ECIO 2022

4th May – 6th May

Milan, Italy

23rd European Conference on Integrated Optics

POLITECNICO MILANO 1863

ECIO22

Photonic chip based biosensing system with fully automatic alignment and parallel detection capability

L. Chang*, W.A.P.M. Hendriks, I. Hegeman, R.N. Frentrop, M. Dijkstra, J.P. Korterik, N.A. Schilder, H.A. Seubers and S.M. García-Blanco

Integrated Optical Systems, MESA+ Institute for Nanotechnology, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands

* l.chang@utwente.nl

We demonstrate a fully portable photonic chip based biosensing system. By a combination of chip design and a mechanical alignment system design, we demonstrate an affordable auto-align solution for biosensing applications.

***Keywords*:** *Optical connectivity, biosensing, invert waveguide taper*

INTRODUCTION

In recent years, optical waveguide based biosensing has gained much interest. However, difficult optical alignment between the chip and the outside world has been one of the bottlenecks hindering the application of this technology outside the research lab [1]. In this study, we demonstrate a fully portable system, including chip design, input-output coupling automation, temperature control, and parallel detection. The input and output waveguides have inverted tapers with a mode size that matches the fiber mode. This largely reduces the alignment accuracy requirement and improves the coupling stability during sensing. Both input and output have been designed without any physical contact to prevent wear of optical surfaces. The system can fully automatically align the optical chips within 30 s.

OPTICAL SYSTEM DESIGN

The optical system design is shown in Fig. 1(a). We will introduce the design following the order from the chip input to the chip outputs.

The coupling between the input fiber and the chip has been designed through a lens system. This lens system re-images the fiber mode with 1:1 ratio, by using two identical aspherical lenses (Thorlabs F260APC-1064 – 1064 nm, f = 15.43 mm, NA = 0.16 FC/APC Fiber Collimation Pkg. and Thorlabs A260TM-B – f = 15.29 mm, NA = 0.16, Mounted Aspheric Lens, ARC: 650 – 1050 nm). This lens system provides ~14 mm working distance to the chip, which leads two key advantages in comparison with traditional end facet contact coupling. First, no wear-out of optical interfaces. This leads to significantly longer fiber lifetime. Second, no collision risk during the auto-alignment process. This leads to a simpler and faster auto-alignment procedure.

Inverted optical tapers are widely used to minimize the coupling loss between fiber and waveguide [2, 3]. The enlarged mode size in the inverted taper not only improves the coupling efficiency, but also improves the coupling stability during long sensing measurements. We design our waveguide taper by optimizing the coupling efficiency with the fiber mode, since our lens system re-images the fiber mode with 1:1 ratio. The waveguide cross section is shown in the insert of Fig. 1(b). The Al_2O_3 core thickness is 450 nm. Simulated coupling efficiency as a function of waveguide bottom width at different side wall angles θ for both TE and TM modes are shown in Fig. 1(b). Our e-beam lithography fabrication provides a side wall close to 90°, thus a waveguide bottom width of 150 nm has been chosen to achieve maximal coupling for both TE and TM modes at a wavelength of 1030 nm.

The input light is split by cascaded Y-splitters to 16 channels. In each channel, there is one microring resonator for sensing. The sensing principle is based on the resonance wavelength shift of a microring resonator when it experiences a refractive index change in its top cladding [4].

Both the Y-splitters and the chip input coupler are not 100% efficient, which results in stray light on the chip. In order to minimize the influence of the stray light, the output waveguides and the detector array are positioned 90° from the input to minimize unwanted background light. The output waveguides have the same inverted taper as the input waveguide. These enlarged modes have a smaller divergence angle compared to a normal waveguide, which allows for a larger distance (<~500 µm) between the chip outputs and the detector array. This distance

ensures no collision risk exists during the auto-alignment process (only the chip is moving during an auto-alignment process.).

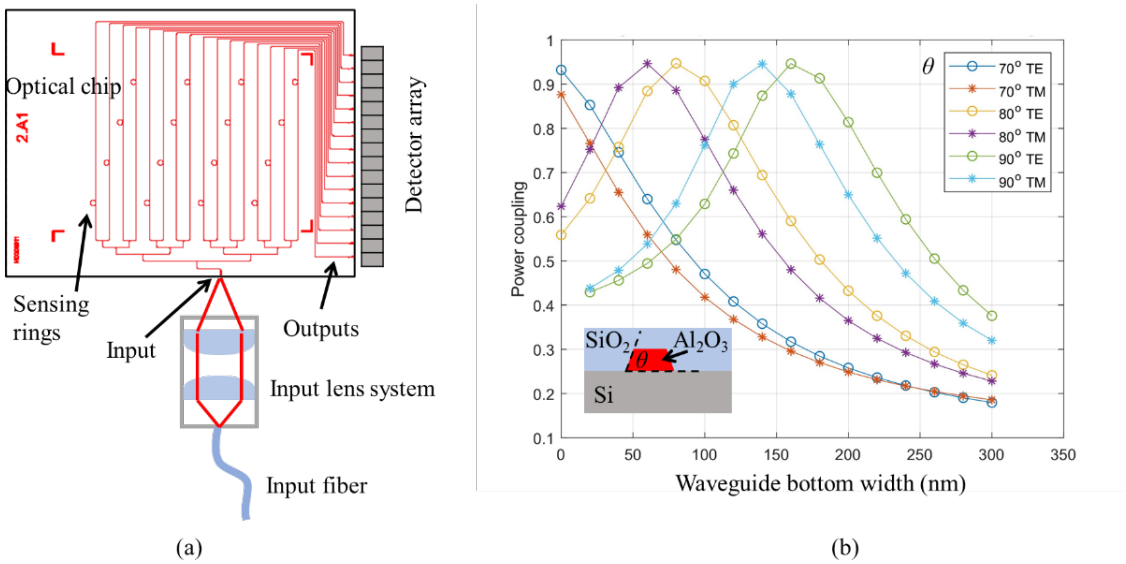

Fig. 1. (a) Optical system design. Both the input and output ports have no contact with the lens nor the detector array during the auto-alignment process. (b) Simulated input coupling efficiency.

OVERALL SYSTEM DESIGN

The full setup (except the laser source) is shown in Fig. 2 (a). It includes the alignment stages, stages control system, chip temperature control system, microfluidics system, 16 channel ADC system for signal readout, and a PC.

The alignment stages are shown in Fig. 2 (b). The input fiber, lens system, and the detector array (Hamamatsu, S4111-16Q with custom designed transimpedance amplifier array pcb) are mounted on two manual stages (Newport, MODEL: 9082-M). The manual stages are used during the first calibration alignment with the first chip. The chip is positioned in a chip holder on a 3-axis motorized stage (Thorlabs, MAX383/M - 3-Axis NanoMax Stage with custom built control system based on an Arduino Uno and 3 micro stepper drivers) for auto-alignment. The chip holder is shown in Fig. 2(c). The chip is inserted into the holder from the bottom left to the direction of the detector array. The chip holder has spring-based mechanical stops and clamps to hold the chip during sensing. At the bottom of the holder, a Peltier element with thermocouple is used for chip temperature control (custom built system using an Arduino Mega and Digilent Pmod AD5 ADC).

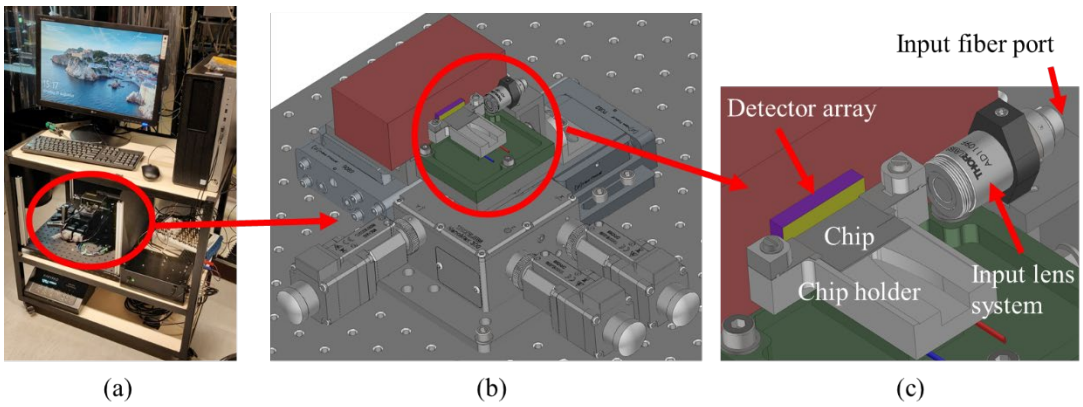

Fig. 2. (a) The full photonic chip based biosensing system is on a small trolly (except the laser source). (b) Solidworks model of the alignment stages. (c) Solidworks model around the chip area.

ALIGNMENT PROCESS

The alignment process has two main steps, namely, passive alignment and active alignment. The passive alignment consists of sliding the chip towards the mechanical stops in the chip holder. The alignment accuracy in this step is

limited by the outer dimensions of the chip, which are typically in the order of ~20-30 µm. The beam waist of the input light is ~5.5 µm, which is much smaller than the passive alignment error. This means normally a 2D scan is needed for the active alignment. However, a 2D scan is time consuming. Our approach is defocusing the input fiber to increase the spot size of the fiber on the end facet of the chip. This allows for more tolerant (albeit less efficient) coupling, thereby ensuring that a position where some light is coupled into the chips is always found. This limits the number of scans to 6 or 3 linear scans as shown in Fig. 3.

Prior to the scans, the chip is moved 300 µm in the negative y direction to defocus the input light. This distance ensures the beam size on the chip facet is bigger than the typical passive alignment error mentioned above. Scan 1 (x), and 2 (z) are in the directions perpendicular to the input light propagation direction. The stage will move to the position of maximum intensity after the scan. The FWHM in these scans is significantly larger than the beam waist due to the defocused light. Scan 3 (y), is along the light propagation direction to find the focus. In principle, this should bring the chip to the best aligned position. However, in practice, we notice some angle between the y axis and the light propagation direction in our setup. Thus, we must repeat the three scans in a smaller range to reach the best coupling position. Scans 4 to 6 may be eliminated in the future with a better alignment between the stage y axis and the input light propagation direction.

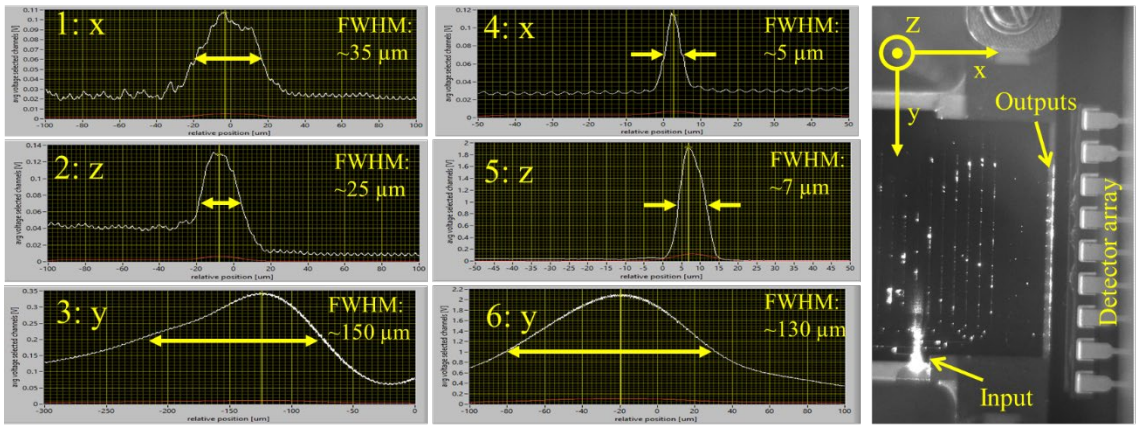

Fig. 3. The active alignment scans and a microscope image of the aligned chip. The y axis of the scans is the average readout from all 16 channels.

CONCLUSIONS AND OUTLOOKS

In this study, we have demonstrated a system capable of performing optical waveguide based biosensing outside a lab environment. The fully automatic alignment process is repeatable, reliable and can easily be used with minimal training.. The alignment speed of the system could be further improved by optimizing the driving software and reducing the angle error between the stage y axis and the input light propagation direction. A cartridge could be introduced to prevent the user to work directly with the bare chip.

References

[1] M. C. Estevez, M. Alvarez, and L. M. Lechuga, "*Integrated optical devices for lab-on-a-chip biosensing applications*," LASER PHOTONICS REV, vol. 6, no. 4, pp. 463-487, 2012.

[2] J. Fernández, R. Baños, D. Doménech, C. Domínguez, and P. Muñoz, "*Low-loss inverted taper edge coupler in silicon nitride*," IET Optoelectronics, vol. 13, no. 2, pp. 62-66, 2019.

[3] V. Nguyen *et al.*, "*Silicon-based highly-efficient fiber-to-waveguide coupler for high index contrast systems,*" Appl. Phys. Lett., vol. 88, no. 8, p. 081112, 2006.

[4] M. de Goede *et al.*, "*Al2O3 microring resonators for the detection of a cancer biomarker in undiluted urine,*" Opt. Express, vol. 27, no. 13, pp. 18508-18521, 2019/06/24 2019.