Tolerance Analysis of Optical Interconnection Based on Image Motion

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***Abstract*— We analyzed the tolerance of a free space optical interconnect using image motion method and a ray tracing software. The simulation demonstrates that the decentering between a VCSEL and a micro-lens should be controlled carefully during fabrication. In addition, the reduced divergence angle due to the micro-lens reduces the sensitivity of the decentering error in a collimating lens.**

Keywords—optical interconnect, passive alignment, tolerance, VCSEL

I. Introduction

The demand for high throughput data transmission is growing rapidly with emergence of the numerous applications such as data center, cloud computing, high performance computing, and UHD (ultra-high definition) contents. Optical interconnection already becomes a main stream technology replacing copper cables between racks in data centers. Furthermore, optical interconnects are trying to extend its application into the smaller range interconnections, for instance, board to board , module to module, and chip to chip. Although optical solution has outstanding performance in terms of speed and compactness, the high price can be an obstacle for this short haul data communication. The cost of an optical interconnection is closely related to the alignment between the optical components. Although an expensive equipment can achieve accurate alignment, this approach still increases the cost due to the low speed and the high price of the equipment. Therefore, the ease of alignment through passive alignment scheme can contributes to the reduction of the module cost and the development of optical interconnection. In this paper, we analyzed a free space optical interconnection using image motion method and ray tracing software. The analysis showed which part we should concentrated on in the design of passive alignment scheme in order to solve this issue.

II. Simulation

In general, the optical interconnection comprises source, lens and detector. Fig. 1 shows a typical example of the free space optical interconnects based on vertical-cavity surface-emitting laser, micro-lenses, and detector [1, 2]. Depending on the system, two lenses reduce into a single lens and a multi-mode fiber replaces a detector. If the array devices work as source or detector, the system becomes a parallel data link. In the configuration as shown in Fig. 1, the VCSEL and lens1 are bonded together to form a transmitter as lens2 and detector are bonded together to form a receiver. Since the beam between lens1 and lens2 is collimated, the distance between two modules can be large compared to the distance between lens and source. Thus, this scheme can apply to board to board connection.

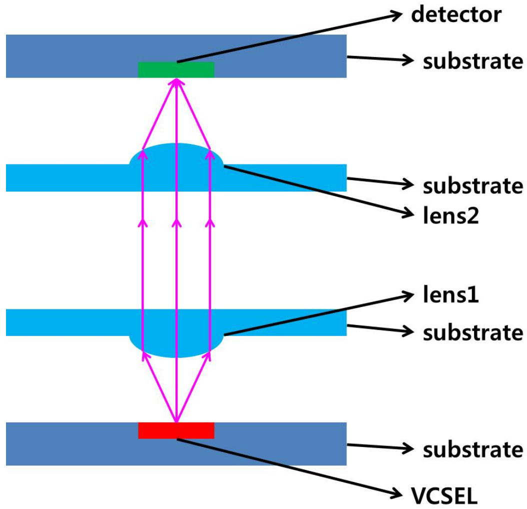

Fig. 1. A free space optical interconnect based on VCSEL, lens, and detector

In order to find out the alignment sensitivity of each component, we carried out tolerance analysis using ZEMAX [3]. A layout of the system is presented in Fig. 2. In the simulation, system consists of the surfaces and the surfaces can suffer from errors in thickness, decenter, and tilt. The ray tracing software calculates the image position on the detector surface as a function of respective errors occurring in the optical surfaces.

As matter of fact, the image motion can be understood analytically by means of image motion theory [4]. This theory is another representation of optical invariant theorem and etendue theorem, which is well known in geometric optics. According to the theory, the product of the marginal ray angle and the object height is same as the product of the marginal ray angle and the image height whatever optics are used in the system. The object height corresponds to the alignment mismatch between VCSEL and lens1. If we use the same focal length for lens1 and lens2, the marginal ray angles are same. Thus, the motion of image is also same as positioning error of the source. In the simulation, the positioning error of VCSEL appears as decentering of the first surface of lens1. In this way, the tolerance of each component can be analyzed both theoretically and computationally.

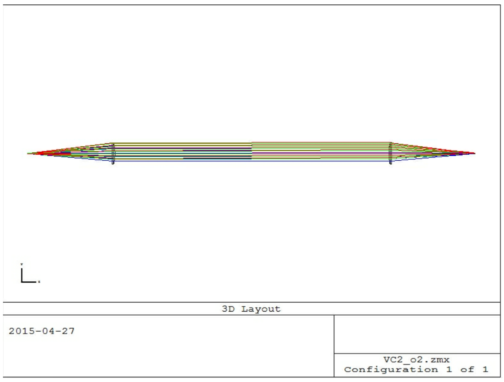

Fig. 2. Tolerance analysis based on image motion using ZEMAX

III. Results and Discussion

The analysis through image motion theory showed that the low divergence angle of the VCSEL can reduce the etendue of the source and decreases the image motion. If multiple VCSELs are bonded in an array, the randomness in positions results in randomness in image positions. To reduce the divergence angle of a VCSEL, we assumed that a VCSEL and a detector have integrated micro-lenses on top.

The image motions as a function of surface errors are displayed in Fig. 3. The decenter of the second surface as shown in Fig. 3-(a) represents the decenter of the micro-lens surface. The image moves 10 µm as the mismatch between a micro-lens and VCSEL is about 10 µm. This agrees well with consequence of the image motion theory. The error bar indicates the RMS spot size in the image plane. Since the micro-lens fabrication also requires mechanical alignment between VCSELs and lenses, the simulation informs that the fabrication tolerance should be carefully controlled for better tolerance management. Fig. 3-(b) shows the image moves about 5 µm as the surface of the collimating lens decenters 10 µm. This also agrees well with the image motion theory since the micro-lens reduces the divergence angle by half and hence the sensitivity of image motion by half. Finally, Fig. 3-(c) shows that the image moves much less with decentering between the transmitter and the receiver. The simulation reveals that the other tolerance parameters are not significant as the ones shown in Fig. 3.

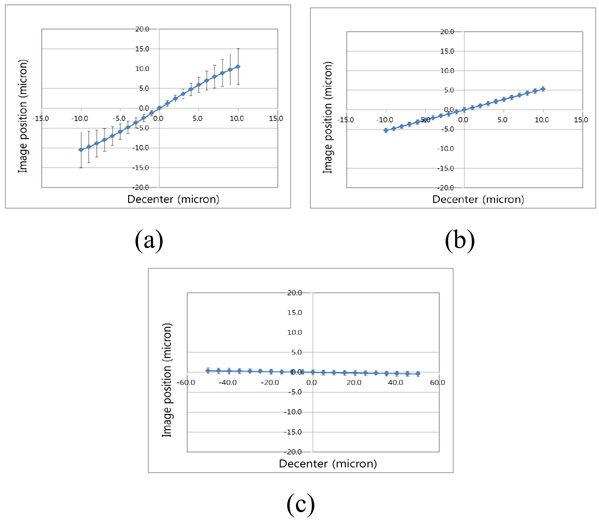

Fig. 3. Image motion as a function of tolerance parameters: (a) decenter of the second surface, (b) decenter of third surface, and (c) decenter of the fifth surface

IV. Conclusion

We analyzed the tolerance of a free space optical interconnect using image motion method and a ray tracing software. The calculation indicates that the decentering between a VCSEL and a micro-lens should be controlled carefully during fabrication. In addition, the reduced divergence angle due to the micro-lens reduces the sensitivity of the decentering error in a collimating lens.

References

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