Combination of binary and analog lithography to fabricate efficient planar-integrated free-space optical (PIFSO) interconnects

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We report about the design, fabrication, and experimental testing of PIFSO-type optical interconnect modules in which diffractive optical elements with multilevel and continuous profiles are combined to optimize the coupling efficiency. For fabrication binary lithography plus reactive ion etching and analog (HEBS-type) lithography plus replication in polymer (ORMOCER) is employed, respectively.

1 Indroduction

Planar-integrated free-space optics is a highly suitable system concept for realizing densely packed parallel free-space optical short-range interconnects that are compatible with established design and fabrication methods of integrated microelectronics [1]. For use in real-world IT systems, however, the coupling efficiency of such PIFSO interconnects needs to surpass levels of the order of –15dB of previous proof-of-principle demonstrators.

2 System approach

To this end we include elements with continuous surface profiles into the optical system design. Their high energetic efficiency is combined with the design freedom and high functional reliability of multilevel diffractive optical elements to demonstrate PIFSO-type interconnects between MT-connected fiber cables with lower loss than an all-diffractive implementation could provide. Two basic system designs (Abb.1) in which continuous-profile coupling lenses are used either in transmission or in reflection are compared. The reflective approach is more complex but can achieve the same optical effect with much more shallow surface profiles [2].

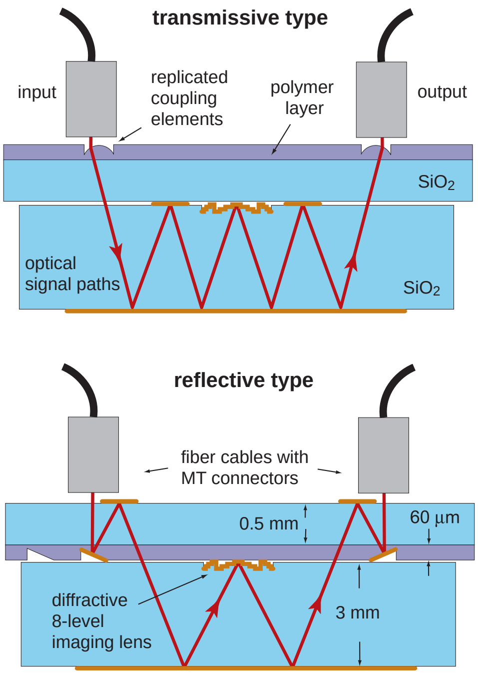

***Abb. 1**: Design approaches for fiber-PIFSO interconnects with multilevel and continuous optical components.*

3 Fabrication

Multilevel and continuous components were realized on separate substrates in Hagen and Jena using binary lithography plus reactive ion etching and analog lithography based on HEBS-glass masks plus a system replication into a thin layer of polymer (ORMOCER) on a SiO_2 carrier, respectively. Abb.2 shows the finished lower substrate of the “transmissive-type” system.

To monitor the shape fildelity of the countinuous-profile elements a linear test wedge was incorporated into the replicated system part (Abb.3a). Its profile was measured with a profilometer and compared with the design data. In Abb. 4 both curves are plotted as well as their difference. Deviations turned out to be less than 200 nm at a maximum profile depth of 40 μm.

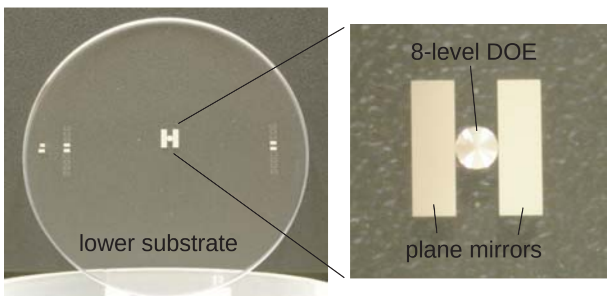

***Abb. 2**: Fully processed lower substrate of the „transmissive-type“ interconnect module with 8-level DOEs.*

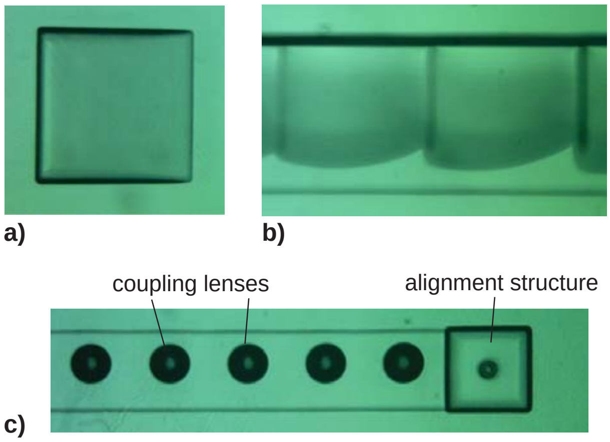

__Abb. 3__ Replicated components with continuous surface profiles: Linear test wedge (a), coupling lenses of the „reflective-type“ system (b) and of the „transmissive-type“ system (c).

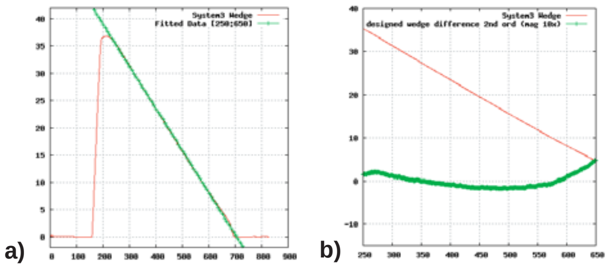

__Abb. 4__ a) Theoretical (green) and actual (red) profile of the linear test wedge, b) difference of both curves.

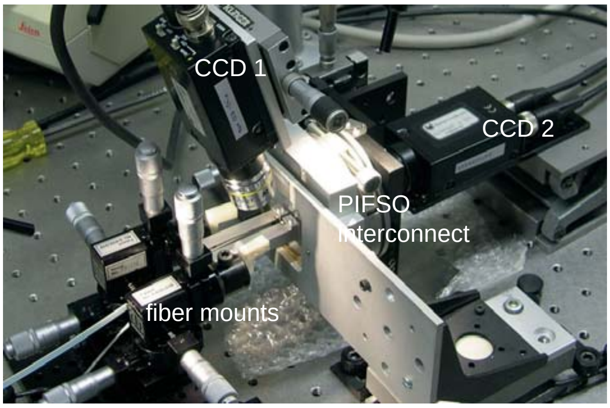

__Abb. 5__ Experimental setup for measuring the coupling efficiency of the fiber-PIFSO interconnect modules.

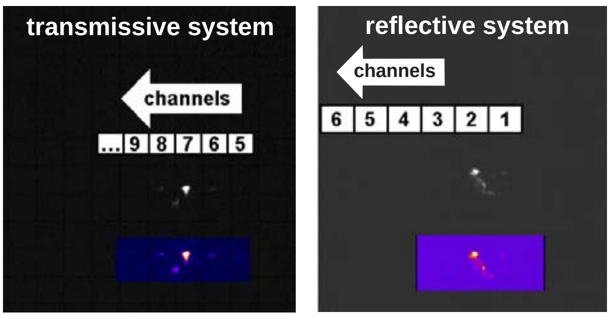

__Abb. 6__ Visual control of the interconnect performance by observing the signal spots generated at the output.

The profiles of the coupling lenses of both system types (cf. Abb. 3b,c) were also evaluated and found to have the same level of shape fildelity.

4 Experimental test

The experimental evaluation of the interconnect modules was carried out with the setup of Abb. 5. Optical signals (λ = 850 nm) were coupled in via single-mode fiber arrays that were mounted on micro-positioning stages. As targets both single- and multi-mode fiber arrays were tested. First, the signal spots generated by the PIFSO system were recorded and found to coincide with their designed positions. The images of Abb. 6 also reveal a reasonably good imaging performance of the 3-element optical imaging systems. Then, fiber-to-fiber coupling efficiencies were measured. Some of the results are listed in Abb. 7.

5 Conclusion

By combining the advantages of staircase-type and continuous-profile optical elements fabricated on the basis of binary and analog lithography, respectively, it was possible to improve coupling efficiencies and reduce losses of PIFSO-type interconnect modules by a factor of 3 compared to previous demonstrators.

reflective-type system				
unit: dB		output channel # (mm)		
		1	2	3
input ch. # (sm)	1	− 7	− 31.3	
	2	− 33.2	− 9.1	− 29.3

transmissive-type system				
unit: dB		output channel # (mm)		
		1	2	12
input ch. # (sm)	1	− 4.4	− 43	
	12			− 4.5

__Abb. 7__ Measured coupling efficiencies in dB.

References

[1] M. Gruber, J. Jahns, "Planar-integrated free-space optics – from components to systems", Ch. 13 in: J. Jahns, K.-H. Brenner (Eds.), Microoptics–from technology to applications, Springer, New York, 2004.

[2] R. Heming, „Efficient planar-integrated freespace-optical systems based on binary and analogue lithography”, Diploma Thesis, FernUniversität in Hagen, 2005.