Increasing the functionality of free-space micro-optical intra-chip modules with DOE's: towards reconfigurable photonic interconnects.

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ABSTRACT

We study the potentialities of three dimensional micro-optical interconnection modules combining refractive microlens arrays, reflective micro-prisms and diffractive fan-out elements, to enhance the functionalities of short-distance intra-chip optical interconnects. As an example, we demonstrate the possibility to enhance the point-to-point interconnection functionality to that of broadcasting data over a chip. We then illustrate this example by a quantitatively elaborated design of a fan-out element from a VCSEL array to a detector array with a 1 to 9 signal broadcasting for every source. Furthermore we show that with the use of DOE's we can achieve a broadcasting functionality that can lead towards reconfigurable optical interconnects, with the aid of wavelength sensitive resonant cavity detectors and WDM-inspired interconnection schemes.

1. INTRODUCTION

Recently the idea of massive parallel optical interconnect was demonstrated within the European Commission ESPRIT-MELARI project 22641 "OIIC". This project has mainly been working towards a manufacturable solution for optical interconnects between CMOS chips[1]. The concept was extended at the Applied Physics and Photonics Department of the Vrije Universiteit Brussel, and multi-channel *free-space on-chip* optical interconnects have been demonstrated for the first time[2]. However, increased optical functionality might give micro-optics an additional and distinct advantage over galvanic interconnect technologies and could be the motive for optics to take the leading edge in short distance interconnects. In the next sections we demonstrate the possibility to enhance the point-to-point interconnection functionality to that of broadcasting data over a chip, using a DOE on the sidewall of a micro-prism.

2. DESIGN AND SIMULATION

A new design of an optical interconnection module (OIM) with broadcasting functionality was modeled with Virtual Lab 1.0 software. This software is understood as a complementary software package to established raytracing software. It allows to simulate on mixed optical systems, combining refractive an diffractive optical elements in one and the same optical system. The complexity of the optics design is handled by only focusing on the functionality of the separate optical elements instead of trying to optimize all structural parameters of the design at once. For simulation purposes, we do have to take into account the restriction of the software to sequential propagation in a homogeneous medium. Simulations on the OIM, developed at the Applied Physics and Photonics Department of the VUB, are necessary to determine if the physical dimensions of the element allow for integration of broadcast functionality. Diffraction

spots of the DOE should fall onto the micro-lenses at the receiver side, so they are focused and coupled into the detectors. The spot pitch and the distance "DOE – receiver lens array" completely determine the grating pitch of the DOE design. In Fig. 1. the concept is outlined and the diffraction formula, linking the "spot pitch – optical distance" and grating pitch, is given in Fig. 2.
In the simulation model of the proposed OIM, we consider only a single channel at the sending side. At the receiver side, we model 9 receiver channels in a 3 by 3 configuration. The optical elements in the simulation model come into sequence. The sequential model is shown in Fig. 1. The sequence contains a VCSEL source, followed by a collimating microlens, the optical prism pathway including a DOE (simulated in transmission), the 3 by 3 focusing microlens array at the receiver side and the detector plane. Only the design of a phase-only DOE is considered, since later on the heterogeneously integrated optical system of refractive microlens arrays, microprism and DOE will be replicated into a monolithic OPB for dynamical reconfigurable optical interconnect. VCSEL sources at the sending side of the OPB were modeled as perfect Gaussian emitters, having a full width half maximum (FWHM) divergence of 12° half angle. The refractive microlenses of sender and receiver microlens arrays were modeled as diffractive counterparts. These diffractive lenses had the same lens diameter of 200 µm, lens pitch of 250 µm and lens focal length of 520 µm. They are also modeled as phase-

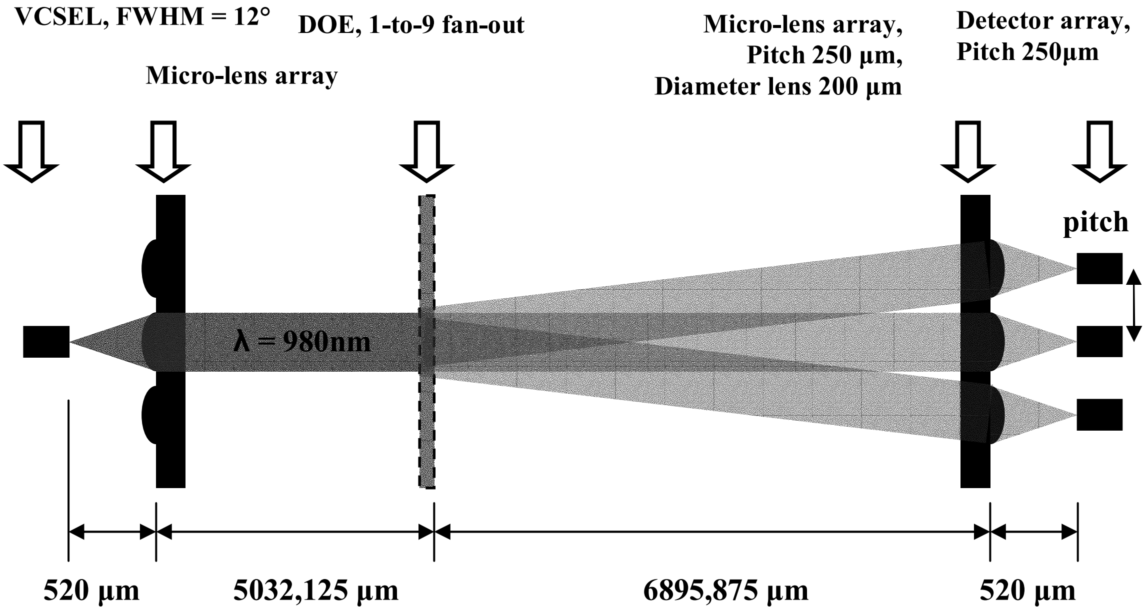

Fig. 1: Virtual Lab simulation model of the optical pathway block equipped with DOEs. The model includes a VCSEL, a 3 by 3 lenslet array, a DOE for 3 by 3 spot fan-out functionality, a second focusing 3 by 3 lenslet array, and a detector plane.

only elements, with lens amplitude transmissions of 100%. The distances denoted in Fig. 1 have been calculated for a specific microlens of the sender lens array. The considered sender channel is indicated at the schematic bottom view of the OPB in Fig. 2. The distance "sender microlens array – DOE" and "DOE – receiver microlens array", have been rescaled using the appropriate index of refraction of 1.491 for the PMMA optical plastic material. For FS propagation of the electromagnetic field in air, from the second lenslet-array to the detector, we used an index of refraction of 1. The total distance which has to be bridged by the electromagnetic field is 12.448 mm. The optical pathway length in the OPB is 8 mm. This distance is multiplied with the refractive index of the OPB material and 520 µm of optical distance is added for the propagation distance from receiver lens array to the detector plane, resulting in a total distance of 12.448 mm. To bridge such a large distance, the Rayleigh-Sommerfeld propagation method was used as simulation model. A 1-to-9 diffraction fan-out functionality was realised by designing an elementary phase-only DOE. This beam splitting element was designed using the Iterative Fourier Transform Algorithm (IFTA) of Virtual Lab. During the IFTA design of beam splitters only one period of the in general periodic transmission is optimised. The discrete Fourier transform of this period gives a field containing the complex amplitudes of all orders of the beam splitter. As a first step, the desired signal field is generated. This ideal output field is a plane wave uniform field with 3 by 3 pixels for the 3 by 3 signal orders. For beam splitter designs, a signal field with randomly chosen signal order phases has shown to be a good selection. Therefore a random phase was superimposed to the ideal output field. The iterative Fourier transform algorithm inversely propagates the desired output field and generates the starting transmission field, which is the wanted design of the elementary DOE. The elementary DOE used for our simulations was quantised for eight phase levels. When the DOE is placed at the correct distance in our simulation model, indeed 3 by 3 diffraction spots are generated. These spots exactly fall onto the lenses of the receiver microlens array and are focused to 7 µm spots in the detector plane.The bottom view of Fig 2. shows the source channel in black and the broadcast target channels in gray. The simulations show for this particular channel that a 1-to-9 diffraction fan-out is feasible in the physical dimensions of the OPB. However when the simulation is repeated for a source channel of another longitudinal lens row, another basic elementary DOE design is needed. Although the total optical pathway length remains constant for all source channels, the actual distance from the DOE to the receiver lensarray does change when considering a different longitudinal microlens row ! Since the optical pathway available for diffraction separation is not constant, ideally every longitudinal microlens row would require its own custom designed basic elementary DOE.

CROSSTALK MEASUREMENTS

When evaluating simulation results, we have to distinguish between diffraction signal and noise orders. Signal orders represent the wanted replications of the input beam and noise orders represent additional unwanted replications, which are in general unavoidable due to the transmission constraints, i.e. the requirement for a phase-only DOE in our design. Stray light is falling between the micro-lenses but will not be unintentionally coupled into the detectors. Besides the stray light, more dramatic are the noise diffraction spots which can be noticed outside the 3 by 3 lensarray. Future optimisation of the design of the DOE should minimise the energy coupled in these noise modes. Noise diffraction modes will be unintentionally coupled into the detectors by neighbouring microlenses. Some energy is diffracted in unwanted spots. The energies in unwanted receiver channels were measured to account for 0.11 %, 0.08 %, 0.03 %, 0.12 % and 0.26% of the total energy incident at the receiver lensarray surface.

CONCLUSION

In this paper we have studied, based on the Rayleigh-Sommerfeld propagation method, the possibility to enhance the functionalities of short-distance intra-chip optical interconnects. As an example, we have demonstrated the possibility to enhance the point-to-point interconnection functionality to that of broadcasting data over a chip within the given physical dimensions of an existing optical pathway block. This optical pathway block combines refractive microlens arrays, reflective microprisms and DOE's. This preliminary work has led to the design of a diffractive fan-out element enabling 1 to 9 signal broadcast for every source from a VCSEL array to a detector array. Combination of this newly designed optical pathway block with multiple-wavelength VCSEL array and tunable resonant cavity detector array is a possible candidate for WDM-inspired reconfigurable optical interconnect in the near future.

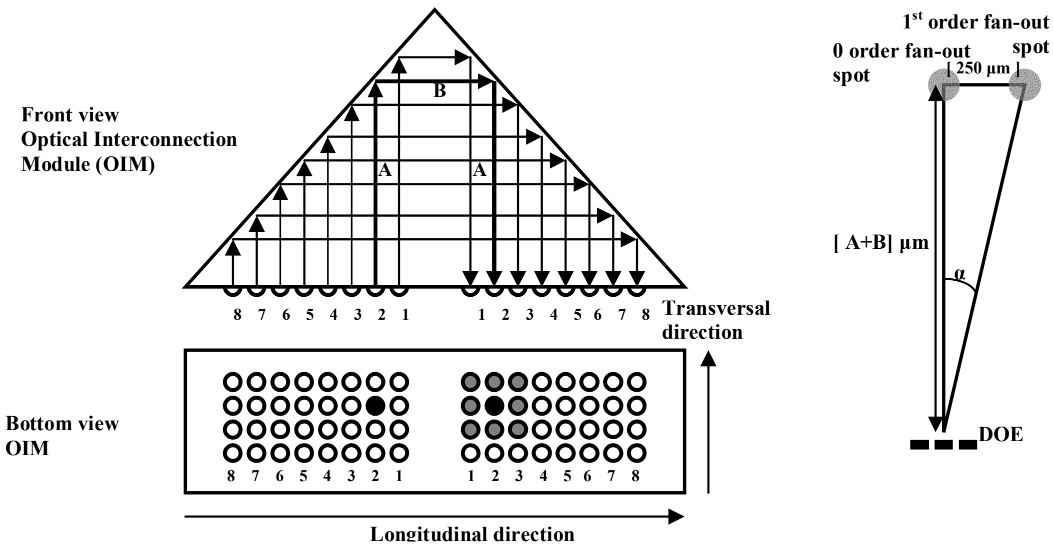

Fig. 2: (top) Optical pathway block schematic showing front and bottom view. Longitudinal and transversal directions are defined and longitudinal micro-lens array rows are numbered. Each of the source channels is focused on its corresponding receiver channel. The optical pathway length measured from lensarray to lensarray, is the sum of distance B and 2 times distance A. At the bottom view, the positions of the source and receiver channel used in the simulations are colored black. When integrating a 1-to-9 fan-out DOE at the left sidewall of the microprism, eight surrounding receiver channels are also reached by the source channel. These receiver channels are indicated with a gray color in the bottom view of the OPB scheme. (right) Diffraction formula for calculation of the elementary DOE grating pitch. Since distances A and B can differ, each longitudinal microlens array row ideally needs a custom designed elementary DOE with a fitting grating pitch D.

$$\tan\alpha = \frac{250\mu m}{n.(A+B)\mu m}$$

$$D = \frac{\lambda}{\sin\alpha}$$

$$\lambda = 980nm$$

$$n = 1.491$$

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