第19卷　第9期　　光学 精密工程　　Vol. 19　No. 9
2011年9月　　Optics and Precision Engineering　　Sep. 2011

文章编号　1004-924X(2011)09-2271-06

用于高速数据传输的微透镜模块设计及评价

田春林[1*]，林彦男[2]，孙文信[2]，林采薇[1]，林宸生[1]，张正阳[2]
(1.逢甲大学 电机工程学系，中国台湾 台中 40724；2.中央大学 光电科学与工程学系，中国台湾 中坜 32001)

摘要：针对英特尔光峰技术提出了一种非球面微透镜模块的光学优化设计及评价方法。该非球面微透镜模块可经由GGP多模光纤应用于高速数据的传输，非球面微透镜的直径为800 μm，数值孔径为0.275。借助光学设计软件Code V及LightTools进行仿真，评估了微透镜模块制造及组装的公差对系统耦合效率的影响，同时考虑了一些影响光功率损耗因素。结果表明，经光学优化设计得到的非球面微透镜模块的耦合损耗为−0.75 dB。最后，对于球面微透镜模块和非球面微透镜的性能进行了评价。

关　键　词：光学设计；非球面微透镜；数值孔径；多模光纤；耦合效率；公差分析
中图分类号：TH703；TN919　　**文献标识码：**A　　**doi：**10.3788/OPE.20111909.2271

Design and evaluation of aspherical microlens module for high speed data transmission

TIEN Chun-lin[1*], LIN Yan-nan[2], SUN Wen-shing[2], LIN Tsai-wei[1],
LIN Chen-sheng[1], ZHANG Zheng-yang[2]

(1. *Department of Electrical Engineering*, *Feng Chia University*, *Taiwan* 40724, *China*;
2. *Department of Optics and Photonics*, *National Central University*, *Taiwan* 32001, *China*)
* *Corresponding author*, *E-mail*: *cltion@fcu.edu.tw*

Abstract: An optimized design and evaluation method for an aspherical microlens module was presented for the Intel Light Peak technology. The proposed microlens module can be used for high-speed data transmission via a multi-mode GGP fiber. The aspherical microlens has a small diameter about 800 μm and a numerical aperture of 0.275. By the optical softwares of Code V and LightTools, the effect of fabrication and assembly tolerances of the microlens module on the coupling efficiency was investigated, and some factors related to the optical coupling loss were also considered. After optimization design of the module, an optical coupling loss of −0.75 dB was obtained. Finally, the comparison between the spherical and aspherical microlenses for the optical performance was evaluated.

Key words: optical design; aspherical microlens; numerical aperture; multi-mode fiber; coupling efficiency; tolerance analysis

---

Received date: 2011-03-08; **Revised date:** 2011-04-30.

Foundation item: Sponsored by the National Science Council of China (Grant No. 98A081)

1 Introduction

The benefits of optical data transmission systems even in short and medium range communication system have widely been studied. One advantage in comparison with electrical signal lines is that the cross-talk between the adjacent channels is not dependent on transmission speeds. Recently, we notice that one important application of the high-speed data transmission is a Light Peak technology demonstrated by the Intel Developer Forum[1]. Intel plans to sell inexpensive cables with a fiber-optic-caliber speed to connect, for instance, a laptop and an external hard drive, or a phone and a desktop computer. Intel proposes to transfer information by several protocols simultaneously, using only optical one cable. The length of this cable can reach 100 m, the data transmission speed is 10 Gbit/s, and with time it can be increased to 100 Gbit/s (i. e. Gb/s). The main advantage in comparison with electrical signal lines is that the crosstalk between the adjacent channels is not dependent on transmission speeds. Therefore, this study concentrates on the optimization design of microlens module for the fast fiber with a high data transfer rate.

Microlens arrays have been widely used in engineering applications during the past ten years. A microlens array can be produced using various methods, such as electron-beam lithography, photolithographic etching, hot embossing, and thermal reflow[2-4]. We use a pair of microlenses to couple the laser beam (850 nm) into a multi-mode fiber, and the microlens module with a low energy loss for high speed data transmission is designed. The effects of microlens and fiber shift on the optical loss are obtained from the simulation results.

2 Design and simulation of microlens

This paper presents a pair of microlenses which have been developed for use in a 10 Gb/s optical link. This optical interconnect module provides an ideal solution to high data rate communication. One microlens acts as a transmitter, and the other acts like a receiver which is connected by a multi-mode fiber. This module is designed for a high data transmission rate up to 10 Gb/s.

The design parameters are the numerical aperture of 0. 275; effective focal length of 1. 3 mm; clear aperture of 0. 72 mm and microlens diameter of 0. 8 mm. The numerical aperture is a key characteristic parameter of an optical system defined by

$$NA = n\sin\theta = \frac{D}{2f}\ , \tag{1}$$

where n is the refractive index of the microlens; θ is one half of the acceptance angle; D is the clear aperture; and f is the Effective Focal Length (EFL) of the microlens. The material of microlens is PMMA.

In the microlens design, a spherical and an aspherical microlenses are primarily considered. The equation for aspherical surfaces can be written as

$$z=\frac{ch^2}{1+\sqrt{[1-(1+k)c^2h^2]}}+Ah^4+Bh^6+Ch^8+Dh^{10}+\cdots+Jh^{20}\ , \tag{2}$$

where z is the sag, c is the curvature of microlens surface, h is the vertical height from any point on surface to the axis of revolution, k is the constant term of the conicoidal surface, and A, B, C, D, *etc.* are the high order coefficients of the aspherical surface. Many high order coefficients for the aspherical surface easily result in surface inflection points, which increases manufacturing difficult.

3 Results and discussion

To achieve a high coupling efficiency and high data transfer rate, the total power loss should be less than 2 dB that suggested by the Fiber Optic Communications, Inc. The transmitter end uses a 850 nm Vertical Cavity Surface Emitter Laser Diode (VCSELD). The laser diode gives us several advantages over the other technology that is being used. The most important advantage is the reliability. We used the optical software of Code V[5] and LightTools[6] to optimize the microlens and to simulate the optical power loss under different conditions. The Code V is the most powerful optical design software with design reliable imaging optics. LightTools software provides a complete illumination design environment to model, simulate, optimize, and visualize illumination optics. Table 1 shows the optical design results of a pair of microlenses with a multimode fiber. It is used to couple a laser beam into a multi-mode GGP fiber. The optical power loss at the fiber end is simulated by the LightTools software, as shown in Fig. 1.

Tab. 1 Optical design results for microlens module

Surface	Surface type	Y-axis radius	Thickness	Material	Semi-aperture
Object	Sphere	Infinity	0.01	GGP	
1	Sphere	Infinity	0.03		0.0314
2	Sphere	Infinity	7.8857	PMMA	0.0398
Stop	Asphere	−2.5903	0.3		1.4183
4	Asphere	2.6454	5.0544	PMMA	1.4241
5	Sphere	Infinity	0.03		0.0403
6	Sphere	Infinity	0.01	GGP	0.0321
Image	Sphere	Infinity	0.0000		0.0319

After designing the micolens module, we simulated the optical coupling loss of the module by using the LightTools software. If we ignore the Fresnel reflection loss at the interface, the optical efficiency at the fiber end is 84.14 % (i.e., the coupling loss is −0.75 dB). The simulation result for the normalized intensity versus y-axis (lateral) shift is illustrated in Fig. 2. Furthermore, the simulation result for the normalized intensity versus tilt angle (±1°) is shown in Fig. 3.

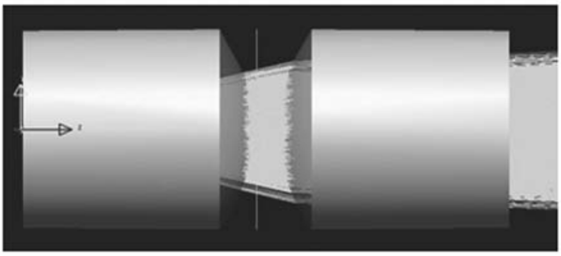

Fig. 1 Simulation for optical power loss of microlens module

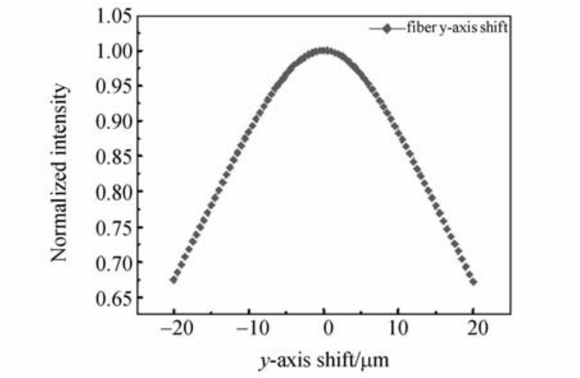

Fig. 2 Simulation result for normalized intensity versus y-axis shift

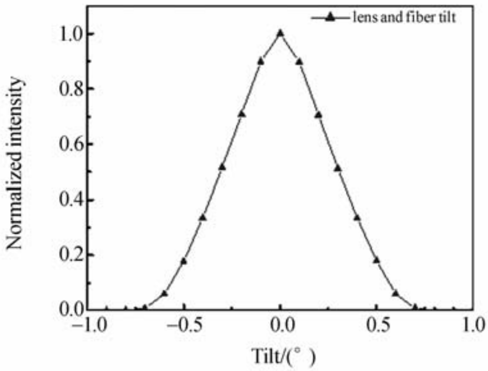

Fig. 3 Simulation result for normalized intensity versus tilt angle

The power loss simulations for the microlens module include three factors: (1) the change of radius of curvature in microlens design, (2) the lateral shift of both microlens and fiber, (3) the lateral shift of the rear microlens. Fig. 4 shows the various simulation results of light power loss under the above conditions corresponding to three different numbered curves. As a result, it was found that the shifting error of the rear microlens caused a large amount of power loss. This can be seen in Fig. 4 indicated by the green curve. The shift in the microlens helped to compensate for the power loss by adjusting the spacing between the rear microlens and the fiber end face. This design method is based on the concept illustrated in Fig. 1.

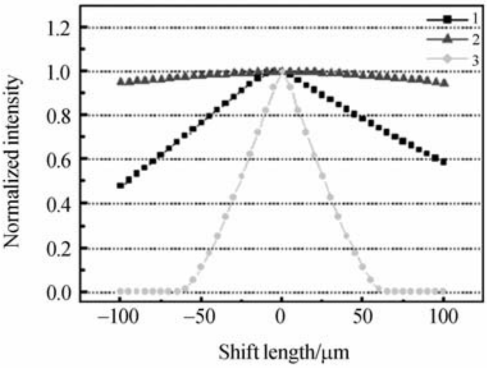

Fig. 4 Power loss simulation for different curvatures, lateral shifts and rear microlens shifts

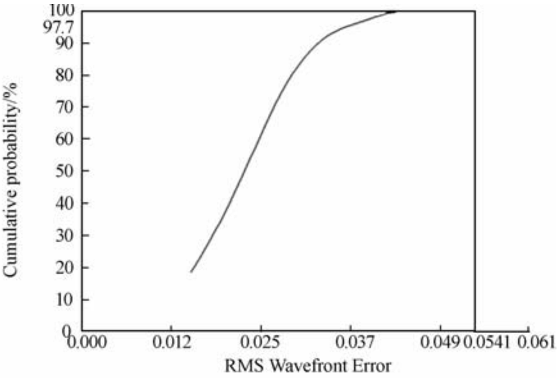

Fig. 5 Tolerance analysis for microlens design

It is often pointed out that RMS (root mean squared) wavefront error is a better characterization method for optical quality than peak-to-valley wavefront error. The latter only tells you the difference between the "highest" and "lowest" parts of the wavefront, while the former tells you how much the "height" varies across the entire wavefront. In this work, the Code V program is used to simulate the tolerance analysis of this design. The RMS of the wavefront error in an aspherical microlens design is 0. 054 1λ (namely λ is 850 nm) for 97. 7% cumulative probability, as shown in Fig. 5. A comparison between spherical and aspherical microlens for the optical performance evaluation is given in Table 2. The results show that an aspherical microlens is better than a spherical microlens, in terms of the RMS wavefront error, Strehl ratio, and spot diameter. The Strehl ratio is usually calculated at the best focus of the optical system under study. The size of a focused spot is inversely proportional of the illumination NA, according to the diffraction theory. After theoretical evaluation, the RMS spot diameter is 0. 807 μm for an aspherical microlens and 28. 783 μm for a spherical microlens.

4 Conclusions

This study presents an optimized design and evaluation method for an aspherical microlens module aiming at the Intel Light Peak technology. For the new generation optical fiber wideband communication, the development of high speed and large capacity optical communication techniques are needed. The optical system is evaluated by two optical design software packages, Code V and LightTools. This microlens has the small diameter of about 800 μm and the numerical aperture of 0. 275. The transmitted power loss of the microlens-fiber module is −0. 75 dB and it is expected that the extremely high speed data transmission of 10 Gbit/s could be attained when the module is combined with a VCSE laser diode.

Tab. 2 Comparison between a spherical microlens and an aspherical microlens for performance evaluation

Microlens	RMS wavefront (waves)	Strehl ratio	RMS spot diameter (μm)
Spherical surface	0.163 1	0.350	28.783
Aspherical surface	0.054 1	0.988	0.807

5 Acknowledgements

The authors would like to thank the Fiber Optic Communications, Inc. (FOCI) for their kind assistance in the design specification discussion. This study was sponsored by the National Science Council of China under Contract number 98A081.

References:

[1] HANNA M F. Intel plots light peak interconnect revolution[J]. *Lightwave Magazine*, 2010:16-18.

[2] AOKI Y, MIZUNO R J, SHIMADA Y, *et al*.. Fundamental study of parallel moduling scheme based on a micro-optical bench and collimating planar microlenses[J]. *Jpn. J. Appl. Phys.*, 2000, 39:1529-1532.

[3] YANG H, PAN C T, CHOU M C. Ultra-fine machining tool/molds by LIGA technology[J]. *Journal of Micromech. Microeng.*, 2001,11(2):94-99.

[4] SINZINGER S, JAHNS J. *Microoptics*[M]. New York: Wiley-VCH, 1999.

[5] Code V Reference Manual. *Version* 9.8[M]. Optical Research Associates, 2007.

[6] LightTools Core Module User's Guide, Version 6.1 [M]. Optical Research Associates, 2008.

Authors' biographies

TIEN Chuen-lin, PhD, He received his BS degree in physics from Changhua University of Education in 1985 and his MS degree in physics from Fu Jen Catholic University in 1987. He received his PhD degree in optical sciences from Central University in 2000. He served as a senior researcher in Chung Shan Institute of Science and Technology from 1987 to 2004. Currently he is a professor with Department of Electrical Engineering, Feng Chia University. He has published more than 100 papers. His current research focuses on optical metrology, thin films, fiber sensors and optical design. E-mail: cltien@fcu.edu.tw

LIN Yan-nan, PhD student. He received his BS degree in Taipei Municipal University of Education in 2005 and his MS degree in optical sciences from Central University in 2007. Currently he is pursuing his PhD degree at the Department of Optics and Photonics, Central University. His research interests include lens design, optical system design and optical engineering. E-mail: s962406003@dop.ncu.edu.tw

SUN Wen-shing received his PhD in Central University in 2002. From 1990 to 1992, he was a lens design engineer with the Industrial Technology Research Institute, Hsinchu. He was a senior engineer for design of optical pickup heads in the Delta Electronics from 1998 to 2001, and was a consultant for conducting design of digital camera in Foxconn Electronics Inc. , from 2004 to 2005. In 2006, he joined the faculty of Central University, and was an assistant professor. His research interests include lens design, optical system design, LED lighting design and optical engineering. E-mail: wssun@dop. ncu. edu. tw

LIN Tsai-wei, MS student. She received his BS degree in technology management from Chung Hua University, Hsinchu, in 2010. She is currently pursuing the MS degree at the Institute of Electrical Engineering, Feng Chia University. Her current research interests include technology management, optical thin films, data acquisition and analysis, and optical system design. E-mail: weicando1988@gmail. com

LIN Chern-sheng received the BS degree from Cheng Kung University in 1982, the MS degrees in mechanical engineering from Taiwan University, in 1987, and PhD degrees in optical science from the Central University in 1994. Since 1995 he has been with Department of Automatic Control Engineering at Feng Chia University where he is now a Distinguished Professor. Dr . Lin had received first - class principal investigator award of Science Council, for distinguished research. He had received the excellent professor award from Taichung Branch in 2007. He had received the best paper award from AOI Forum & Show in 2009. He is a member of the CIEE and listed in Who's Who in the World and Who's Who in Science and Engineering. Dr. Lin has published more than 200 academic articles in reputable journals and conferences. He has obtained 40 patents from USA, and China. His current research interests include pattern recognition, image processing, and human-machine interface design. E-mail: lincs@fcu. edu. tw

CHANG Jenq-yang received the BS degree in chemical engineering and MS degree in material sciences and engineering from Taiwan University, in 1980 and 1985, respectively. He received the PhD degree of material sciences and engineering from Massachusetts Institute of Technology at Cambridge, U. S. A, in 1992. He is currently a professor at Department of Optics and Photonics, and the Director of Optical Sciences Center in Central University. Prior to this, he was the Chairman of Institute of Optics Sciences in the University. He also involved in the local and international conferences, served as chairman and committee chair in OPT, IEDMS and ODF. His research is in the fields of optics and semiconductor materials and devices, including solar cell, LED, micro/nano optical devices and modules, crystal growth, devices and characterization of nonlinear optical materials. He was in charge of and involved in integrated research projects of solar cell, LED, communication, and micro/nano optics. He is the author or co-author of more than 130 papers for professional journals and conferences. E-mail: jychang@dop. ncu. edu. tw