Micro-optical fiber switch for a large number of interconnects

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Abstract— **We experimentally demonstrate two configurations for 1 × N free space optical switches with large number of interconnects. First, we use an adaptive deformable mirror which corrects for the aberrations. Second, we use an array of microlenses to minimize the aberrations. Power coupling efficiency (including losses due to the optical elements) ranges between 6 dB and 3 dB with the deformable mirror and between 3 dB and 2 dB with the array of microlenses for an optical switch allowing up to 3000 receiver fibers.**

I. INTRODUCTION

The deployment of optical telecommunication networks has boomed during the past few years in order to satisfy the ever growing demand for data transmission. In order to realize transparent optical networks, optical switches have to be developed. Optical switches with a few interconnects (1 × 2, or 2 × 2) have been published for a couple of years and are commercially available. Nevertheless, optical telecommunication networks need optical switches with a large number of interconnects. Alignment tolerances, diffraction of the Gaussian beams and aberrations are parameters which are more critical for optical switches with a large number of interconnects than for optical switches with a few interconnects. In this work, we present two original configurations for optical switches with a large number of interconnects. The first one uses an adaptive mirror to correct for the aberrations and the misalignments. The second one has an array of microlenses to minimize the aberrations and to relax the alignment tolerances. In this work, 1 × N optical switches are studied, aiming high power coupling efficiency.

II. EXPERIMENTAL SETUP

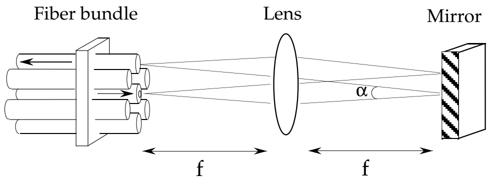

Fig. 1. Schematic setup of the free space optical switching system.

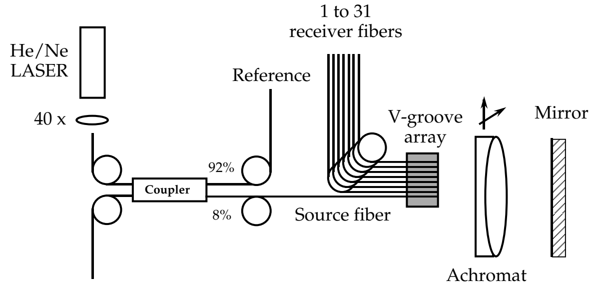

Fig. 2. Experimental setup of the switching system.

Figure 1 shows the basic optical system, which has two functions. First, it images a singlemode source fiber on a singlemode receiver fiber (coupling function). Second, it deflects the beam to address one of the receiver fibers (switching function). The experimental setup is schematically shown in Fig. 2. Light emitted from a He-Ne laser ($\lambda = 633$ nm) is coupled into a singlemode fiber using an aspheric lens. A 92%/8% coupler splits the signal into a reference fiber and a source fiber. The source fiber is part of a linear array of 32 singlemode fibers. The 32 fibers are held in a silicon V-groove array. The distance between adjacent fiber cores is 250 μm ± 0.5 μm. The mode diameter is $2w_s = 4.5$ μm, corresponding to a core diameter of $\phi_{core} = 3.8$ μm. The lens is an achromat (doublet) with a focal length $f = 40$ mm. Switching from the source fiber to any of the 31 receiver fibers is possible by moving the achromat laterally using a precision x-y stage with a resolution of ~ 0.14 μm. The ratio of the receiver and the reference signal gives the coupling efficiency. Using the first fiber as the source fiber demonstrates the feasibility of a system which is twice as large, assuming a symmetric displacement of the achromat. The 32 fiber linear array can therefore demonstrate the feasibility of a 1 × 62 1-dimensional system. Moreover, 2-dimensional arrays of fibers can be switched if the achromat is displaced in both x and y directions. The 32 fiber linear array can thus demonstrate the feasibility of a 1 × 3019 2-dimensional system.

A. Deformable mirror

In order to correct the aberrations generated by the achromat, we use a deformable mirror built by bulk silicon micromachining at T.U. Delft [1] (see Fig. 3). The membrane has a diameter of 15 mm. The surface of the membrane is coated with a reflective aluminum layer. Electrostatic deflection is generated by 37 electrodes, structured under the membrane with a hexagonal geometry. The maximum applied voltage is around 190 V. The membrane mirror has the capability to efficiently correct the first fif-

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teen Zernike polynomials. The optimization of the shape of the membrane for maximum power coupling efficiency of a connection is made with the help of an evolutionary algorithm [2].

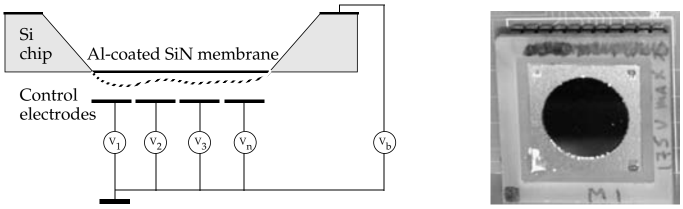

Fig. 3. Schematic drawing and photograph of the membrane micromachined deformable mirror [1].

B. Array of microlenses

In order to reduce the numerical aperture, and therefore the aberrations, we place microlenses on-axis in front of every fiber. Figure 4 shows the setup of the proposed system. The switching is again realized by laterally displacing the achromat. We choose a system with microlenses with 245 μm diameter and a focal length of $f_{ml} \cong 660$ μm to collimate the Gaussian beam from the source fiber and an achromat of 40 mm focal length to deflect the light. For fibers with $NA = 0.11$, the effective aperture of the achromat has a diameter of $0.22 f_{ml} = 145$ μm, which is only 0.8% of the total aperture diameter of the achromat. The beam is focused onto the receiver fibers with identical microlenses. The microlenses are fabricated by the melting resist technology [3].

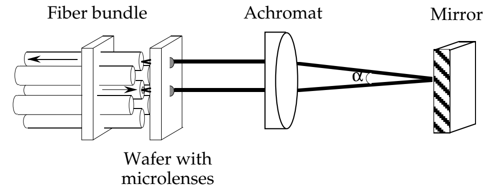

Fig. 4. Schematic setup of the free space switching system using microlenses to reduce the numerical aperture and an achromat to switch from the source fiber to the receiver fibers.

III. Results

A. Deformable mirror

Figure 5 shows the coupling efficiency of the system using the deformable mirror, compared to the same system with a conventional flat mirror. The flat mirror system has a rapidly decreasing power coupling efficiency with increasing number of the receiver fibers. In comparison, the optimized power coupling efficiency using the deformable mirror is between 25% and 51% without any sign of decrease. The total loss due to the optical elements is estimated to be 22%. The difference between the maximum coupling efficiency (78%) and the measured ones (51%) originates in residual stress in the membrane, which causes astigmatism, and from instability of the voltage supply.

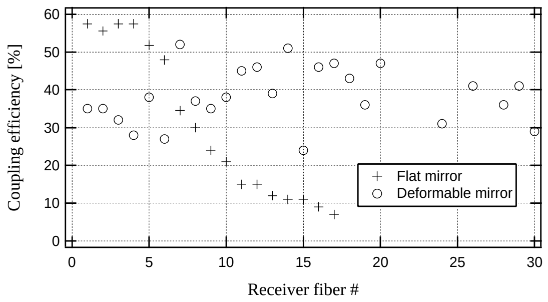

Fig. 5. Measured coupling efficiency using a deformable mirror, compared with a flat mirror.

B. Array of microlenses

The system using an array of microlenses allows to switch the signal from the source fiber, up to the 31th fiber with a coupling efficiency between 50% and 61%, as shown in Fig. 6. The total loss due to the optical elements is estimated to be 36%.

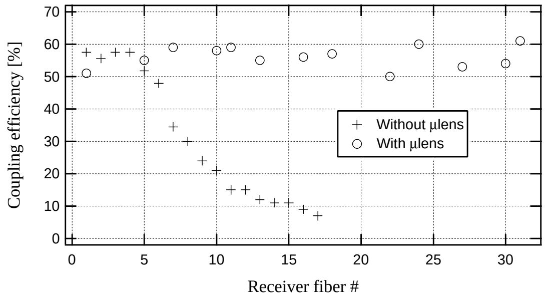

Fig. 6. Measured coupling efficiency using an array of microlenses, compared with a system without microlenses and using a flat mirror.

IV. Conclusion

We have shown two switching systems which provide high coupling efficiency for a large number of interconnects. The measured coupling efficiencies for connections up to the 31th receiver fiber of a 1 dimensional, 1 directional switch ranges between 25% and 51% (including the 22% losses due to the optical components) using the deformable mirror, and between 50% and 61% (including the 36% losses due to the optical components) using an array of microlenses. We demonstrated a 1-dimensional, 1 directional 1 × 31 optical switching system, which corresponds to a 1 × 3019 2-dimensional system.

References

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