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Characterization of a MEMS Based Optical System for Free-Space Board-to-Board Optical Interconnects

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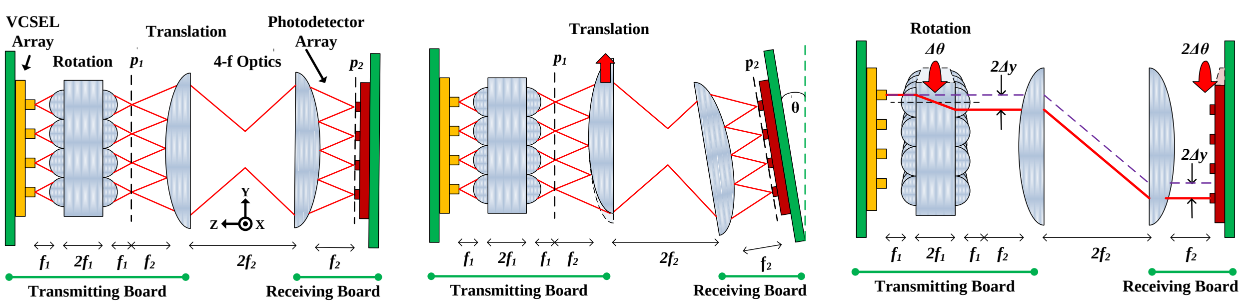
Abstract: We demonstrate alignment of an array of VCSELs to detectors, using a MEMS-based lens system for free-space board-to-board optical interconnects. Our optical system is capable of aligning up to 5 degrees of freedom.

OCIS codes: (060.2605) Free-space optical communication; (220.1140) Alignment

1. Introduction

Free-space optical interconnects between computer boards in servers offer great advantages in communication speed and power consumption over traditional electrical techniques [1,2]. With a 10x10 array of 10 Gbps vertical cavity surface emitting lasers (VCSELs), bandwidths of up to 1 Tbps can be readily achieved. However, as with any free-space optical system, precise alignment of the VCSEL array to the photodetector array is critical. Previously, a telecentric 4-*f* optical system (Fig. 1a) immune to lateral displacement in the X-Y plane has been reported [3]. Up to ±1 mm lateral misalignment tolerance was achieved, however, the telecentric system is sensitive to board tilt, with tolerances of only ±0.1°. Typical computer boards in server racks are estimated to have vertical tilt of up to ±1°, exceeding the tolerance of the 4-*f* system. In addition, the rotational misalignment between the VCSEL and the photodetector chips due to imperfect assembly (~±1°) must also be corrected.

In this paper, we propose a micro-electromechanical system (MEMS) solution for automatic alignment of board-to-board free-space interconnect. It provides up to 5 degrees of freedom for simultaneous alignment of VCSEL arrays with zero stand-by power consumption. We have previously reported an electrothermal MEMS lens scanner capable of moving millimeter-scale lenses with a maximum displacement of ±170 μm [4]. Once the optical beams are aligned, the lens position is fixed by integrated MEMS brakes, thus dissipating zero power. By inserting our MEMS lens scanner into the "Translation" position in Fig. 1b, we can correct for board tilting and increase the tilt tolerance by over an order of magnitude to ±1.6°.



(a) (b) (c)

Fig. 1 Illustrations of a proposed free-space board-to-board optical interconnect system integrated with MEMS actuators. (a) shows the full diagram at perfect alignment. (b) shows a board tilt away from the Y-axis being corrected with our translational MEMS lens scanner. (c) shows a board rotation about the Z-axis (optical axis) being corrected with our MEMS rotation stage.

Rotational misalignments about the Z-axis (optical axis) are due to fabrication and assembly errors of VCSEL and photodetector arrays. Our recent paper describes an electrothermally actuated rotational stage with double-sided microlens arrays [5]. By placing the VCSEL array at the back focal plane of the microlens array, we can rotate the image of the VCSELs by rotating the microlens array itself. Again, we have bi-stable mechanical brakes capable of holding the stage in place at fixed positions, thus dissipating zero stand-by power. We measured the rotational actuator to have a displacement of ±1.15°. The rotational correction is illustrated in Fig. 1c.

By combining the translation and rotation MEMS stages [3-5], we are in principle able to correct up to 5 degrees of freedom, as illustrated in Fig. 2. This paper serves to experimentally confirm and characterize the fully integrated optical solution in Fig. 1.

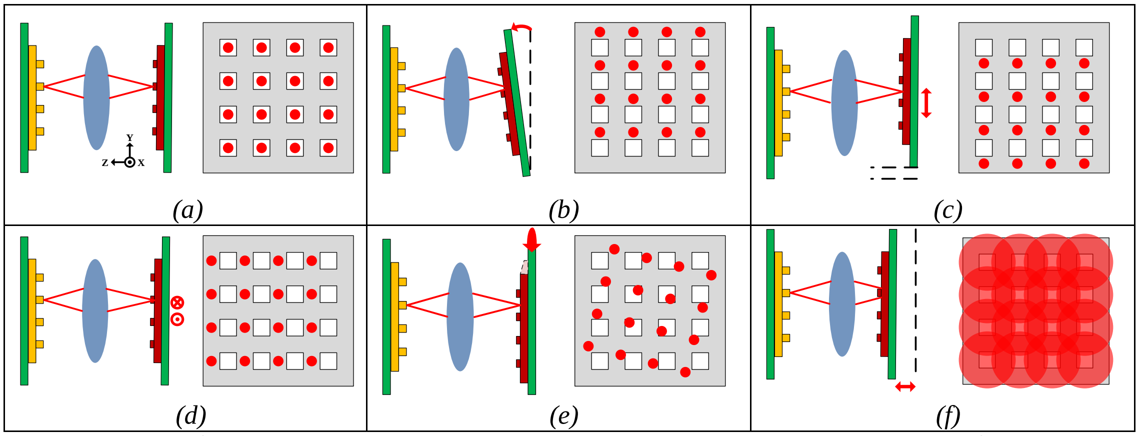


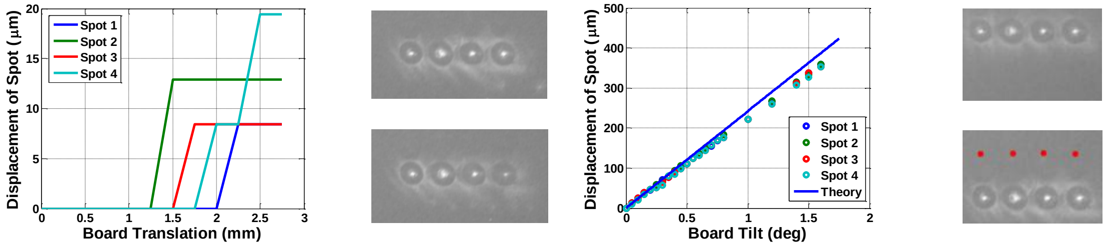
Fig. 2 Illustrations of misalignment schemes and their corresponding detector plane images, using a single lens focusing system. The white boxes represent photodetectors. All of these cases can be corrected with our optical system. (a) Perfectly aligned case. (b) Tilt misalignment. (c) Lateral translation in the ±Y direction. (d) Lateral translation in the ±X direction. (e) Rotation about the Z-axis (optical axis). (f) Translation in the ±Z direction, causes the laser light to be defocused, which can lead to cross talk and lower power densities.

2. Optical Setup and Measurement Methods

The full optical system in Fig. 1a is reconstructed in a 30 mm cage system with manual micrometer scanners used to simulate MEMS actuators. A 1x4 VCSEL array with center wavelengths of 850 nm is placed at the back focal plane of the microlens array. The 4x4 microlens arrays lenses have dimensions $D_1 \approx 250\mu m$ and $f_1 \approx 250\mu m$. The millimeter scale lens at the "Translation" location has dimensions D_2=6.33mm and f_2=13.86mm. A gray-scale CCD camera with 8.4 µm × 9.8 µm pixel dimension is used to record the optical intensity distribution at the detector plane. Beam spot locations are determined by the location of the peak intensity values of each spot. An optical filter is inserted to reduce the optical power so as to not saturate the CCD signal. We assume that the radius of a 10 Gbps photodetector is 25µm, and any spot displacement above this value will be considered a lost link.

3. Passive Alignment Measurements

To experimentally verify that our full optical system still benefits from the 4-*f* optical system reported previously [3], we measured the beam spot displacements due to lateral translation and board tilting. Figure 3a shows the measured results of scanning the receiving board in the X direction and the corresponding displacement of the beam spots. We can see that even at 2.75 mm board displacement, the maximum beam spot displacement is measured to be less than 20 µm, well within the tolerable limit of 25 µm. Due to the circular symmetry of the system, similar results are achieved for Y-axis displacements. Figure 3c shows the measured beam spot locations as a function of the board tilting. At a board tilt of 0.1°, the beam spot locations are at 24.2 µm, which is at the cusp of the tolerable limit. Although not shown here, the passive 4-f system is also immune to misalignments due to Z-axis (optical axis) board displacements. After displacing the receiving board by several millimeters, no noticeable change was detected at the detector plane. This can be attributed to the small divergence of the collimated light propagation between boards. The key parameter to a successful 4-f optical setup is placing the VCSEL and photodetector arrays precisely at their corresponding focal points. Once this is achieved, the system will benefit from all passive alignment schemes.

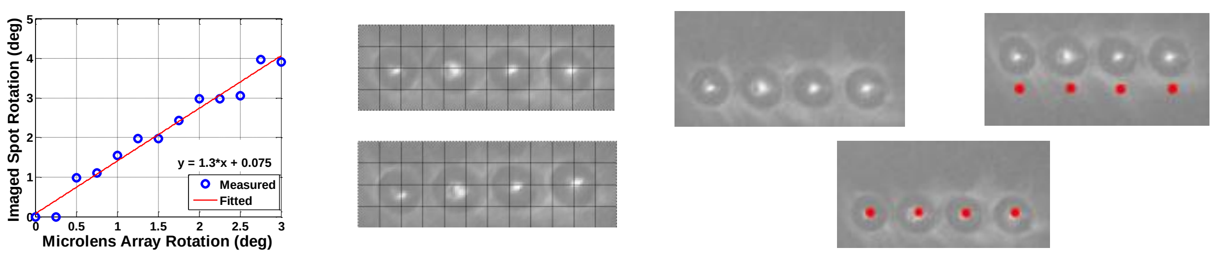


(a) (b) (c) (d)

Fig. 3. Passive alignment measurements. (a) shows the measured beam spot displacement as a function of moving the receiving board along the X direction. (b) *(top)* The beam spot image at 0 mm displacement, (*bottom*) beam spot image at 2.75 mm displacement. (c) Spot displacement as a function of board tilting. The blue solid line is obtained from geometric optics. (d) (*top*) Beam spots at 0° board tilt. (*bottom*) beam spots at 1.6° board tilt. Red dots indicate beam spot locations at 0° board tilt.

4. Active Alignment Measurements

Rotational misalignments between the VCSEL and detector arrays due to assembly errors can be corrected by rotating the double-sided microlens array. Figure 4(a) and (b) show the rotated image of the VCSEL array as a function of rotating the microlens array. At a 3° microlens array rotation, the image rotates by 4°, which is caused by the 2f_1 thickness of the microlens array. If the microlenses were fabricated to the targeted design specifications, there should be a factor of 2 enhancements for small angles between the imaged array and the rotated microlenses. Here the enhancement is only 4/3 due to imperfect microlens fabrication.



(a) (b) (c)

Fig. 4. Active alignment measurements. (a) The measured image rotation as a function of the microlens array rotation. (b) (*top*) Spot image at 0° rotation. (*bottom*) Spot image at 3° rotation. (c) (*top left*) Beam spot location at 0° board tilt. (*top right*) Beam spot location at 0.7° board tilt. Spots are displaced by 157.4 µm from the original positions (red spots). (*bottom*) Spots are moved back to 0° location with the millimeter lens displaced by 170 µm.

Board tilting errors can be corrected for by translational lens scanner. Figure 4c shows a board tilt of 0.7° being corrected by a 170 µm scan of the millimeter lens, which is the maximum displacement achievable by our MEMS device. The maximum correctable board tilt angle by the MEMS is determined by $\theta=\Delta y/f_2$, thus we can increase the total correctable board tilt with shorter focal length lenses. For example, a focal length of 6.1mm corresponds to a maximum angle of 1.6° [4].

5. Summary

We successfully demonstrate the feasibility of our MEMS integrated optical setup for board-to-board optical interconnects with simultaneous alignment corrections of up to 5 degrees of freedom. Our MEMS system is able to correct board tilt of ±1.6° of board tilt, and VCSEL image rotation of ±2.3°, more than sufficient to address all major forms of misalignment in free-space board-to-board systems.

6. References

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