THE FOURTEENTH MICROOPTICS CONFERENCE

MOC '08

Sept. 25 (Thu.)
Sept. 26 (Fr.)
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TECHNICAL DIGEST

Organized by

Vrije Universiteit Brussel

Department of Applied Physics and Photonics

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LEAKY MODE MEDIATED HIGH EFFICIENCY GRATING EXCITATION OF HEAVILY MULTIMODE SLAB WAVEGUIDES

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Abstract: *A grating coupler located at the basis of a multimode slab waveguide and composed of a corrugated metal mirror with conformal high index dielectric coating diffracts an incident beam into the different modes of a multimode slab waveguide with an unexpectedly high efficiency.*

Grating coupling of a free space beam to a mode of a slab waveguide can be optimized by adjusting the grating radiation coefficient and the beam diameter as well as the position of the beam impact zone in the corrugated area [1]. The theoretical limit of 80% for a Gaussian beam can be pushed to 100% by using a blazed grating [2] or a phase shifted double corrugation [3]. Interestingly, more than 30 years after these pioneering works have laid down the basic principles, grating mode coupling is now given a concrete objective and an enabling technology by the development of on-chip optical interconnects; impressive coupling efficiency has been reported from/to a single mode fiber to/from an all-silicon waveguide wire [4].

High efficiency grating coupling into a multimode waveguide has always been considered as irrealistic since the radiation coefficient, which is proportional to the normalized field strength in the corrugated region, is very small in a thick waveguide for all the guided modes. Multimode waveguide grating coupling can however be envisioned from a free space diffraction stand point whereby a light beam incident from a homogeneous half-space impinging onto a corrugated dielectric film backed by a plane or corrugated lossless mirror experiences 100% -1st order diffraction efficiency provided the layer thickness t_{lm} and index n_{lm}, the wavelength λ and incidence angle θ satisfy the resonance condition of a leaky mode of the mirror-based structure [5]. The key issue is that under such condition the Fresnel reflection coefficient can be cancelled which implies that the optical energy has nowhere else to propagate but along the –1st diffraction order. Going from the said free space wave configuration to a multimode waveguide configuration is immediate: the role of the free space incident beam is played by the zigzagging beam corresponding to a mode propagating in the thick multimode waveguide. The incident medium has become the waveguide material of refractive index n_g instead of air. Figure 1 illustrates the high efficiency coupling mechanism. The law of inverse propagation of light ensures that high efficiency multimode waveguide input coupling is achievable by the same device.

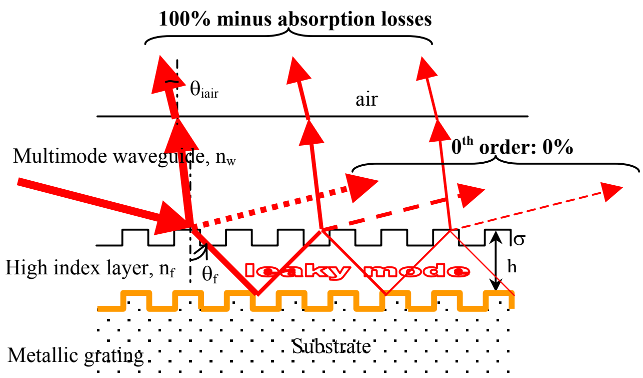

Fig. 1. Outcoupling resonant grating and scheme of the leaky mode mediated destructive interference of 0th order reflection.

The experimental demonstration was made with a device simulating an optical interconnection. Optical interconnects between boards will make use of a backplane made of a fiber reinforced epoxy substrate coated with a lowloss multimode waveguide layer of about 60 µm thickness and refractive index larger than 1.5. The input/output coupling approach which is widely envisaged presently uses inserts plugged into the waveguide where oblique input/output mirrors have been ablated by excimer laser machining [6]. Grating coupling hasn't been considered so far. The possibility of reaching high coupling efficiency is likely to place this technology as a possible candidate which has the interesting characteristics of being producible by batch processes at the board level.

The device aimed at the experimental simulation of an optical interconnection is shown in Fig. 2. It performs the input and output coupling as well as the waveguide propagation functions. It comprises an input grating, a gratingless guided propagation length of 30 mm, and an output grating identical to the first one. The waveguide is a 50 µm thick slab layer of index n_g =1.568. The critical element is the grating coupler in that it has to satisfy the condition for 100% diffraction. It is a bilayer of 100 nm thick gold and 200 nm thick hafnium oxide deposited by sputtering. The metal-dielectric bilayer was deposited onto a 550 nm period, 165 nm deep surface corrugation etched in a pyrex substrate. At the wavelength λ = 850 nm, and with a period Λ = 550 nm the narrow angular spectrum of the guided modes ($90° < \theta_g < 68.44°$) gets extracted into the air cover under a 1.29° to –5.00° angular range. Under such grazing incidence the dispersion equation of the leaky mode propagating in the high index layer between the gold mirror and multimode waveguide basis is essentially satisfied for all the modes:

$$k_0 n_f h \cos\theta_f + (\phi_m + \phi_c)/2 = m\pi \quad (1)$$

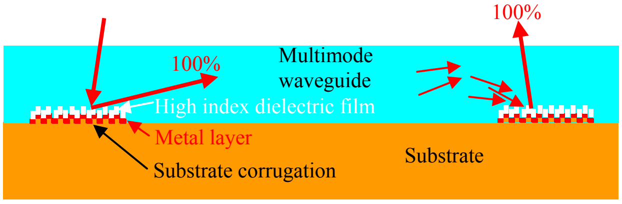

Fig.2: Experimental simulation of an optical interconnect input/output multimode waveguide grating coupler

where $k_0 = 2\pi/\lambda$ is the wave number in vacuum at wavelength λ, h is the multimode waveguide thickness, θ_f is the incidence angle relative to the normal in the high index layer ($\theta_f = \sin^{-1}(n_g/n_f \sin\theta_g)$), m is an integer number, ϕ_m and ϕ_c are the reflection phaseshifts of the wave zigzagging in the high index layer at the metal and waveguide borders respectively. For a TE polarized wave,

$$\phi_c = 0$$

$$\phi_m \cong \pi - \mathrm{arctg}\left(\frac{2\sqrt{n_l^2 - n_c^2 \sin^2\theta_i}}{\sqrt{-\varepsilon_{mr}}}\right) \quad (2)$$

where ε_{mr} is the real part of the metal permittivity [7].

The functional test of the experimental model was made at 850 nm wavelength under slightly off-normal contradirectional coupling, successively with a collimated and a slightly focused incident beam, and TE polarization with adjustment of the beam axis relative to the front of the grating area to avoid double diffraction by the input grating. The power throughput P was measured some centimetres away from the output grating. Figure 3 illustrates the dependence of P versus the incidence angle on the input grating. The excitation of the different modes of the waveguide can be clearly distinguished when the beam coupled into the waveguide is collimated. Considering that two diffraction events are involved as well as a 30 mm long waveguide propagation, the maximum throughput of 61 % reached when the device is excited with a slightly focused incident beam is a remarkably high preliminary results which compares well with the present mirror insert coupling technology.

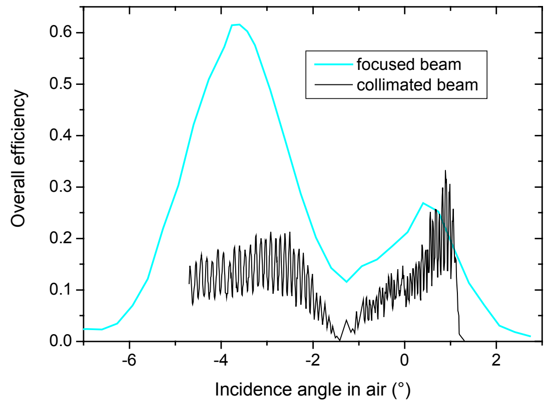

Fig.3: Overall efficiency measured with a focused and a collimated beam at 850 nm wavelength under TE polarization

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References

[1] M.S. Klimov, V.A. Sychugov, A.V. Tishchenko, O. Parriaux, "Optimization of optical waveguide grating couplers," Fiber Integ. Opt., **11**, 85-90 (1992)
[2] A. Gruss, K.T. Tam, and T. Tamir, "Blazed dielectric gratings with high beam-coupling efficiencies," Appl. Phys. Lett. 36, 523-525 (1980)
[3] I.A. Avrutsky, A.S. Svakhin, V.A. Sychugov, O. Parriaux, "High-efficiency single-order waveguide grating coupler," Opt. Lett., **15**, 1446-1448 (1990)
[4] J.V. Galan, P. Sanchis, J. Blasco, J. Marti, "Study of High Efficiency Grating Couplers for Silicon-Based Horizontal Slot Waveguides," IEEE Phot. Tech. Lett., 20, 985-987 (2008)
[5] A.V. Tishchenko, V.A. Sychugov, "High grating efficiency by energy accumulation in a leaky mode," Opt. Quant. Electron., 32, 1027-1031 (2000)
[6] N. Hendrickx, J. Van Erps, G. Van Steenberge, H. Thienpont, and P. Van Daele, "Tolerance Analysis for Multilayer Optical Interconnections Integrated on a Printed Circuit Board," J. Lightwave Technol., **25**, 2395-2401 (2007)
[7] M. Flury, A.V. Tishchenko, O. Parriaux, "The leaky mode resonance condition ensures 100% diffraction efficiency of mirror-based resonant gratings," J. Lightwave Tech., 25, 1870-1878 (2007)