Invited paper

Index difference evaluation using optical circuits in organic-mineral material

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Abstract : Organic mineral technology is now a good alternative to develop integrated optical circuits. The process needs only a few steps with low-cost equipment. The index change due to simple UV polymerization, usually performed through a mask, is now sufficient to confine light beams in many optical circuits which are designed. The facility to print functional circuits conjugated with the facility to run computer simulations lead to a simple measurement methodology derived from comparisons between simulated and measured performance.

Introduction

New technologies based on organic-inorganic materials[1,2] are shown to be very flexible, while they present interesting performance. Several solutions have been given to design basic structure of guides and hence to make optical circuits which cover the domain of power splitters to DWDM including directional couplers, gratings… To ensure a perfect reproducibility, every parameter has to be studied, the index change between the core and the cladding in circuits plays a key role and is particularly examined here.

In next section, the fabrication process leading to a combined network of organic-inorganic material is given, while direct index measurements are proposed in section 3. Section 4 gives a brief summary of the computer tools developed, and following sections give examples of circuits which give through exploratory simulations a way to evaluate index changes.

Fabrication of a basic organic-mineral guiding structure

The vitreous, deposited by dip coating to make thin layers, is characterized by the conjunction of two networks : the mineral network derives from the sol-gel process while the organic network is created by the polymerization of double bonds under UV action.

The basic guiding structure consists of three layers deposited on a silicon substrate: buffer layer, guiding layer and protective coating. The basic material[3] is synthesized by hydrolysis and polycondensation of methacryloxypropyl trimethoxysilane (I). Methacrylic acid and zirconium n-propoxide are combined with (I) in a ratio 2.5: 1: 1. Each layer needs no more than four steps : synthesis, deposition, UV exposure (for the guiding layer), thermal treatment. All depositions are made by dip-coating on a silicon substrate.

A photosensitizer is added to the sol for the guiding layer. This enables the drawing of optical circuits through a local refractive index increase caused by UV-polymerization. The symmetry of the guide section is ensured by the addition of a protective coating. This upper layer is scratch resistant, and UV transparent[4].

The circuit is imprinted in the guiding layer through the protective coating by UV exposure through a predefined mask which can combine several functions as well as test structures in which we are interested here. An alternative to the printing through a mask the direct writing using a He-Cd laser[5] emitting at a wavelength of 325 nm. After the UV polymerization (through a mask or by laser direct writing) the sample is stabilized by a 30 min. final heating at 120 °C. This enables the formation of a solid mineral network.

Refractive index

The basic index can be as low as 1.46 using silicate precursors, and can be much higher using aluminates, zirconates or titanates… It can be precisely adjusted to the values encountered in plastic or silica fibers. Within this index range, the local index change can be selected between 0.0001 to 0.03 by ultraviolet polymerization of the organic part. The basic index may vary in the near infrared, but the index difference is kept unchanged.

The polymerization is depending mainly on the presence of a double bond C=C, of a UV photon and a photosensitizer at the same time in the same place when the mineral network is not yet established.

A measurement of the basic index can be performed within a layer deposited on a transparent substrate : the reflections at the top and the bottom of the layer interfere. When the light injected has several wavelength (white light is chosen) the interference patterns give two informations : The interference magnitude allow refractive index calculation, while interference period, knowing the refractive index, gives the layer thickness[6]. The refractive index is evaluated with an accuracy better than 0.1% . This method can be applied to polymerized part (to evaluate the index change) but needs a large polymerized part with a large surface on the sample, i.e. dedicated samples. The saturation value of the index change is clearly demonstrated, as well as the penetration depth which is much higher than the typical layer depths (up to 10 microns). This implies a constant index change versus the depth.

The university of Lille has developed a dynamic measure of the index change[7] through the diffraction efficiency of visible light at the surface of a sample, while a modulated index grating is being UV imprinted. Besides the well known strong non linearity of the curve index change versus UV absorbed energy, besides the numerous parameters playing a role in the value of the saturation level, the index change is observed as a time delayed (several minutes) reaction.

Computer Tools for parameter extraction through simulations

The measurements of index change can be performed not only on dedicated samples but also through functional circuits. This is made possible by the development of simulations with software tools.

The emergence of the technology based on organic-inorganic materials has widened the possibilities to rapidly design new optical circuits. New tools are needed to develop waveguide structure with complex shapes, multilevel optical circuits to increase density, or interconnects with level coupling. Improvements over existing software have been made, for instance integrations are performed over bilinear elements : the modes of waveguides of nearly any shape can be analyzed with accuracy. Our beam propagation code enables the description of several circuit levels one over the other. This allows to simulate our multilevel circuits, to optimize thickness or to study the guide coupling.

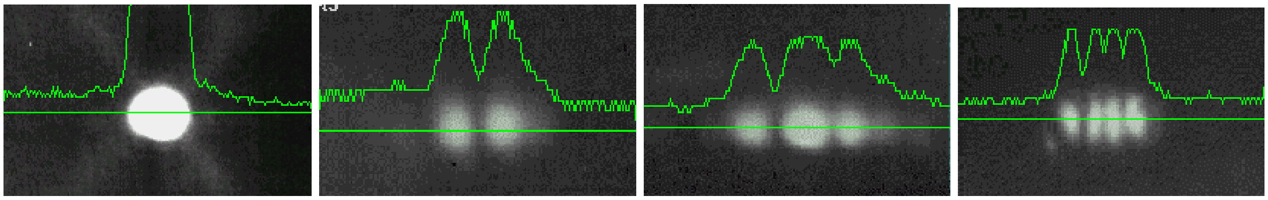
More important here : besides the predictive use of these tools, parameter extraction can be performed by comparing the observed results and the simulated. This use is made comfortable, because the sofware codes do not need a special knowledge, or long installation : the tools are written in the Java language with a truly object oriented approach. This allows us simplified maintenance and easy extensions, and provides a standard user-friendly interface. The tools are portable on any kind of computing system (thanks to « Java virtual machine ») and can be run through Internet[8] i.e. the application programs are converted to « applets ». Figure 2 in section 6 shows typical screens of an internet session of beam propagation simulation.

Besides an accessory graphical application analyzing a line on a picture defined with the mouse, this, to evaluate the transverse profiles in near field photographs at the output of guides (see figure 1 in next section), we have developed software for modal analysis, and beam propagation codes, eventually on several coupled levels[9].

Mode profiles, effective indices in straight channel waveguides

The most simple structure is naturally the straight wave guide which present the advantage to be easy to model. Though the analytical resolution is only available for circular guides (fibers) or slab waveguides, both the effective method index, or the numerical extraction of the eigenmodes can be performed with accuracy enough. We have developed several modeling tools to study the transverse field profiles in guides of sections such as those encountered with our technology.

Figure 1 : Near field images at the outputs of a straight waveguide depending on injection.



One of our program, which can be run over Internet, is based on the effective index method : it requires two steps (vertical study and horizontal study) to compute the modes : their number, their effective index, and their profile depending on the width of channels and difference of indexes.

A more precise software[10] based on the resolution of the Helmholtz equation (eigenvalues search), after sine expansion in two directions, give the effective indexes and field profiles. This can be directly compared with the modes observed with an infrared camera, when light is injected in parallel waveguides of width varying from 2 to 10 microns.

Table 1 shows an exploration of all the guided modes for square ridge guides, with varying side from 4.5 to 8 microns and with an index change between 0.005 and 0.024.

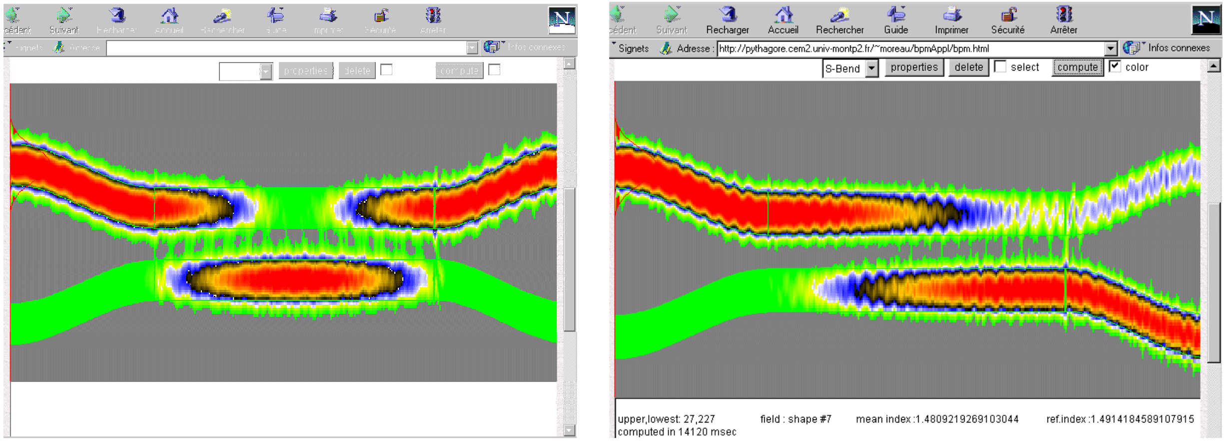
Table 1 : Effective index of guided modes in channel waveguides of various width and Δn

Δn \ width	**4.5**	**5**	**5.5**	**6**	**6.5**	**7**	**7.5**	**8**
0.01				1.47904	1.48064	1.48182	1.48271	1.4834
0.015			1.48077	1.48344	1.48528	1.48656	1.4875 1.47965	1.48823 1.4812
0.02		1.48107	1.48529	1.48815	1.49008	1.49142 1.48139	1.49239 1.48374	1.49313 1.4856 1.48163
0.024		1.48459	1.48904	1.492	1.49397 1.48132	1.49534 1.48464	1.49632 1.48728 1.4812	1.49708 1.48928 1.48554

Directional couplers and beam propagation simulations.

If room can be found on a mask to print a coupler, the evaluation of the index change can be made. Figure 2 shows the role played by the index change for a given coupler. Couplers may be designed in cascade to measure accurate index change.

Figure 2 : Beam propagated beam in a directional coupler with index change of 1.49, 1.494 (Simulations run through Netscape browser over internet).



Adresse : http://pythagore.cem2.univ-montp2.fr/~moreau/bpmAppl/bpm.html

S-Bend ☐ select ☑ color

upper,lowest: 27,227 field : shape #7 mean index :1.4809219269103044 ref.index :1.4914184589107915
computed in 14120 msec

Multimode interference effect

The MMI effects[11] can also be used to evaluate the index change, however less sensitive than the directional coupler. An incident electromagnetic field from a single mode guide is injected into a large multimode structure. Each excited mode in the large guide has a specific propagation constant β_k, and thus, a different propagation speed. After a propagation length z, in the multimode guide, the field profile corresponds to the superposition of the field associated with each guided mode k.

The propagation speed differences result in interference between the guided modes. The field can be a reproduction of the incident field if: $\exp(-j\beta_k z) = 1$ for each mode (and for a given wavelength). The self-imaging is obtained for z = 2xL to be determined in each case by computations, when each mode has been propagated over an integer number of periods. At a distance of L measured from the injection point in the large guide, the field reconstruction is symmetrical with respect to the incident one. At distances L/2, L/3..., the field profile exhibits 2,3 … images of the incident field. Outputs placed at the positions of these images recuperate the major part of the energy : a low loss power splitter is designed.

A 1x32 power splitter made with the chosen organic-inorganic technology has been demonstrated[12]. The maximum number of images depends naturally on the number of modes i.e. on the width of the multimode guide and on the refractive index change between guides and cladding.

Conclusion

The technology based on organic inorganic vitreous material has many qualities (low cost, simple process…). Among them, a refractive index change is directly created by UV polymerization onto th organic part of the network. This index change can be as high as 0.03, a value large enough to design many types of optical circuits, which can be printed as side circuits in large optical integrated devices. Because simulations can be carried out in a very efficient way, fast comparisons between simulated and observed performance lead to parameter extraction such as the index change evaluation.

References

/1/ Proceeding No3469, "Organic-inorganic Hybrid materials for Photonics", SPIE-annual meeting, San Diego, July 1998.

/2/ P.Coudray, P. Etienne, Y. Moreau, "Integrated optics based on organo-mineral materials", Invited paper, European Material conference (E_MRS spring meeting) - Strasbourg (France), June 1-4th, 1999

/3/ H.Krug, F. Tiefensee, P. W. Oliveira, H. Schmidt, “Organic-inorganic composite materials : optical properties of laser patterned and protected coated waveguides”, S.P.I.E. Sol-gel optics II, 1992, vol.1758, pp.448-455

/4/ P. Etienne, P. Coudray, Y. Moreau, J. Porque, "Photocurable sol-gel coatings : channel waveguides for use at 1.55 µm", Journal of sol-gel science & technology, 1998, N°13, pp. 523-527

/5/ R.B. Charters, B. Luther-Davies and F. Ladouceur, “Laser direct writing of polymeric PLC’s using a TEM_{01}^{*} beam”, 23rd Australian Conference on Optical Fibre Technology, Melbourne, Australia, July 1998, pp.37-40

/6/ O.S. Heavens, "Optical Properties of thin solid films", Dover Publicatins, New York, 1991

/7/ W.Xie, P. Niay, P. Bernage, M. Douay, T. Taunay, J.F. Bayon, E.Delevaque, M. Monerie, "Photoinscription of Bragg gratings within preform plates of high NA germanosilicate fibers : searching for an experimental evidence ogf type IIA photosensitivity in preform plates", Opt. Comm. 124, (1996), pp.295-300

/8/ see Web : http://w3.cem2.univ-montp2.fr/~moreau/

/9/ Y.Moreau, J.Porque, P. Coudray, P. Etienne, K. Kribich, "New simulation tools for multilevel optical circuits", SPIE,annual meeting, Denver, July 1999

/10/ http://w3.cem2.univ-montp2.fr/~moreau/modAppl/basic.html

/11/ Soldano, L.B., and Pennings, E.C.M.: Optical multimode interference devices based on self-imaging: Principles on application, J. Lightwave Technol., 1995, LT-13, (4), pp.615-627

/12/ P. Coudray, K. Kribich, R.Charters, P. Etienne, Y. Moreau, 1x32 power splitter MMI using laser fabricated in an inorganic-mineral material, Electron. Letters, to be published.