Automatic Waveguide-fiber Alignment Algorithm based on Polynomial Fitting

Yu Zheng, Baibing Li and Ji-an Duan
State Key Laboratory of High Performance Complex Manufacturing, College of Mechanical and Electrical Engineering, Central South University, Changsha, 410083, China

Keywords: Optical Waveguide Device, Aligning and Coupling, Coupling Model, Alignment Algorithm.

Abstract: We report on a highly efficient alignment algorithm, which based on coupling model, between an optical fiber and an optical waveguide device. For 1×16 optical waveguide splitter, many repeated experiments can guarantee that the insertion loss of the device channels is less than 13.5 dB, with the maximum uniformity of 0.40 dB.

1 INTRODUCTION

Optical fiber communications has driven the need for complex photonic integrated circuit (PIC) to process the massive amounts of data transmitting through global networks (Yamada et al., 1993; Zheng and Duan, 2012). As the complexity and feature size of photonic integrated circuit, automatic optical alignment has become a key technique for optical waveguide devices, such as arrayed waveguide gratings, optical beam coupler/splitters, optical switchers and variable optical attenuators (Zheng and Duan, 2009). The core diameter of the single mode fiber is 8~9 µm, and the optical channel section feature size of photonic integrated circuit is 0.2~8 µm. Each fiber must be positioned correctly on the part, and each part must be aligned in six dimensions (three translational and three angular) to assure low coupling losses.

Automatic precise alignment coupling is the only way of improving optical quality for optical waveguide devices, and is necessary to step into scientific manufacturing from technological manufacturing. Alignment coupling algorithm of optical waveguide chip and optical fibers is premise of its automatic packaging, and good alignment coupling algorithm shows in rapid alignment, high precision and high reliability. Although several algorithms for the automatic fiber to waveguide alignment have been developed, such as hill-climbing algorithm, simplex algorithm, pattern search algorithm, Hamilton algorithm and genetic algorithm (Zheng and Duan, 2013a; Zheng and Duan, 2013b; Tang et al., 2001; Mizukami et al., 2001; Masahiro et al., 2004; Tseng and Wang, 2005; Chun et al., 2006), all of these are based on mathematical optimization algorithm, which make these extremely sensitive to the disadvantages of algorithm itself and the precision of motion stages Zheng and Duan, 2013b). For those reason, automatic waveguide-fiber alignment algorithm which based on coupling model, according to the theory of waveguide-fiber coupling, has been preferred.

The coupling model and coupling theory of waveguide-fiber alignment are treated in section 2. In section 3, the experimental results of automatic waveguide-fiber alignment based on the new algorithm, which based on coupling model of waveguide-fiber alignment, are presented.

2 COUPLING MODEL AND COUPLING THEORY

Figure 1 is the schematic of waveguide-fiber

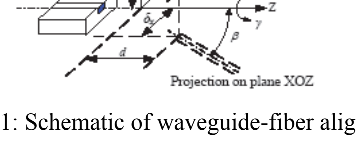

Figure 1: Schematic of waveguide-fiber alignment.

Zheng Y., Li B. and Duan J..
Automatic Waveguide-fiber Alignment Algorithm based on Polynomial Fitting.
DOI: 10.5220/0005328400770080
In *Proceedings of the 3rd International Conference on Photonics, Optics and Laser Technology* (PHOTOPTICS-2015), pages 77-80
ISBN: 978-989-758-093-2

alignment. Geometric alignment error includes horizontal dislocation δ_x and δ_y, angular deflection α β, and γ, and longitudinal spacing d.

According to Ref. (Zheng and Duan, 2013b), the coupling efficiency of optical waveguide and optical fiber is

$$\eta \simeq \eta_x \eta_y \tag{1}$$

where,

$$\eta_x = k_x \exp\{-k_x[\frac{\delta_x^2}{2}(\frac{1}{W_{wa}^2}+\frac{1}{W_f^2}) + \frac{\pi^2\beta^2[\omega_{xa}^2(d)+W_f^2]}{2\lambda^2} - \frac{\delta_x \cdot \beta \cdot d}{W_{wa}^2}]\} \tag{2}$$

$$k_x = \frac{4W_{wa}^2 W_f^2}{(W_{wa}^2+W_f^2)^2+\lambda^2 d^2/\pi^2} \tag{3}$$

$$\omega_{wa}^2(d) = W_{wa}^2[1+(\frac{\lambda d}{\pi W_{wa}^2})^2] \tag{4}$$

where, W_f is radius of optical fiber mode field, W_{wa} and W_{wb} are mode field radius of optical waveguide along the ellipse long and short axes, respectively. In Formula (2), used y in place of x, η_y can be obtained. Set $\alpha = \beta = 0$ and $W_{wa} = W_{wb}$, for the given longitudinal spacing d and wavelength λ, k_x is a constant. The insertion loss (IL_d) of one optical channel is

$$IL_d = -10\lg\eta = -20\lg(k_x) + 10\lg e \cdot [\frac{k_x}{2}(\frac{1}{W_{wa}^2}+\frac{1}{W_f^2})](\delta_x^2+\delta_y^2) \tag{5}$$

Thus, theoretically there is quadratic function relation between insertion loss of alignment coupling of optical fibers and optical waveguide chip and horizontal dislocation. The new automatic waveguide-fiber alignment algorithm is base on the Formula (5).

3 EXPERIMENT AND RESULTS

3.1 System Architecture

Construct automatic waveguide-fiber alignment coupling system based on Figure 2. The waveguide chip (WG chip) was held in a holder unit. The input and output fiber arrays (FA) were set on 6-axis precision stages, which line repositioning resolution was 0.3 μm, and angle repositioning resolution was 0.001°. The machine vision system includes two orthogonally positioned microscopes with charge-coupled device (CCD) cameras. Laser source, two-channel optical power meter, and control box of the input and output stages were adopted, and they communicated with the computer via GPIB connector.

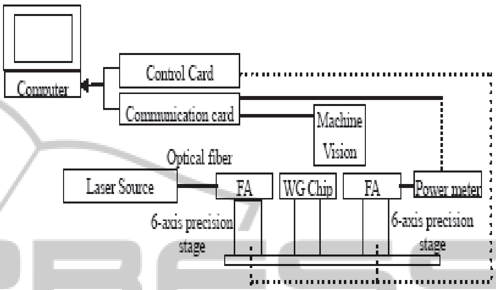

Figure 2: Structure figure of automatic alignment system.

3.2 Experimental Results

Optical waveguide used for alignment coupling is 1×16 optical waveguide splitter, and the adhesion used for solid joint of coupling interface is index matching adhesion. Table 1 shows the geometric dimensioning and material parameter of optical waveguide splitter. The environment temperature and humidity were respectively 23℃ and 50%. The motion velocity was set to 10mm/s, and the target of Insertion Loss was set to 14dB, as shown in Figure 3.

Table 1: Geometric dimensioning and material parameter of optical waveguide splitter.

Parameters	Units	Specification
Length	mm	15
Width	mm	3.5
Height	mm	2.5
Material	Core Cladding	Silica+GeO$_2$ Quartz
Core size	μm	8×8
Operational wavelength	nm	1260~1650
Theoretical Insertion Loss	dB	12.04
Insertion Loss (Max.)	dB	13.2
Uniformity	dB	0.50

Alignment coupling loss was caused by the process of device packaging and manufacturing, and it was related to motion stages, controlling, alignment algorithm, etc. For 1×16 optical waveguide splitter, the required time was less than 3 min. According to Table 2, it can be known that for 1×16 optical waveguide splitter, many repeated experiments can guarantee that the insertion loss of the device channels was less than 13.5 dB, with the maximum uniformity of 0.40 dB.

Table 3 show the experimental results of alignment coupling of 1×16 optical waveguide splitters based on manual stages. The insertion loss was more than 13.5 dB, and the maximum uniformity was more than 0.75 dB. The alignment time was more than 5 min. Such results demonstrated the effectiveness of the alignment coupling algorithm which based on coupling model.

4 CONCLUSIONS

We have demonstrated a highly efficient alignment algorithm, which based on coupling model, between

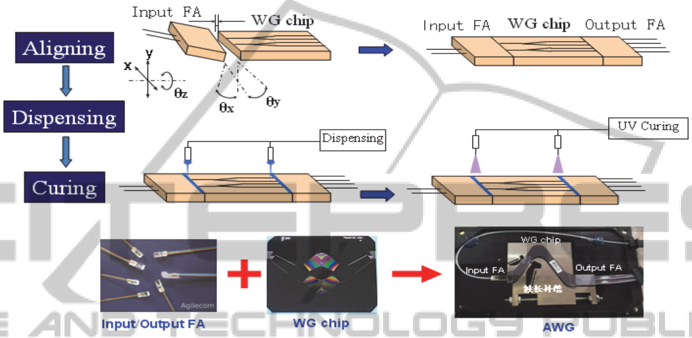

Figure 3: Process of automatic alignment system for waveguide-fiber.

Table 2: The automatic alignment results (Insertion loss, dB).

NO.	CH1/9	CH2/10	CH3/11	CH4/12	CH5/13	CH6/14	CH7/15	CH8/16	Avg.	Max-Min
1	12.73	12.83	12.84	12.80	12.72	12.71	12.89	12.80	12.78	0.18
	12.71	12.75	12.76	12.77	12.71	12.80	12.78	12.80		
2	12.82	12.85	12.93	12.87	12.79	13.01	13.07	12.88	12.89	0.32
	12.75	12.81	12.84	12.96	12.76	12.95	12.96	12.95		
3	12.76	12.75	12.88	12.83	12.98	12.91	12.88	12.83	12.82	0.33
	12.65	12.76	12.80	12.88	12.72	12.84	12.81	12.85		
4	13.08	13.10	13.02	13.13	13.07	13.14	13.14	13.10	13.12	0.37
	13.21	13.10	13.05	13.08	13.39	13.17	13.11	13.08		
5	13.00	12.90	12.89	13.10	13.20	12.96	12.94	13.01	12.97	0.37
	12.85	12.88	12.90	13.05	13.08	12.89	12.83	12.99		
6	12.84	12.72	12.89	12.88	12.86	12.94	12.97	12.92	12.89	0.25
	12.82	12.84	12.86	12.93	12.87	12.95	12.95	12.93		
7	12.99	12.95	12.95	13.01	13.12	12.97	12.89	13.00	13.00	0.23
	13.04	13.02	12.98	13.05	13.05	12.97	13.00	13.03		
8	13.11	12.81	12.92	12.85	13.11	12.84	12.88	12.83	12.92	0.30
	12.97	12.92	12.92	12.87	12.85	12.86	12.97	12.94		
9	12.90	12.91	12.94	12.93	12.88	13.01	13.00	12.92	12.93	0.18
	12.92	12.83	12.89	12.92	12.95	12.91	12.97	12.90		

Table 3: The automatic alignment results (Insertion loss, dB).

NO.	CH1/9	CH2/10	CH3/11	CH4/12	CH5/13	CH6/14	CH7/15	CH8/16	Avg.	Max-Min
1	13.25	13.33	13.29	13.36	13.10	13.29	13.74	14.01	13.53	0.95
	13.41	13.80	13.54	13.15	14.05	13.54	13.66	14.03		
2	13.51	13.50	13.15	13.49	14.02	13.26	13.67	13.45	13.53	0.93
	14.08	13.62	13.43	13.25	13.54	13.28	13.85	13.42		
3	13.58	13.24	13.40	13.68	13.22	13.24	13.56	13.54	13.50	0.76
	13.66	13.54	13.26	13.67	13.36	13.98	13.54	13.58		

an optical fiber and a silica waveguide. For 1×16 silica waveguide, many repeated experiments can guarantee that the insertion loss of the device channels is less than 13.5 dB, with the maximum uniformity of 0.40 dB. High efficiency, high precision and reliability demonstrate its potential for multi-channel waveguide-fiber alignment applications.

ACKNOWLEDGEMENTS

The authors thank for the finical supported by the National Natural Science Foundation of China (Grant No. 51475479 and 51075402), the National High-Tech R&D Program of China (Grant No. 2012AA040406), the Research Fund for the Doctoral Program of Higher Education of China (Grant No. 20110162130004), the Natural Science Foundation of Hunan Province (Grant No. 14JJ2010), and the open project of stage key laboratory of Fluid Power Transmission and Control (Grant No. GZKF-201401).

REFERENCES

Y. Yamada, A. Takagi, I. Ogawa, et al, “Silica-based optical waveguide on terraced silicon substrate as hybrid integration platform,” Electronics Letters. 29(5), 444-445(1993).

Y. Zheng, J.A. Duan, “Alignment algorithms for planar optical waveguides,” Optical Engineering. 51(10), 103401(2012).

Y. Zheng, J.A. Duan, “Coupling analysis between planar optical waveguide and fiber array,” Journal of Central South University. 40(3), 681-686(2009).

Y. Zheng, J.A. Duan, “Transmission Characteristics of planar optical waveguide devices on coupling interface,” Optik, 124(21): 5274-5279(2013a).

Y. Zheng, J.A. Duan, “Automatic Planar Optical Waveguide Devices Packaging System Based on Polynomial Fitting Algorithm,” Advances in Mechanical Engineering, 2013, 398092(2013b).

Z. Tang, R. Zhang, S.K. Mondal, et al, “Optimization of fiber-optic coupling and alignment tolerence for coupling between a laser diode and a wedged single-mode fiber,” Optics Communication. 199(1-4), 95-101(2001).

M. Mizukami, M. Hirano, K. Shinjo, “Simultaneous alignment of multiple optical axes in a multistage optical system using Hamiltonian algorithm,” Optical Engineering. 40(3), 448-454(2001).

M. Masahiro, N. Yoshihiro, H. Tetsuya, “An automatic fiber alignment system using genetic algorithms,” System and Computers in Japan. 35(11), 80-90(2004).

C.Y. Tseng, J.P.Wang, “Automation of multi-degree-of – freedom fiber-optic alignment using a modified simplex method,” International Journal of Machine Tools and Manufacture. 45(10), 1109-1119(2005).

J. Chun, Y.L. Wu, Y.F. Dai, et al, “Fiber optic active alignment method based on a pattern search algorithm,” Optical Engineering. 45(4), 045005 (2006).