better control of the geometric dimensions at the level of the fabrication.

4. MULTIPLEXING BY CODE : PRINCIPLES

In the basic technique of code division multiple access (CDMA), each bit of message " 1 " or " 0 " is replaced at the level of each transmitter by a code attributed to each user. This code is a pseudo-random sequence of "chips"[- 1, 1, 1, - 1...] and its complement for "0". In the basic technique for CDMA, because of the chip-rate is N times the symbol rate, the spectral band is N times larger ("spread spectrum").

In reception the correlation with the specific codes makes it possible to extract the messages (figure 2). The codes are to be orthogonal (orthogonal codes of Walsh, or m-sequences, or Gold codes) to ensure a negligible correlation when the wrong code is used.

The application in optics of the techniques of spread spectrum to share transmission medium cannot be a simple transposition of the techniques used in radio frequencies (mobile telephony of third generation..or GPS system), because detection rests *a priori* only on the intensity of the signal. The principles were formulated by Salehi which suggested the use of unipolar orthogonal codes [0,1] so-called " optical codes". The symbol "1" is coded by a time sequence of short pulses (10-100 psec i.e. spread spectrum) obtained with a network of parallel lines with delays ("tapped delay lines"). The decoder consists of combined delay lines which realign the pulses issued from the transmitter chosen, which are added to rebuild an impulse of strong amplitude : it needs a non-linear element to discriminate simultaneous pulses from a sequence of close pulses. The pulses which don't correspond appear as noise. Because only positive intensity is exploitable, the system is unipolar, the quantity of pulses ("weight")/symbol of message is weak, the number of orthogonal codes, thus the number of users is weak. Many alternatives were explored to improve this technique.
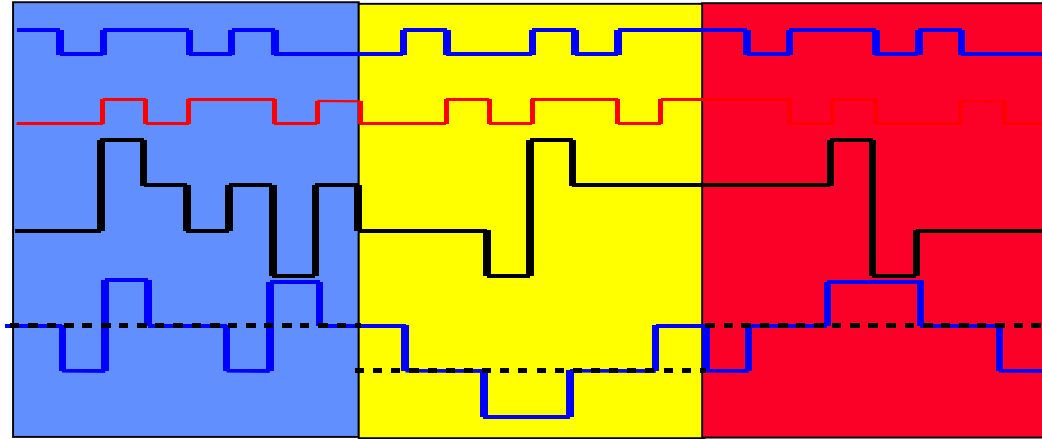
Fig. 2: From top to bottom: - coded signals A and B (code with 8 " chips "), - transmitted signal, - signal decoded for user A with average/symbol (---) obtained by filtering

Bipolarity is necessary to optimize the number of orthogonal codes : the sums of the pulses of both polarities are compared : -equal if there is no correlation between the received signal and selected code, -unequal if the message is " 1 " or " 0 ". Bipolarity may be introduced by using - two phases [0, π], separated with detection, - two wavelengths, two physical channels, two polarizations or temporal multiplexing. Zaccarin and Kavehrad[13], then Lam[14] suggested a spectral variant of CDMA: the code is a spectrum characterized by a set of wavelengths.

5. MULTIPLE ACCESS BY SPECTRAL CODE

It is possible to design devices where the code is defined in the wavelengths-domain ' . A broad source - controlled electronically at the rate of the symbols is filtered: each bit " 1 " or " 0 " is a selected definite unit among 2xN wavelengths. Since there is no cyclic risk of correlation, one can use orthogonal codes like the codes of Walsh. If one is satisfied with codes with weak but non-null periodic autocorrelation, the number of users can be about N^2 (" Gold codes ") by considering N possible shifts distributed among the users.
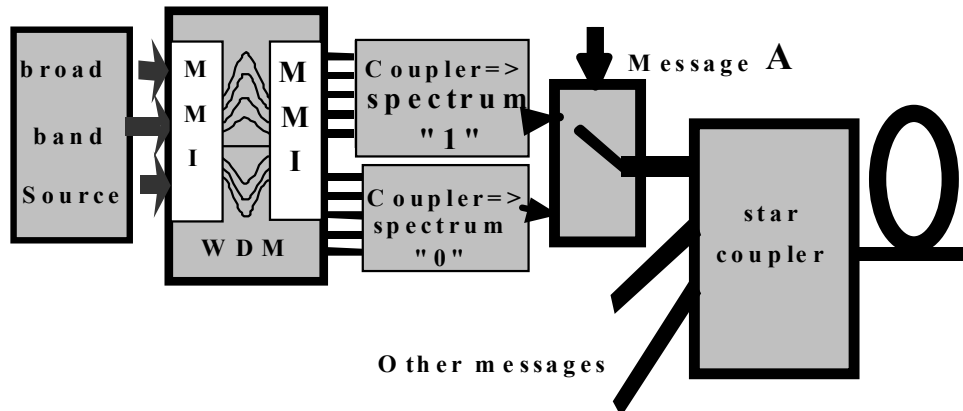

Fig. 3 : CDMA Optical Transmitter with spectral encoding.

The broad band source (doped Fiber, superluminescent LED) feeds a device synthesizing a given spectrum for the "1" and the complementary spectrum for the "0". Instead of doing this spectra synthesis with optical mask[13], or series of MachZehnder[14] , we use a MMI phasar such the one presented in section 3, where adjacent outputs do not correspond to adjacent wavelengths. This enables to build spectra corresponding to orthogonal codes by regrouping per half the

wavelengths according to the outputs placements. The spectrum corresponding to the " 1 " or to the " 0 " is added onto the optical link, through an optical switch according to the message to transmit.

Detection uses a analog scheme where the switch is replaced by two photodiodes for a measurement out of differential of the outputs of the couplers. We propose the use of WDMs realized according to the MMI technique: the close outputs in such a device do not correspond to close wavelengths, moreover, the wavelengths of output are permuted if the input of first MMI is changed: By feeding (entered 7) a WDM built with two MMI to 8 ways, on the four first outputs one recover λ_0, λ_1, λ_3, λ_6 which constitutes the spectrum of the 1 " then " and which corresponds to the positions of the bits with one of the code C_A on figure 2; the spectrum from the " 0 " is complementary. If input 2 is used, one finds the code C_B of figure 2.
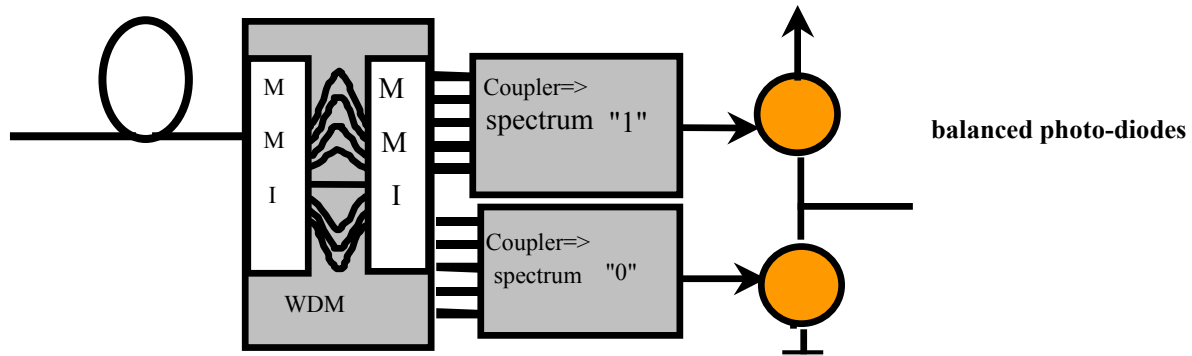

Figure 4: CDMA receiver with spectral decoding

6. CONCLUSION

The organic inorganic technology is adapted to the development of passive devices for multiple access in optical telecommunications. Wavelength division multiplexers can be easily implemented through the use of compact MMI circuit. Also, these latter circuits allow the fabrication of code division multiplexer based on spectral encoding working with non coherent source The economy on the safety margins in the separation of wavelengths, on the taking into account of the temporary inactivity should allow a significant spectral effectiveness.

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