Set the Pace on the Data Highway

Automated packaging is a complete solution for silicon photonics

Steffen Arnold and Ellen-Christine Reiff

Some years ago, silicon photonics was already an important topic with regard to fast telecommunication solutions, today the focus lies more on datacom, implying that optical interconnect is not only used for long-haul data transmission, but also for on-chip communication, chip-to-chip, chip-to-board, and so on. The major buzzwords in this context are cloud computing, fast Internet and a number of other computer-supported services requiring the highest possible transmission rates. Here, silicon photonics enable data rates to the magnitude of Tbit/s. However, it is far from easy to place the optical components on the silicon substrate or to handle the optical connectivity necessary to move data to and from the chips. To pave the way to cost-optimized mass production it is necessary to automate a number of complex positioning tasks, adding also machine vision and active measurements.

Silicon photonics employs fairly standard silicon semiconductor processes to build the optical elements required for sending, receiving, and distributing optical information between CPUs and other electronic components. To this purpose, optical components are integrated next to the electronic components in the silicon substrate. The resulting microchips can send data at terabit-per-second rates via optical waveguides with very low power consumption and heat generation. The various components for manufacturing such semiconductor chips can already be produced with commercial equipment. Production at wafer level has become highly automated

All images: PI miCos

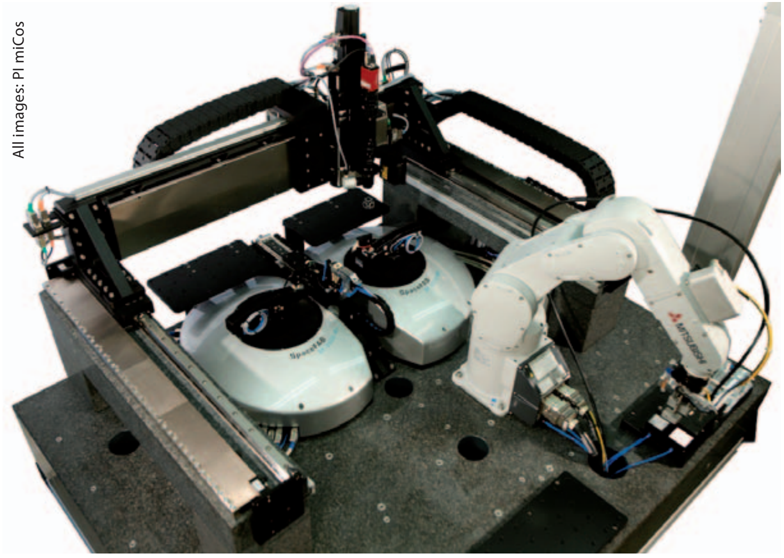

Fig. 1 Automated solution for silicon photonic chip production and inspection: the system integrates several hardware components and software for the automation of assembly and alignment, such as pick-and-place robot technology, image processing, or devices for precision positioning. The bench has already been delivered and installed in the labs of CNIT-TeCIP (University of Pisa), who has an ongoing collaboration with STMicroelectronics.

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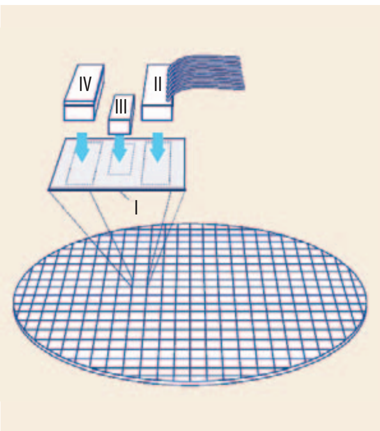

Fig. 2 Chip packaging: silicon substrate (I), fiber connection (II), external laser source (III) and flip-chip bonds (IV).

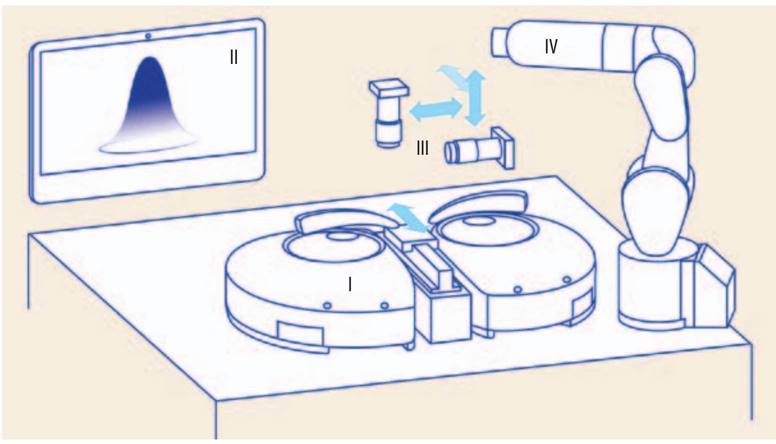

Fig. 3 Schematic design: positioning system for fine adjustment (I), application-specific software and user interface (II), industrial image processing (III) and conventional robotics for pick-and-place of the components (IV).

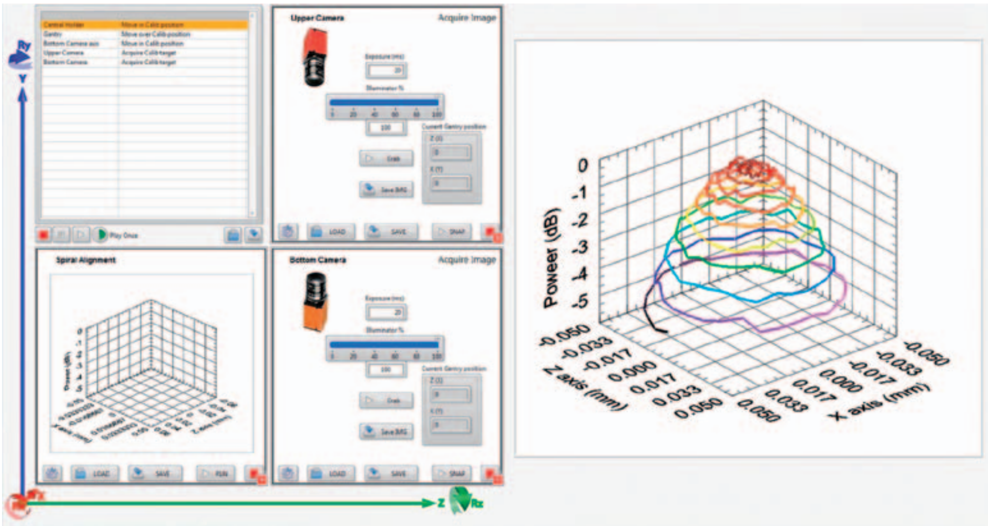

Fig. 4 Fine adjustment for fiber array: The light throughput is measured and optimized via scan algorithms.

at reasonably low prices. But as soon as you break away from the wafer level to full packaging technology, the costs soar upwards.

The integration of light sources at the wafer level and the connection of the optical inputs and outputs prove to be difficult. As a rule, the optical waveguides on silicon wafers have a width ranging from 200 to 400 nm, and are therefore much smaller than optical mono-mode glass fibers with an average core diameter of approximately 9 µm. Therefore some special "tricks" are required to funnel the light in and out the chip (tapers, gratings, etc.). Managing such an automation task is indeed a major challenge: it requires maximum precision in handling, positioning and adjustment as well as the highest possible production speed in order to serve mass markets.

PI miCos, a PI subsidiary, has taken on this challenge and developed an automated photonic assembly and alignment system which has already proven itself in pre-production use.

The specialists for micro- and nanopositioning were able to leverage on a number of in-house technologies for this task. This resulted in a turnkey automated solution which can be adapted well to various application requirements (**Fig. 1**). Here, a silicon chip already diced from a complete wafer is assembled in a ceramic package and other optical elements are then bonded to it, for example, a fiber array, positioned with sub-µm accuracy (**Fig. 2**).

Nanopositioning and Robotics

Four different areas needed to be covered for the implementation of this complex assembly and alignment bench (**Fig. 3**): micro- and nanopositioning, machine vision, robotics for the pick-and-place of the various components, as well as the application-specific software and graphical user interface (**Fig. 4**).

The principal design and function of the system are relatively easy to understand:

The vision-guided robot picks up the components and places them on intermediate holders. Then the photonic components are positio-ned with high accuracy on the Si substrate, employing an high resolution image processing system (**Fig. 5**) based on cameras in the visible and shortwave infrared range (SWIR). The task is managed by a combination of linear positioners and micro-fabrication robots operating in six degrees of freedom, the so-called SpaceFAB's from PI miCos (**Fig. 6**).

The Parallel-Kinematic Principle

The parallel-kinematic SpaceFab principle is based on three XY stages that jointly position a platform using three struts with a constant length and a suitable joint configuration (**Fig. 7**). This enables the realization of fast and high-precision travel.

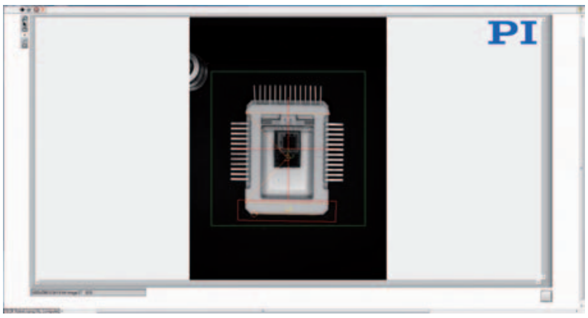

Fig. 5 Integrated image processing supports chip alignment prior to assembly (chip by STMicroelectronics).

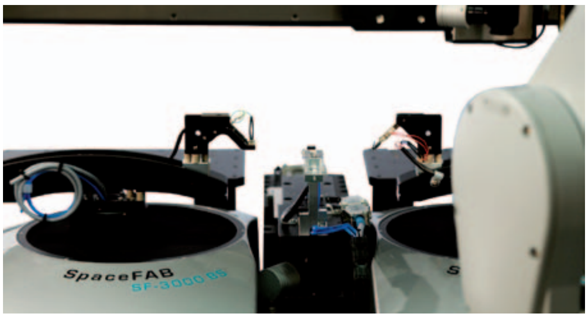

Fig. 6 Exact alignment of the optical fibers on a silicon photonic chip package using two SpaceFab positioning systems.

Fig. 7 In contrast to serial kinematics, in parallel-kinematic systems all the actuators act directly on the same platform, in other words there is no accumulation of guiding errors as in "stacked" systems, thus increasing accuracy greatly.

In contrast to serial kinematics, in parallel-kinematic systems all the actuators act directly on the same platform, in other words there is no accumulation of guiding errors as in "stacked" systems, thus increasing accuracy greatly. But there are also other advantages: for example, low moved mass and consequently better dynamic performance equal for all motion axes, no moving cables to cause friction, and a considerably more compact design.

The XY stages, which were developed especially for applications in optical waveguide alignment, can be equipped with rotary encoders or high-precision glass measuring scales in a closed servo loop. Commanding the Hexapod system has been made very easy. The Hexapod controller allows the user to set an arbitrary point in space as center of rotation. This freely definable pivot point is maintained independently of the motion, a feature which has proven especially invaluable for optical adjustment.

This method allows extremely precise positioning of the photonic components, and the so-called "first light" is achieved, based on the initial position feedback of the photonics components supplied by the imaging system. This term states that optical signal continuity can be measured and monitored. This is a prerequisite for searching and detecting peaks in the sub-micron range with a high level of accuracy. Successful fine alignment is followed by an automated bonding cycle with epoxy resin, optionally with UV or thermal curing. This customized pre-production automated solution for silicon photonics reduces the entire manufacturing process to only a few minutes, which compares very favorably with the usual 40 minutes or more required today for manual production. With their turnkey assembly and adjustment system, the specialists for micro- and nanopositioning have contributed to a major advance in driving silicon photonics ahead and getting closer to the needs of silicon photonics mass production. It will be interesting to see how the future develops.