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Development of High-Precision Parallel Kinematics for Industrial Automation and Silicon Photonics

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Abstract
Among other things, the testing and packaging processes in the field of Silicon Photonics make demands on new mechatronic systems, alignment algorithms (e.g., first light detection), and software solutions. The development of new mechatronic systems for these applications faces great challenges. Especially the demands for high precision, repeatability and alignment speed due to an alignment tolerance of less than +/-2 µm [1] in an industrial 24/7 environment have a great impact onto system design and lifetime. To meet those needs a hybrid multi axes system was developed. It consists of a 6-axes motor spindle driven and a 3-axes piezo driven parallel kinematics. Parallel-kinematics with several degrees of freedom are used due to their high precision, stiffness, and speed. The spindle driven system is mainly used for coarse movements in the range of mm with a resolution of 0.2 µm and for angular alignment with a resolution less than 2.5 µrad. The piezo system is used for fine alignment and tracking application in the range of 0.1 mm with a resolution of 0.4 nm with high duty cycles. A further increase of throughput can be realized by sophisticated controller algorithms.
Within this contribution, the development of multi-axes solutions for probing, chip and wafer testing, and packaging based on different technologies will be presented.

Type the keywords here: parallel kinematics, hexapod, fiber alignment, Silicon Photonics

1. Introduction

The fast rise of Silicon Photonics presents many challenges. Silicon Photonics is a combination of two very important inventions of the 20th century. The semiconductor laser and silicon integrated circuit. It enables faster data transfer and less power consumption [2] compared to traditional electronics.[3] IBM has even spoken of a gaudily multi core future chip architecture with hundreds of cores all interlinked by an on-chip optical mesh.[4] Silicon photonics is not the same as the CMOS process used to make chips. It has its own manufacturing requirements that differ from those used to make pure electronic chips. These processes do not just include the wafer processing to make the photonic circuits but also custom circuit testing equipment and device packaging.[5] One of the key challenges is the need to align fiber optic devices to optimize optical throughput before testing and packaging can begin. In many cases, alignment in multiple degrees of freedom is required across more than one input and output coupling. Fast throughput is required in this accurate automated micro process to increase the economic efficiency.

Among other things, the testing and the packaging processes in the field of Silicon Photonics make demands on new mechatronic systems, alignment algorithms (e.g., first light detection), and software solutions. Mechatronic systems for these applications face demands for high precision, repeatability, and alignment speed.

2. System Design

The main specifications for a mechatronic single sided system for testing of integrated circuits on a waver level can be summarized to:

- two active axes for planar scans, both parallel to the waver surface
- one active axis to adjust focus length (when focuser is used) or to adjust distance between fiber and waver
- in some applications three rotational axes (crossing in the fiber tip or the focal point) to improve signal level
- double-sided system for signal input and output alignment -> factor two of controlled axes
- design space is limited by the typical arrangement of probing equipment in a waver prober (see fig 1)
- contact is forbidden to prevent damage to the wafer and probe fibers or coupling optics (fully-patterned wafers value can exceed several million dollars)
- alignment speed must be < 1 s due to the amount of devices needed to be tested on a waver
- high precision, resolution and repeatability in the range of microns and nanometers (e.g. alignment tolerance of less than +/-2 µm [1])
- robust design for industrial 24/7 environment

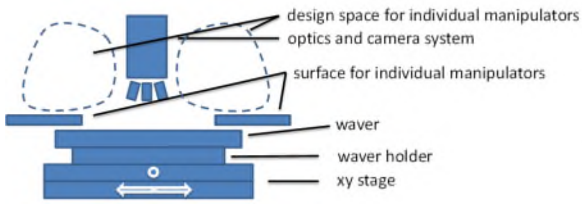

Figure 1. Design space for additional manipulators on a waver prober

To meet these requirements a hybrid multi axes system was developed. It consists of a 6-axes motor spindle driven and a 3-axes piezo driven parallel kinematics. In the following sub-section the 6-axes motor spindle driven system, the coarse stage, is explained. The fine stage is a 3-axes piezo driven parallel kinematics.

2.1. Coarse Stage

The typical design space on a waver prober for individual manipulators is limited to a volume of less than $(300\ \mathrm{mm})^3$. Two active axes for planar scans and coarse adjustment, one active axis to adjusted the focus length or to adjust the distance between fiber and waver and in some applications three rotational axes (crossing in the fiber tip or the focal point) to improve signal level are needed. Therefore, a small and dynamic hexapod with 6-DoF is needed [6]. A H-811 hexapod fulfills these requirements and is a solution for a coarse motion due to its compact design, an arbitrarily definable center of rotation, high stiffness for a 6D-motion of a few mm travel range. The hexapod struts consist of a BLDC motor driving a ball screw with an encoder resolution of 5 nm / cnt. The coarse alignment stage has its limitation to repeatability down to 60 nm with a resolution down to 80 nm. To integrate it into the typical design space in a waver prober the hexapod has to be rotated by 120° and to be mounted to several brackets (see Fig 2).

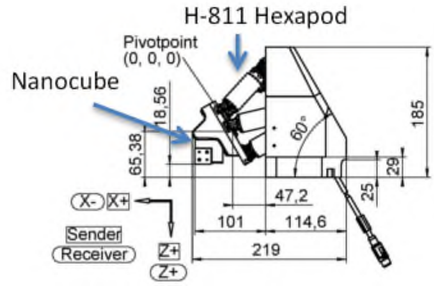

Figure 2. Single sided system (coarse / fine stage)

The hexapod coordinate system can be rotated into prober orientation. The travel range for the hexapod is transformed to the new coordinate system and changes accordingly as shown in Table 1. The coarse stage can be used for coarse positioning, angular and transversal area scans as well as gradient scans. Due to mechanical wear the piezo flexure stage should be used for permanent tracking and fine alignment.

2.2. Fine Stage

To perform gradient scans and to lock on to the maximum signal level (tracking) a 3-axes piezo flexure stage (P-616 NanoCube) is mounted to the hexapod endeffector. It is designed as a parallel-kinematics structure. Similarly to hexapods, all actuators are acting directly onto a single motion platform. Hence, all axes can be designed to have identical dynamic properties, reducing the moving mass considerably. Furthermore, the errors and masses of each individual axis do not accumulate. The flexure guides are free of wear and maintenance and therefore the NanoCube is predestined for tracking and scanning.

Table 1

Travel range coarse stage		**Unit**
X, Y, Z	±6.5, ±16, ±8.5*	mm
θ_X, θ_Y, θ_Z	±14.5, ±10, ±10*	deg
Travel range fine stage		
X, Y, Z	100	µm

3. Results

PI's controllers E-712 for the fine stage and C-887 controllers for the coarse stage provide routines for fast alignment of one or more senders and receivers. The goal of the routines is to align each sender and receiver such that the maximum intensity of the emitted signal is measured on the receiver side. The following fast alignment routines are provided:

- *Area scan*: Spiral or sinusoidal scan to find the position of the global intensity maximum of the measured signal
- *Gradient search*: Circular scan with gradient formation to find the maximum intensity value

Typically, the final position of an area scan routine is used as the starting position for a gradient search routine. Multiple gradient search routines can run synchronously for the axes on both, the sender and receiver side.

Using a double sided system with one fine and one coarse stage on each side (18 active axes) the alignment time for an area scan of 100 µm x 100 µm (max. deviation of peak intensity 0.02 dB)[1] is less than 1 s. The alignment time for a gradient search, randomized with ±5 µm (repeatability < 0.01 dB)[1] also is less 1 s.

4. Conclusion

The combination of a coarse stage for movements in the range of mm and a fine stage for fast movements in the range of 100 µm for fine alignment and tracking allows a flexible setup for on-wafer probing. Especially having the lock-on possibility using the fine-stage compensates any thermal drift due to thermal expansion in the coarse stage and the complete experimental setup.

The double sided high-precision parallel kinematics can be integrated into different probe systems or can be used as a standalone system for on-waver tests.

In Fig. 3 the alignment system is shown as a part of the Cascades CM300xi probe system which is used in industrial applications.

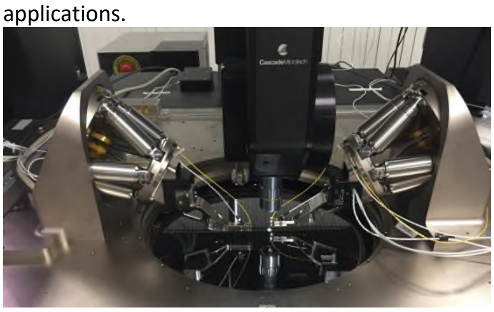

Figure 3. Cascade Microtech's pioneering CM300xi photonics wafer probe station, with integrated PI's Fast Multichannel Photonics Alignment systems for high throughput, wafer-safe, nano-precision optical probing of on-wafer Silicon Photonics devices. Photo courtesy Cascade Microtech, a FormFactor company.

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