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High-accuracy micro-assembly by intelligent vision systems and smart sensor integration

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ABSTRACT

Innovative production processes and flexible strategies for small lot production and mid-sized volumes are playing a decisive role in economical fabrication of microsystems. In particular, micro-assembly is a crucial operation in the production of MST products. Due to large batch sizes many microsystems can be produced economically by conventional assembly techniques using specialized and highly automated assembly systems. At laboratory stage, microsystems are mostly assembled by hand. Between these extremes there is a wide field of small and middle batch production wherefore common automated solutions rarely are profitable. To automate the assembly of these batches few attempts have been made. At *iwb* a flexible automated assembly system has been developed. It is based on a modular design. Actuators as grippers, dispensers or other process tools can easily be attached due to a special tool changing system. Therefore new joining techniques can easily be implemented. The system is based on different optical sensors and actuators. A fiber optic sensor is integrated in the dispensing module to measure contactlessly the clearance between dispense needle and substrate. Robot vision systems using pattern recognition are also implemented as modules. In combination with relative positioning strategies, an assembly accuracy of less than 3 μm can be realized. A laser system is used for manufacturing processes like soldering.

Keywords: Flexible micro-assembly system, modular micro-assembly tool-system, sensor integration, relative positioning strategies

1. INTRODUCTION

Smaller, smarter and more complex – microsystem technology (MST) is the key technology to enter emerging markets. MST is showing new potentials in innovative product design. After the triumphant advance in the automotive industry, microsystems are spreading into more and more fields of daily life like IT-peripherals, telecommunication, medicine technology and household applications [1]. MST-products with largest market shares are currently known applications like inkjet printheads, read/write heads for hard disk drives and sensor components. These products are economically produced in high volumes. In addition, numerous miniaturized products like MOEMS, RF-MEMS and bio-sensor applications are emerging, which are mostly based on hybrid technology. Hybrid microsystems consist of several subcomponents with specific functionalities. In order to achieve a new extent in functionality in micro-products, different subcomponents out of various materials and fabrication processes are combined to an integrated product design (see fig.1). Therefore highly accurate processes are necessary in order to produce these micro-products at a continuous quality. Unfortunately, most of these complex products exist only as hand-made prototypes because of a lack of innovative micro-manufacturing, micro-assembly processes and automated and flexible production strategies for small volumes. Anyhow this dilemma is showing new potentials in micro-production technology.

Because hybrid microsystems are set up of various subcomponents, highly accurate micro-assembly is the core process in producing hybrid micro-products. New combinations of materials and the constant decrease in part size with edge

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lengths below 300 µm leads to a rising demand of assembly capabilities. E. g. in micro-optical systems and high frequency applications, the components must be aligned to each other by precision tolerances down to 1 µm. Therefore suitable processes like handling, joining, mounting and packaging have to be optimized or developed which enable technologically these capable micro-products and offer new possibilities in designing products. Due to smaller part sizes and smart surfaces of subcomponents, handling of fragile and surface-sensitive components offers a special challenge. Handling systems, which are currently developed in the area of MST, tend to be based on the mechanical-tactile contact between effector and micro-part. In order to avoid the inherent disadvantages of tactile handling, a contactless and accurate handling technology of micro-parts is necessary. The promising potentials of these innovative sub-processes in micro-assembly like handling, joining, dispensing and mounting technologies, which are all developed at *iwb*, are shown in the next chapter.

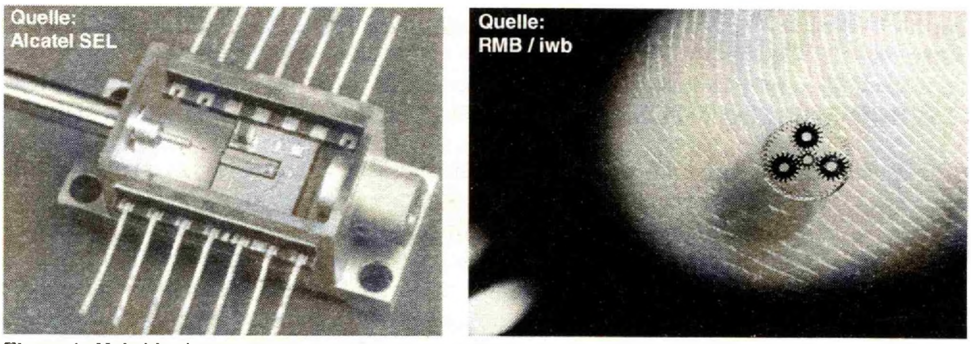

Figure 1: Hybrid microsystems

Customization in MST causes a multitude of different hybrid products and subcomponents out of suitable materials. Therefore diverse manufacturing processes are necessary. The manufacturers try to meet this vast variety by modular setup of the hybrid products and subcomponents in order to reduce the total number of different parts and production processes. Similarly, process development has to focus on flexible assembly and packaging technologies using standardized setups and components as modules in production systems. Particularly, activities have to aim for reduction of the proportional cost of assembly processes which can currently sum up to 70% to 80% of the product costs [2]. The most costly process steps are precision alignment and joining operations. Due to these highly specialized and highly accurate assembly processes, micro-assembly systems are nowadays optimized for one detailed assembly scenario and are run at best in automatic mode. According to likely small production volumes, the proportional costs of assembly and the initial expenditure are increasing. This high capital expenditure for micro-assembly systems and the allocation of highly qualified personnel for operating and maintaining the machines, is setting a huge entrance barrier for small companies into MST markets. Based on the innovative sub-processes in micro-assembly mentioned above, smart modular tools for handling, joining and mounting tasks are developed at *iwb*, to enable flexible and efficient assembly strategies. The functionality and benefit of these modules is discussed in this paper focusing on smart sensor integration and intelligent sensor systems.

According to global production volumes from 1 to 1.000.000 per year of mechatronic micro-components of sensor devices and the mentioned multiplicity of different product types due to customization, the lot sizes of hybrid microsystems are rather small [3]. Therefore assembly operations are often done manually as long as the assembly tolerances allow. Due to similar product types, most assembly tasks are more or less equal. Nevertheless a partly automated or even automated assembly platform, which is built like conventional systems, e. g. customized high precision die-bonders, is not efficient due to high amount in technical and capital expenditure. Also these known systems are not optimized for frequent product changes and permit a planar assembly only. But highly specialized and customized microsystems require automated and agile assembly solutions for reliability issues and cost-efficient production processes at small lot sizes. Agile assembly strategies rest upon sensor-based and semi-autonomous components and assembly tools which are designed for various assembly processes. By exchangeable modules an agile system allows short set-up times between product changes. Therefore various types of microsystems can be produced economically due to the high capacity of the production system. An agile micro-assembly system for assembly tasks of parts with reference structures on the top used as marks for positioning and functionals structures at the bottom (flip-chips) is presented in the last chapter in order to show the benefit of a modular setup.

2. POTENTIALS OF MICRO-ASSEMBLY PROCESSES

2.1 HIGH-ACCURACY POSITIONING STRATEGIES FOR MICRO-ASSEMBLY

The demand on high accuracy positioning in micro-assembly technology is a result of still diminishing part and product dimensions. Nowadays accuracy, down to the single micron, requests high precision positioning systems. In order to realize the requested high accuracy of positioning systems cost-effectively, workspace of the precise systems is minimized as much as possible. Contrary to this development, the size of part magazines is still increasing due to higher rates of yield. E. g., as a result in development of economic wafer technology, 200 mm wafers are replaced by 300 mm ones in order to reduce the handling area in comparison to process area. The combination of these two developments asks for new strategies to obtain high accuracy and large workspaces integrated in an economic system. A high positioning accuracy over a large work space results in high capital expenditure, which can only be afforded in high volume production.

Especially for assembling Microsystems in small and mid-sized production volumes, a more cost efficient solution is necessary. One of the possibilities is the combination of two positioning systems designed for different aspects: First a coarse positioning system is used for part feeding and other tasks which require a large workspace. Additionally a fine positioning system ensures the given accuracy demands of joining and assembly processes. This idea was performed for several years at *iwb*. In [4] a modular tool with integrated sensor technology for the assembly of laser diodes was presented. The coarse handling system is a standard handling robot with repeat accuracy of +/- 25 µm. The robot provides a large work space of 1.2 m diameter. A tool with an integrated fine positioning system is attached to this robot. It is based on piezoelectric actuators which achieve the requested positioning accuracy in combination with a smart image processing system. Thus, high precision assembly can be realized using an inexpensive standard robot and a "tuning kit" for fine positioning.

This combination demands a closed loop relative positioning strategy by vision control. Relative positioning has another economic advantage: since the closed loop is located in the fine positioning system, requirements on its repeatability are less important than small positioning increments and a high resolution of the measuring equipment. Apart from the advantages of this technology, disadvantages have also to be discussed. To implement the relative positioning strategy, the involved sensors have to be selected carefully. The attention has to be directed mostly on the optic and the image processing system. A problem of the optic system is the small depth of focus. Despite that, the process time is increased because of the image processing. But on the other hand fine positioning can be controlled.

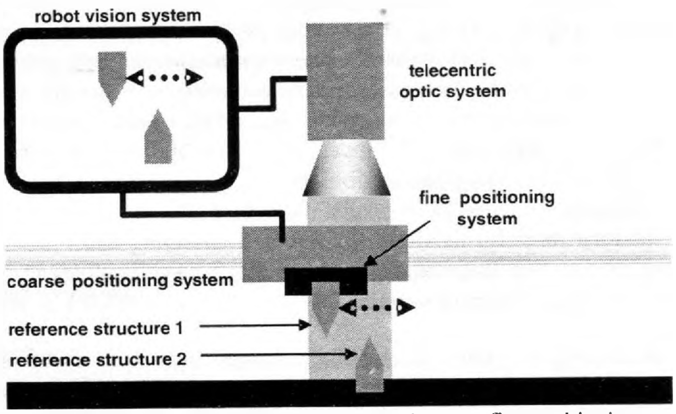

Figure 2: Relative positioning strategie and coarse-fine positioning – both joining partners are in field of view of optic sytem

2.2 AGILE MICRO-ASSEMBLY STRATEGIES

At first agile micro-assembly systems are capable of executing different assembly tasks. Therefore a system has to provide functions and components for different positioning strategies in micro-assembly (see fig. 3). At least three scenarios can be classified [5]: In the first scenario the reference marks which are fixed on the top of both parts, which have to be assembled, are visible during the assembly process. Therefore image-processing can be done by a top-view optical system with variable or fixed focus. In the second positioning scenario also both reference marks are on the top-side of the substrate and the micro-part. Hence the mark on the micro-part is visible, but the positioning mark on the substrate is covered by the micro-part during the assembly process. An image-processing can be done by an infrared optical system, if the micro-part is translucent in this wave-length. Also a top-view optical system is suitable, if the part can be moved in and out of the object field of the camera. In the last scenario the reference mark of the micro-part is covered due to the position on the bottom side of the part. Therefore this positioning task can be set up in different ways: by using an infrared camera for translucent parts, by using two optical systems showing both references or by using a splitfield optic which can map both references by inserting between the substrate and the part [6].

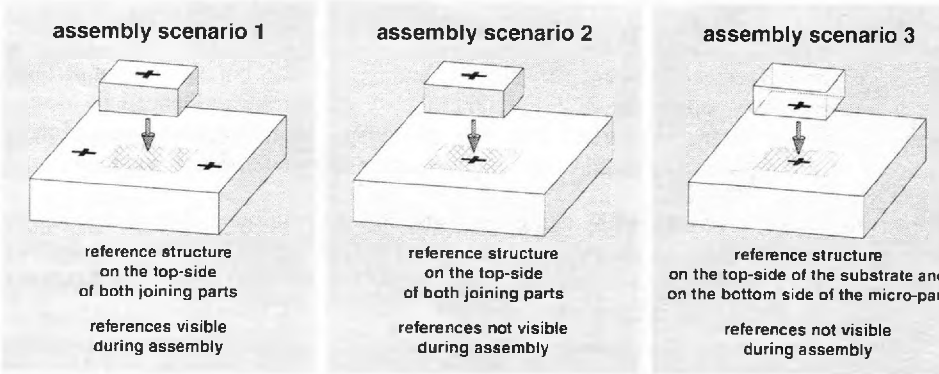

Figure 3: Positioning strategies for micro-assembly

As a second topic agility means the possibility to carry out different sub-processes of micro-assembly within one automated assembly system. Thus many additional processes like dispensing, part feeding, welding, soldering can be found in nearly every micro-assembly scenario. Any implementation of these processes is currently a stand alone and inflexible solution in automated systems for high volume production. Implementing these solutions in production system for small and mid-sized batches, is a dilemma in micro-assembly due to the technical and financial expenses. Therefore modular principles for a flexible tool box must be developed to implement different processes easily on one handling system.

Not only modularity is essential, but also reduction of setup times is of crucial interest during automated assembly of small and medium batches. For example this can be realized by an automated tool changing system. It allows any combination of processes by customized endeffectors. Due to the advantages of image processing, the tool changing system does not need an absolute accuracy. When a tool is changed, image processing determines the new position of the tool and uses the new coordinates for further processes. Setup times between product changes can also be reduced by tele-operated teaching and calibrating processes. Based on telepresence technology, the operator can move the kinematic system to given coordinates by suitable haptic input devices which enable a close-to-reality impression of the assembly scenario. This promising technology makes processes more ergonomic and faster.

2.3 NON-CONTACT HANDLING PROCESSES

At the moment several commercially available products in MST are based on semiconductor processes. Generated by standard or adapted lithography processes, mounted on standard substrates, these microsystems are posing as high demands on assembly as e.g. high frequency applications. To fulfil these requirements there are often some workarounds: Free functional structures like pressure or air flow sensors with very thin membranes must not be touched. Here special landing zones for conventional vacuum grippers are designed, which increase the size of the single dice. Only the use of new non-contact handling and mounting will enable the employment of these parts directly. Also the handling of other still exotic parts like coated dice or very small parts can be enabled by adapted handling technology. Non contact handling can be realized by an equilibrium of attracting and repelling forces. These forces can be applied by air cushions generated by pressure fields or ultrasonic waves, by electrostatic or magnetic forces and gravity (see fig. 4). A key task is the possibility of realizing a part's position. Thus part centering forces have to be applied, preferably contact less as well. Especially this is possible by the use of air cushions.

2.4 INNOVATIVE JOINING TECHNOLOGIES

Another challenging field is spanned by joining technologies. The use of adhesives is the most widespread principle for joining parts. Especially in small and middle volumes common dispensing technologies are not suitable any more. In mass production screen printing techniques are used, which should not be applied at small numbers due to the high costs of the screens. Therefore in many cases of small volume assembly, principles for single drop generation have to be used. These can be needle dispensing, drop on demand dispensing and a new principle, the use of small fluid containers.

Needle dispensing technologies are very flexible and easy to use, but usually not as fast as drop on demand techniques due to the necessary movement in z-direction. The processes are influenced by many parameters: viscosity, surface tension, needle geometry and surface materials and several more. Improvements of these known but in small volumes still delicate processes can be made by sensor integration. This will be desribed later.

Many influences can be avoided by non contact dispensing techniques. Recent developments open new fields in drop on demand dispensing: New equipment is able to dose fluids of higher viscosities in droplets of nanoliter size. Thus, many more adhesives and other fluids can be used. This kind of non contact dispensing has many advantages:

- Faster than needle dispensing
- Constant droplet size because of independence from surface adhesion and needle clearance
- Loose component parts cannot be moved by needle and fluid ("adhesion gripper")
- Elimination of physical contact of equipment with the substrate (height sensors, needle) to avoid vibration and wear/damage
- Less parameters to observe (height adjustment)
- Possibility of different droplet sizes on the same substrate by shooting several small droplets to one depot without affecting neighbour depots
- Dispensing of depots with ideal geometrical proportions
- High throughput

There are still some necessary improvements concerning splashing, satellite droplets and air enclosures, but the mentioned advantages offer several new possibilities, especially at the use of high viscosity fluids.

Another new approach to dispense high viscosity fluids is proposed by *iwb*: Using microcapsules enclosing fluids, tiny droplets can be generated by gripping one single capsule, placing it like a single component and opening the capsule. The liquid is set free and can be used. Although not every fluid can be used for this process, there are several advantages:

- The amount of fluid is known exactly already before starting the process
- Many different fluids can be used in parallel without cleaning dispensers
- Gripping small parts is a known process
- There are less dependencies on surface properties.

3. SETUP OF MODULAR TOOLS FOR MICRO-ASSEMBLY

3.1 FLEXIBLE MICRO-ASSEMBLY TOOL SYSTEM

Starting from the assembly processes shown above, several flexibly usable micro-assembly tools were developed in order to integrate them at last in an agile assembly system. Based on the agile and highly accurate assembly strategies, a modular tool system has been designed and improved for several generations [2]. The core component of the tool system SATURN (sensor-based **a**ssembly **t**ool **u**sing **r**obot visio**n**) is the tool head, in which all necessary sensor components are integrated. All process specific endeffectors are attached to the tool head by an automated tool changing system (see fig. 4). Thus a telecentric optical system which is used for highly precise image processing is located in the central axis of the tool head. Due to the telecentric lens optical distortion will not occur. The resolution of the optical system is 3 µm / pixel and the field of view is nearly 2 x 3 mm². The central position of the camera enables relative positioning strategies as shown in chapter 2. All tools and processes are designed in a way that their structure is located in the focal plane of the optical system in about 35 mm from the telecentric lens (image plane). All endeffectors can be extended and retracted into or out of the field of view. So the parts, which are gripped by the endeffectors and the substrates can be identified precisely by image processing. Based on this imaging data, the vision control system calculates the deviation vectors in cartesian coordinates and rotational directions for relative positioning movements. By this setup of the assembly tool system both assembly scenarios one and two (see fig. 3) can be fulfilled. In addition to the visual sensors, a high resolution force sensor is integrated into the central tool head, which is used for monitoring the contact forces in z-direction during joining and mounting processes. The sensor is preloaded by a pneumatic system in order to eliminate the weight of the tool head and to increase the resolution of the monitored forces. Also fibre optic distance sensors can be integrated into the tool head in order to control e. g. the needle clearance during a dispensing process.

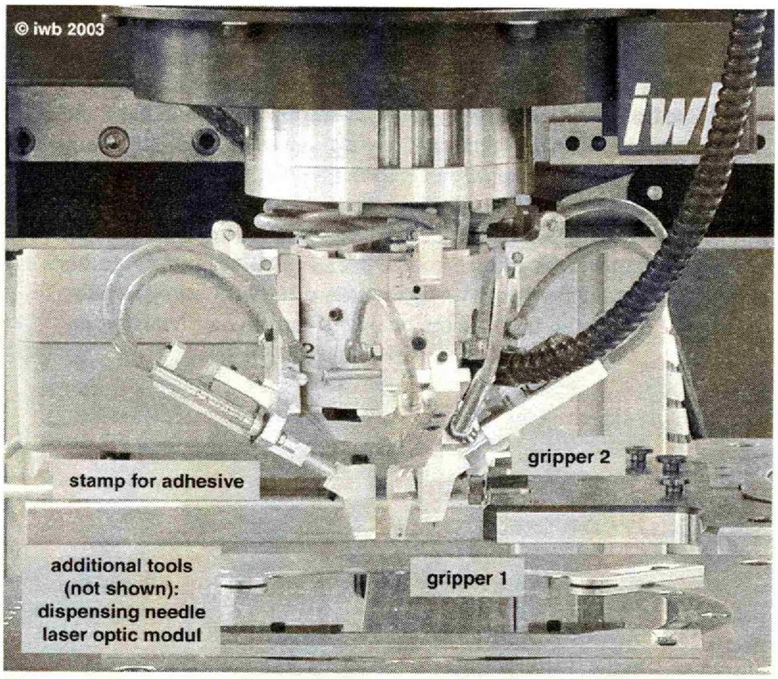

Figure 4: Flexible micro-assembly tool system with an automated tool changing system

A new development is the automated tool changing system. Possibilities to change tools manually between different assembly tasks were already implemented in first concepts of SATURN. But for the rising number of tools used for one micro-assembly scenario the interfaces on the tool head were not sufficient anymore. Also the setup times had to be reduced because of the rising number of different products. Therefore a new automated tool changing system was developed which enables fast and simple changing procedures also between assembly steps. All process specific tools are placed in suitable tool change stations in the workspace of the kinematic system. Four tool-interfaces are attached to the tool head. The interfaces consist of two lead throughs for air pressure or vacuum. Positioning and fixing of the endeffectors at the tool head is realized by a conical interface which is adapted from the interface of machine tools. A strong magnet is located at the top of this cone in order to fix the tools by magnetic force. Further improvements like the implementation of optical and electrical connections are in conceptual state.

3.2 SPLITFIELD-OPTIC

An additional optical system is necessary, if the flexible tool system has to be suitable for assembly operation within the assembly scenario 3 (see fig. 3). Therefore the optic module, called splitfield, has been developed for flip chip assembly tasks [6]. Instead of using a gripper with special alignment structures for flip-chips, the optic module is used for the positioning process. It is based on two cameras, one taking the picture of the bottom side of the component part and the other taking the picture of the substrate. For measuring purpose the optic module is moved between the part and the substrate. With image processing the part is aligned in x -, y – direction and φ_z -direction. After alignment and the retraction of the splitfield module, the chip can be assembled by a precise z-motion. Therefore the module can be attached flexibly into the assembly system (see fig. 6).

3.3 NON-CONTACT GRIPPER

As new modules non-contact grippers are currently developed (see fig. 5). Gripper tips for small parts levitated by aircushions will be implemented. The part hovers under a kind of preloaded air bearing in a distance of 50 – 150 µm.

Small parts below 3 mm edge length will be transported. On the one hand the air bearing can be generated by air pressure and a field of very small nozzles. A precise air pressure source for vacuum and the air bearing is necessary in the system. On the other hand the levitating forces can be generated by a combination of ultrasonic and vacuum. The ultrasonic near field effect is generating an air cushion comparable to an air bearing. It is possible to generate significant forces using this principle. Not only small parts, but also big disks like wafers or glass sheets can be transported by this effect. At present further investigations are performed to decrease the size of ultrasonic transducers below 10 mm. As air bearings are frictionless by definition, the parts have to be centered to the gripper actively. Tactile methods as well as non contact methods are currently developed.

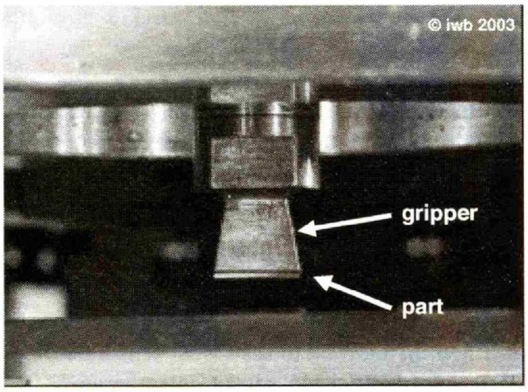

Figure 5: Non contact die-handler

3.4 IMPROVED NEEDLE DISPENSING

Conventional needle dispensing can be improved, too. Main influences on this process derive not only from fluid parameters like viscosity and wettability but also from surface parameters of needle and substrate, needle diameter and needle clearance. At *iwb* several sensors were tested for assuring the needle clearance. Directly implemented into a closed loop including the control of the z -axis of the handling system, height differences due to product or process tolerances can easily be compensated. This is especially important in the field of multilayer packages and 3D assembly. The developed sensor is very small, so it is possible to implement it in a modular tool. By the geometrical design the needle clearance is measured directly between needle and substrate which increases precision significantly. [2] shows a dispensing module for monitoring z-axis movements near the dispensing needle.

3.5 NON CONTACT DISPENSING

To use the advantages of non contact dispensing as described above, also drop-on-demand dispensers can be implemented. New dispensers are very compact (compare the dispensing principles of the companies HSG-IMIT, Microdrop and Picodostec). At the moment a further reduction of droplet sizes from 5 nl down to 0.5 nl with high viscosity fluids is done in the Bavarian research cooperation ForµProd. Based on the Picodostec dispenser fluid simulations are done for investigating droplet generation and fluid stresses. The droplet is produced by a tappet pushing into a small nozzle. Based on the simulations, new dispenser parts are developed, which are currently tested. First results are giving droplet sizes below 1 nl at viscosities of 3700 mPas. The dispensing system itself is very fast: A droplet generating frequency of 250 Hz is possible and should meet most requirements.

4. SETUP OF FLEXIBLE CONFIGURABLE MICRO-ASSEMBLY SYSTEM

To enable economic assembly processes of hybrid microsystems in small to mid-sized lot-sizes, the above mentioned modular micro-assembly devices have to be integrated into one agile assembly system. Therefore a flexible configurable micro-assembly system is developed at *iwb* which supports all assembly scenarios classified in figure 3. In order to show different assembly processes and tasks in operation, following products are produced at the system as examples for the scenarios: Scenario 3 is represented by a flip-chip assembly operation of test-dies onto a test substrate, showing a new joining technology by adhesives [8]. Scenario 1 and 2 is represented by an assembly operation of atomic force microscope probes (AFM), including a solder-paste dispensing process.

The core components of the micro-assembly station are two kinematic systems (see fig. 6). At first, a high precision portal robot enables precise relative position strategies. By axis in all cartesian directions and rotation round the z –axis, the system provides four degrees of freedom. Due to the high resolution of 0.5 μm in all translation axis and an angular resolution of 0.001°, position accuracies down to a single micron are possible. Currently the above mentioned micro-assembly tool system (see fig.4) is fixed to the portal robot. Therefore assembly scenarios 1 and 2 (see fig.3) can be fulfilled anywhere in the workspace of the robot system. In order to change all process-specific endeffectors, like individual grippers for different parts, dispensing unit, adhesive-stamp and a fibre coupled diode laser optics, automatically by the tool changing system integrated into the tool head, also the tool changing station has to be located in the workspace of the robot. To enable flip-chip assembly operations with the same tool system, the splitfield optic module can be extended into the work-space and retracted by a pneumatic kinematic system. This setup increases the flexibility within the workspace, because the additional optic device engage in the working environment only if required. The parts and substrates, which should be assemblied, have to be supplied above and below the optical interface.

Due to the restricted work-space of the portal robot and a lot additional devices within this area, the tool-system can not reach all parts, without moving the joining parts. Therefore a planar table with two couriers, based on linear motor technology, is integrated into the assembly system for part and tool supplying purposes. One courier provides magazines like chip-trays for flip-chip parts and a wafer-level magazine of AFM-probes on a bluetape. The courier carries the test-substrate, the flip-chips are mounted onto and a pneumatic chuck for the AFM substrate (150 mm wafer). Dividing part supply and substrate provision reduces setup times, because the magazines can be reloaded while assembly operations are taking place. Furthermore using up to four couriers additional part supply devices can be integrated into the assembly system. Between product changing the magazines and substrates can be fixed on the couriers by standardized interfaces or by changing the carrier plates, if additional devices have to be installed onto the courier.

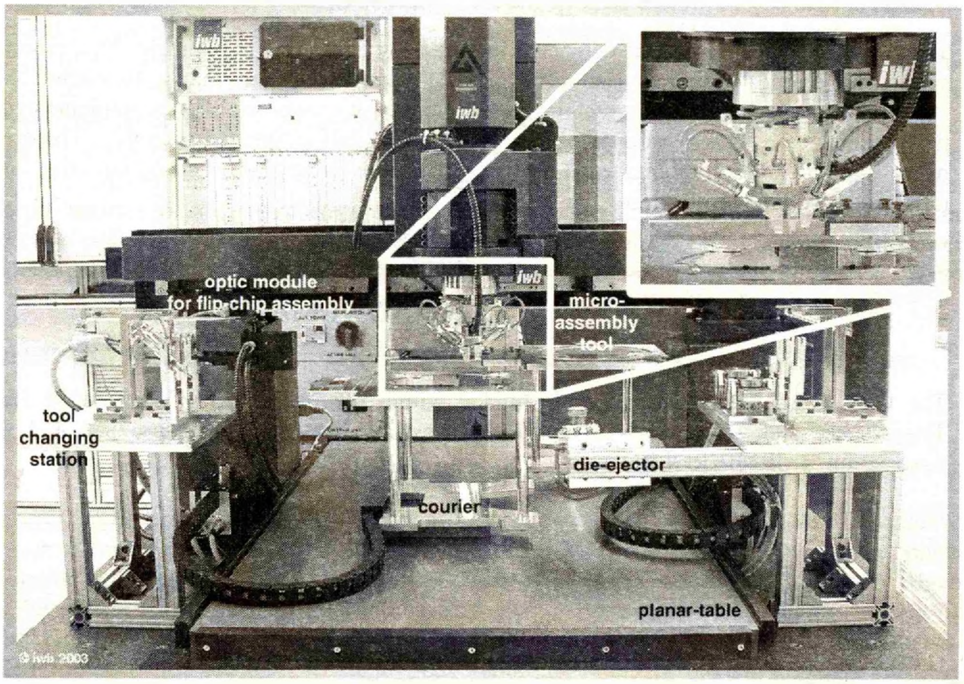

Figure 6: Flexible configurable micro-assembly system

By online monitoring of every work step, closed loop control strategies enable precise and sensible assembly and joining operations down to a position accuracy of 3 μm at 3 σ. Because parts and substrates are supplied right at the mounting position, long lateral movements between the capture of a picture with the vision control and the positioning of a part, are avoided. To place the parts sensibly with a defined joining force e.g. in a joining process with glue, the joining force is monitored by a high-resolution force sensor, which is integrated into the tool-head. Control master of this assembly system is the robot control. The control communicates via serial bus interconnection with the part feeding system and the vision system.

Additional assembly tools, like the non-contact die-handler or further dispensing units mentioned above, can be easily integrated into the assembly system. Due to their purpose and the chosen assembly strategy they can mounted onto the couriers of the planar table or round the planar table.

5. CONCLUSION AND OUTLOOK

Small and medium batches will play a decisive role in future markets. The more flexibility for products is requested the less mass products are produced. This has especially in MST consequences: nowadays microsystems are produced for mass markets. For the development of future production technologies for microsystems smaller batch sizes have to be kept in mind. A promising concept is the modularization of production systems. This means for microsystems to make a balancing act between high accuracy and modularity. Relative positioning strategies are best to implement these two extremes. In addition to that new assembly processes are developed. For the more and more fragile parts a contactless handling is of great importance. To join these parts with high viscose adhesives demands also new processes as the mentioned capsule technology or the contacless dispensing principles are demanded.

These principles have to be implemented in a flexibly configurable platform. This requires an advanced tool changing system, not only providing air lead-throughs. The idea of modularity has to be carried to the control processes as well. For teaching processes the new technology of telepresent production will be implemented. It will allow to reduce setup times dramatically as well as opening the wide field of half automated assembly. These efforts will result in a modular micro-assembly system strengthened for future demands in micro-assembly, not only for medium batches but also for rather small volume production.

6. ACKNOWLEDGEMENTS

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REFERENCES

[1] Microsystems World Market Analysis 2000-2005 - NEXUS Task Force Market Analysis, Duesseldorf: VDI 2002.

[2] Jacob, D.; Höhn, M.: Assembly of semiconductor based microsystems with sensor guided tools. In: Reichl, H. (Ed.): System Integration in Micro Electronics, Nuremberg. Berlin: VDE 2000, pp.193 – 202.

[3] Wicht, H.; Bouchaud, J.; Bahle, C.: Vergebene Liebesmüh oder Wachstumsmark? In IVAM NRW e.V (Ed.): inno Nr. 20, Dortmund 2001.

[4] Reinhart, G.; Jacob, D.: Positioning Strategies and Sensor Integration in Tools for Assembly MOEMS. In: Motamedi, M.; Goering, R.: MOEMS and Miniaturized Systems, Santa Clara. Washington: Proceedings of SPIE Vol. 4178 (2000), S. 395 - 402, 2000.

[5] Höhn, M.: Sensorgeführte Montage hybrider Mikrosysteme. In Reinhart, G.: iwb Forschungsberichte 149. München: Utz 2001

[6] Jacob, D.: Verfahren zur Positionierung unterseitenstrukturierter Bauelemente. In Reinhart, G.: iwb Forschungsberichte 167. München: Utz 2002

[7] Reinhart, G.; Jacob, D.; Fouchier, M.: Automated Assembly of Holder Chips to AFM probes. In: Nelson, B. J.; Breguet, J.-M. (Eds.): Microrobotics and Microassembly III, Boston, USA. Washington: Proceedings of SPIE Vol. 4568 (2001), pp. 310 - 317.

[8] Neuhaus, H. J.; Wernle, E.: Advances in Materials for Low Cost Flip-Chip. In: Materials Edition of Advancing Microelectronics 2000, V. 27, No. 4, pp. 12-14