# ALICE POWERED BY ALICIA

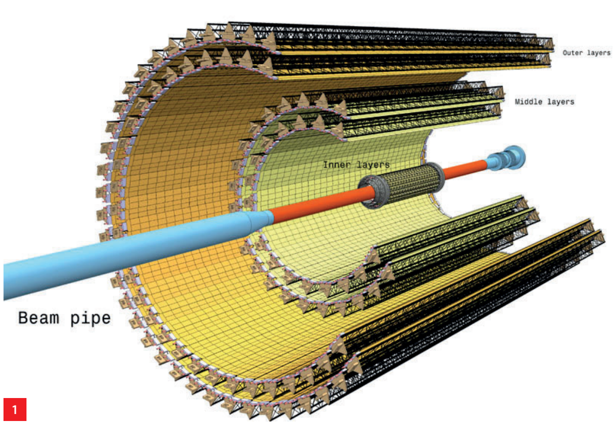
**In the spring of 2015, IBS Precision Engineering was awarded a major contract by CERN as part of the ALICE detector upgrade project. Just over one year later, the first sensor module assembly machine, called ALICIA, that was developed and constructed for this upgrade by IBS, passed the site acceptance test at CERN. Six more machines will be delivered by IBS to sites around the globe. Key success factors of the ALICIA development project were system integration and flexibility.**

IBS Precision Engineering, with 30 employees and its headquarters in Eindhoven, the Netherlands, is an expert in metrology and developer/supplier of solutions to measurement, positioning and motion systems demands where ultra-high precision is required. For IBS, the contract with CERN was a follow-up to the metrology software it provided for assembly machines for the original ALICE detector.

## Detector upgrade

ALICE (A Large Ion Collider Experiment) is one of the four detectors of the Large Hadron Collider (LHC), CERN's well-known flagship. It is a general-purpose, heavy-ion detector, designed to address the physics of strongly interacting matter, and in particular, the properties of the quark-gluon plasma, using nucleus-nucleus collisions at high energies.

During the LHC shutdown in 2019 and 2020, CERN will upgrade the ALICE central barrel detectors (Figure 1) with a new low-material and high-resolution 7-layer tracker (Inner Tracking System, ITS) based on monolithic silicon pixel detectors in order to greatly improve features like spatial resolution, tracking efficiency and read-out rate capabilities.




1 *The detector configuration of ALICE's Inner Tracking System.*

## Sensor pixels

The new ITS consists of seven concentric layers of pixel detectors, so-called Monolithic Active Pixel Sensors (MAPS), based on a 0.18μm CMOS process. The basic MAPS element is a pixel chip consisting of a single silicon die of about 15 mm x 30 mm, built on a high-resistivity silicon epitaxial layer (sensor-active volume), which incorporates a matrix of charge collection diodes (pixels) with a pitch of the order of 30 μm, and the electronics that perform signal amplification, digitisation and zero-suppression. Only the information on whether or not a particle was crossing a pixel is read out.

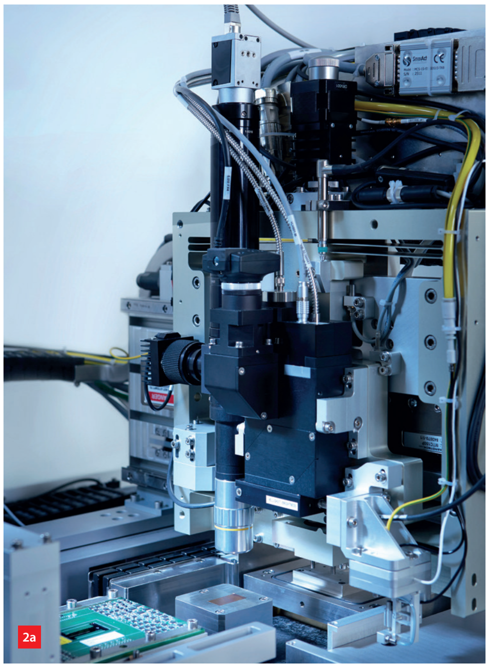
## Automatic assembly

The contract with IBS involved precision engineering for this advanced upgrade. IBS was commissioned to develop and construct an automatic assembly system – aptly called ALICIA (acronym for ALICE Integrated Circuit Inspection and Assembly machine), after IBS's habit to give all its machines a female name – and supply seven of these stand-alone machines, to CERN and six other institutes around the globe – to a large degree they are copies, but each system will have its own site-specific details. CERN itself will use the machine to manufacture the modules for the innermost layer, which entails the highest demands on assembly accuracy.

The automatic assembly system is to produce the sensor modules by high-accuracy sensor array positioning and interconnect. The sensor chips are only 50 or 100 μm thick and require ultra-precision laser soldering of no less than 67 interconnects per chip. The soldering has to take place under vacuum to avoid contamination. For the ITS upgrade, tens of thousands of frames have to be manufactured, with each frame taking up 2 hours of production time. Here, the soldering process is the limiting factor.

## Pick & place and inspection

The ITS detectors comprise of sensor modules, i.e. frames each containing 14 chips. ALICIA (Figure 2) has to pick up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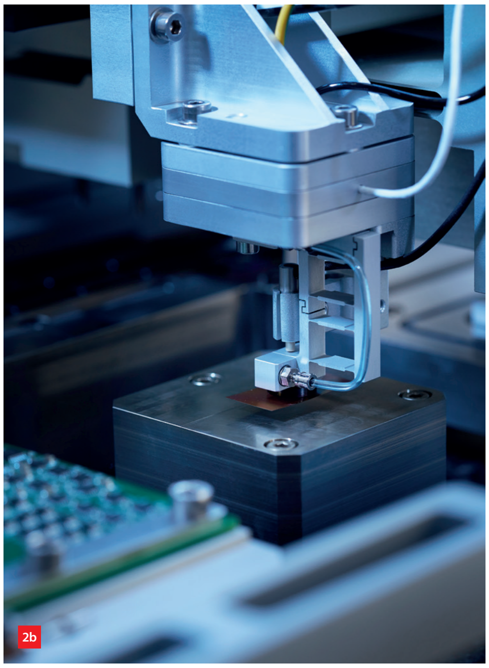
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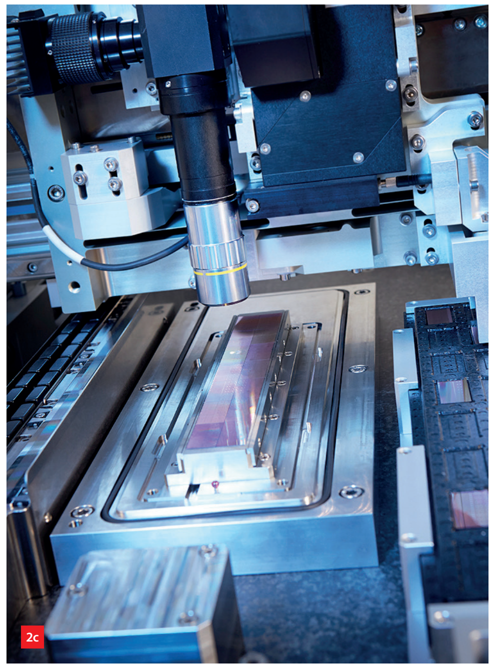
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**2** *The ALICIA sensor module assembly machine. (Photos: Nicole Minneboo)*
*(a) Overview.*
*(b) The chip placement module.*
*(c) Visual inspection unit.*
**3** *ALICIA in all its glory.*

each (fragile) chip from a supply tray, place it accurately on a stage using position markers measured by the vision system, inspect it, then place the chip on the frame and solder all interconnects. Precise assembly and inspection of the sensor modules are of course crucial for the accurate and reliable detection and identification of collision products.

In order to give ALICE the required accuracy, the position of the individual chips with respect to the local reference markers is crucial. In order to achieve this, a high-accuracy (< 0.1 μm) image system was developed to measure both the reference and chip marker, determining the final positioning of the chip. In combination with high reproducibility of the lateral X and Y axis, the chip can be manipulated with sub-micron accuracy, achieving a final assembly accuracy of < 5 μm over the full array of chips. In the vertical (Z) direction, a compliancy in combination with a high-resolution displacement sensor is used to accurately determine first contact with the chip, to avoid damaging the delicate chips.

Inspection of the chips pertains to the electronics as well as the mechanics. Visual inspection of the chips is used to reveal possible fractures and determine the cleanliness. Also the dimension of the chip is measured with a required accuracy of better than 0,8 μm. After assembly, another inspection of the complete frame is performed. This whole process, including the full inspection of one module generates 0.5 terabytes of information. The collection and processing of this amount of big data was an additional challenge IBS had to resolve.

## Flexibility

IBS based its design of the machine on proven technologies for metrology, pick & place, soldering and inspection. The biggest challenge, according to Theresa Spaan-Burke, Innovation Director at IBS, was system integration, in combination with flexibility: "The specifications by CERN included some 500 parameters and these were still subject to change during our design phase. So a lot of flexibility was required from our side and we incorporated this flexibility as much as possible in the design to accommodate last-minute changes. In fact, on some aspects we exceeded the specifications in anticipation of future CERN demands." The rock-solid foundation underlying this flexible approach is the rigorous procedure for process qualification that IBS follows: "This is what won the contract for IBS, in combination with our metrology expertise."

## To be continued

To warrant undisturbed operation – the time schedule towards the actual ITS upgrade starting in 2019 is tight – IBS provides online machine support to each production site. A one-day operator training accompanies the delivery of a machine. Now that the first machine (Figure 3) passed the site acceptance test at CERN, IBS will commence construction of the next systems, for which software expansions and upgrades are foreseen. CERN will keep on raising the bar in the quest for understanding quark-gluon plasma physics. ■

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