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AUTOMATED ASSEMBLY OF MICROOPTICAL COMPONENTS

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ABSTRACT

In the field of microsystem technologies one future trend is recognized. Manufacturing microsystems monolithically is becoming less reasonable and practicable with increasing applications and complexity. Assembly processes will be needed for the majority of microsystems due to difficulties arising in manufacturing complex structures out of one piece, the need for components to be manufactured by different processes, or simply to connect the microsystem with the macroscopic environment. Additionally, high production output at competitive costs is attainable only by replacing manual assembly with new automatic handling, positioning and joining technologies. To assist in development of microassembly processes, techniques from macroassembly technology may be transferred. Especially in microoptics existing know-how from macroscopic lens-assemblies might be transferred.

The microsystem presented in this paper involves a wide range of requirements needing to be satisfied frequently in microsystem assembly. It represents a microoptical beam forming system consisting of one SELFOC- and two GRIN-microlenses joined by adhesive bonding, fixed in a protection-mount, which serves additionally as a coupling unit of a multimode fibre, and finally adjusted to a laser diode at a defined distance according to an optical design. Besides complications due to the sensitive optical surfaces and the small and varying geometries of the system components, there is the additional requirement of high accuracies, of 0.1 to 2 µm and down to 1 arcsec, needed to realize the optical function of the microsystem.

The assembly system, based on a six-axis-precision robot accurate to less than 1 µm, consists of a modular designed tool changing system, specially-adapted, self-adjusting grippers, several sensors to monitor positioning , dosage devices to dispense measured quantities of adhesive, in the range of nanolitres, and a specially designed assembly platform to clamp microparts of different geometries.

Keywords: microassembly, microoptics, adhesive bonding, gripper, adjustment

DESIGN AND FUNCTION

In optics there are several basic functions which can be realized with microoptical assemblies. Major applications involve coupling laser diodes with optical fibres, including beam shaping systems and pumping of solid state lasers or optical scanners.

Most difficulties occuring in hybrid assembly arise from the small size of the various elements, the high sensitivity with respect to damage from handling, bonding and welding and the small range of tolerances for positioning (0.1 to 10 microns per axis and some arcsec in angle tilt).

The prototype to be assembled is a microoptical sub-assembly to shape the beam of a wide-stripe laser diode /1/. The emitting area of this kind of laser diode is rectangular. The field distribution in the direction perpendicular to the laser facet is a fundamental mode, while the field distribution in the direction parrallel to the facet has one or more higher order modes. The beam profile is shaped by two crossed cylindrical GRIN-lenses due to the differing divergence angles parallel and perpendicular to the junction of the laser diode. The first GRIN-lens collimates the beam profile perpendicular to the junction of the diode (fast axis) and the second lens in the lateral direction of the diode (slow axis) shaping a circular spot. Finally a SELFOC-lens collimates both directions to yield a high coupling efficiency of the whole system (fig.1). The aim is to realize a power range from a few watts to kilowatts combined with high incident beam intensity, which is especially interesting for laser diode material-processing systems requiring microoptic components.

The assembly consists of one SELFOC- and two crossed GRIN-microlenses fixed in a mount. The assembly involves joining these three lenses automatically and with defined distance from both the laser diode and the optical fibre with an accuracy of less than 2μm.

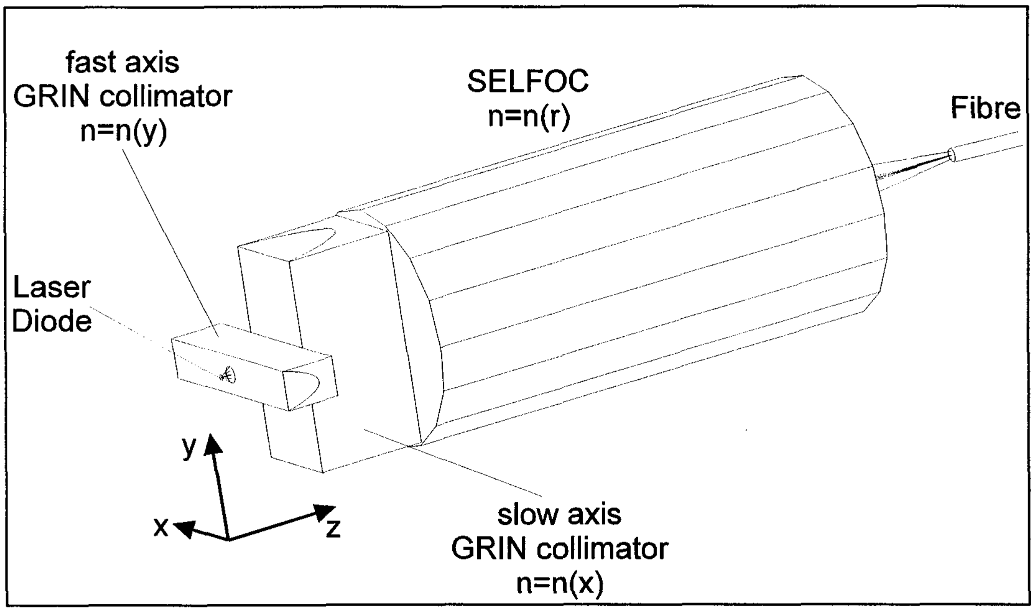

fig. 1 microoptical sub-assembly

At the end of the assembly process the assembly is joined in a housing by either welding or adhesive bonding /2/. The results of the optical design calculated with the program ZEMAX are summarized in tab.1. Most of the components were purchased, based on these parameters, with the exception of the GRIN-lenses, which were manufactured by silver-ion exchange processes at IOF. After examining the first experimental results, it might be that a redesigning is necessary based on the determination of the refractive index profile.

Tab.2 shows the tolerances which have to be realized during the assembly process. These numerical values were calculated under the assumption of a coupling effeciency of 98% to 80%, by varying only one parameter while fixing the others. In this case the highest deviation value of the parameters is as well the maximum deviation permissible for assembling the sub-assembly. Other readjusting parameters include the position of the laser diode and optical fibre relative to the microoptic sub-assembly. To realize the optical design and calculations an adhesive layer thickness of less than 10 µm is required.

component	type	company	specification
LD	JO LD 0.3 SIM 670	JO-LD, Jena	active area 1µm x 44µm NA: 0.2x / 0.5y $(HW1/e^2)$ 670 nm
fast axis collimator	300µm cylindrical GRIN n=n(y)	FhG.IOF, Jena	(1.5 x 0.3 x 0.38) mm^3 g=2.3
slow axis collimator	750µm cylindrical GRIN n=n(x)	FhG.IOF, Jena	(0.75 x 1.5 x 0.75) mm^3 g=0.82
SELFOC	SLH1.8 0.25 156	NSG, Japan	Ø 1.8mm x 3.77mm
Fibre	HCG M0100T	L. Comp., USA	Ø 0.1mm 0.22NA

tab. 1 calculated parameters of the integrated components

fast axis collimation	-	±10 µm	±1.2°	±1.5°	±13°
component	offset x	offset y	tilt x	tilt y	tilt z
slow axis collimation	±13 µm	-	±2°	±1.1°	±16°

tab. 2 tolerances of geometric and beam parameters of a microoptical collimator

CLASSIFICATION OF COMPONENTS USED IN MICROOPTICS

The first step in designing an assembly process is to focus on the individual microcomponents to be handled. The microcomponents of the discussed assembly system are shown in fig. 2. Generally the components in microoptics need to be classified according to the characteristics important in an assembly process /tab. 3/:

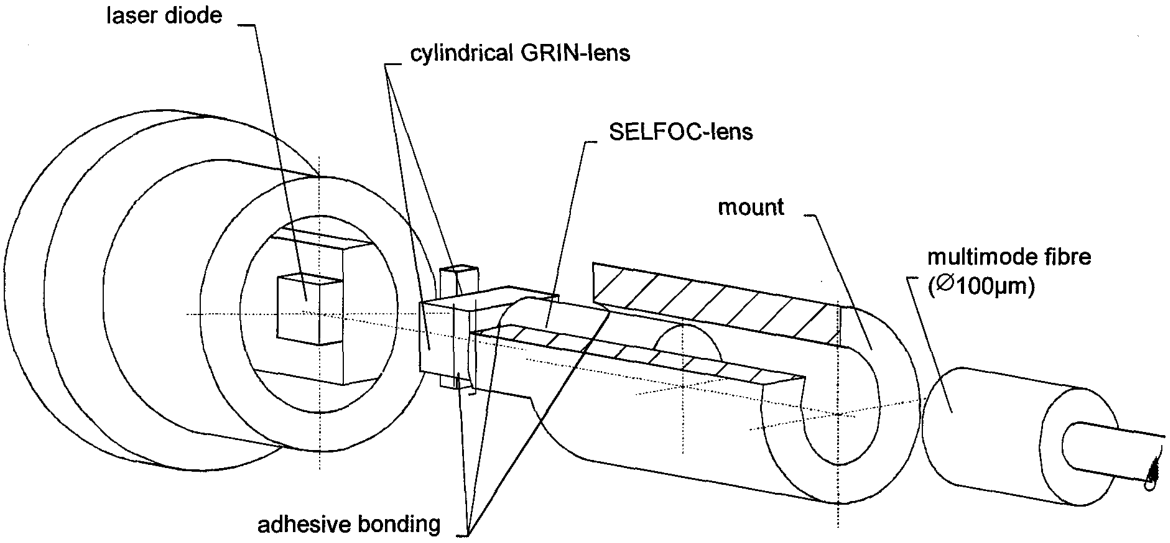

fig. 2 schematical view of the microoptical system

feature	*1st GRIN-lense*	*2nd GRIN-lense*	*SELFOC-lense*	*mount*	*laserdiode (incl. mount)*	*fibre*
geometry	rectangular parallelepiped	rectangular parallelepiped	cylindrical	irregular	irregular	flexible cylinder
characteristic dimensions	0,3x0.34x 2.3 mm	0,75x0.75x 2.3 mm	∅1.8x2.3 mm	∅3x2.3 mm	5 - 10mm	∅ 50 - 100 µm, length of fibre <1m
aspect ratio	4 - 9	4 - 9	4 - 9	4 - 9	4 - 9	> 100
characteristic elements of form	edges	edges	edges	edges	edges	edges
material	glass	glass	glass	glassceramics	semiconductor materials	joining of glass/polymer
weight	0.6 mg	4.5 mg	34 mg	138.7 mg	20 g	—
surface roughness (of the optical surface)	VVVV	VVVV	VVVV	VV	VVVV	VVVV
condition of delivery (packing)	palette/ packaging	palette/ packaging	palette/ packaging	palette	packaging	reel
condition of delivery (account)	11 - 100	11 - 100	11 - 100	to order	to order	to order
cleaning	yet cleaned, ultrasonic	yet cleaned, ultrasonic	yet cleaned, ultrasonic	yet cleaned, (ultrasonic)	yet cleaned	yet cleaned
cleanroom requirements	cleanroom classification <1000	cleanroom classification <1000	cleanroom classification <1000	cleanroom classification <1000	cleanroom classification <1000	cleanroom classification <1000

feature	*1st GRIN-lense*	*2nd GRIN-lense*	*SELFOC-lense*	*mount*	*laserdiode (incl. mount)*	*fibre*
sensitivity	soiling, mechanical stress	soiling, mechanical stress	soiling, mechanical stress	mechanical stress	soiling, mechanical stress	soiling, mechanical stress
possible planes for handling	1 - 5	1 - 5	1 - 2	1 - 2	1 - 5	1
gripping techniques (in use)	fluidic	fluidic	mechanical, fluidic,	mechanical	mechanical, fluidic,	mechanical, fluidic,
joining techniques	adhesive bonding	adhesive bonding	adhesive bonding	adhesive bonding, soldering	mechanical	adhesive bonding, mechanical

tab. 3 characterization of microoptical components within the assembly process

The above table shows that in assembling microoptical systems mostly uncomplex geometrical components of different dimensions need to be handled and mounted /3/. Additionally it is shown that the most common material in microoptical systems is glass, which is amorphous and brittle, requiring shock- and vibration-free handling to ensure the functionality of the system. Therefore, the microparts have to be gripped at defined points or surfaces adjacent to the active parts of the optical surface.

DESIGN OF THE ASSEMBLY DEVICES

Corresponding to the mentioned requirements an assembly system was designed to provide an automated assembly of optical microsystems with higher quality standards than achievable by manual assembly or former automatic systems. Based on the precision robot μ-KRoS 316 these developments include the design of adapted magazines, a modular tool-changing-system, grippers specially adapted to the geometry of the microcomponents and of an assembly platform to fix the assembly parts during the joining process.

DESIGN OF THE MAGAZIN

The design of a magazine is of particular importance for achieving an efficient process flow /4/. Typically, optical components are highly sensitive to contamination and mechanical stress /tab. 3/. Usually they are delivered by the optical company in palettes in which they lay seperated in nests, but with no defined position and orientation. This kind of feeding does not support an automated assembly. An effective supply of optical components involves developing a magazine fulfilling the following requirements:

- precisely orientated positioning of the parts in the magazine for defined gripping,
- avoiding mechanical stress and contamination of optical surfaces by using suitable materials
- easy manual equiping of the magazine.

These requirements were developed during the design developing following new solutions (fig. 3):

- Defined deepenings were milled into a plate, conforming to the cylindrical and rectangular parallelepipedical shapes of the demonstrators′ components.
- The plate is made of a macjinable glassceramic called MACOR®. This material guarantees machining without leaving any burr, so that the optical components are not damaged lying in the deepenings.
- To equip the magazine with assembly components easily the deepenings were machined with a tolerance of +0.1mm. The defined position of the deepenings themselves and their structure were machined with an accuracy <5µm to ensure a precise handling position. The position accuracy in the magazine combined with a self-centring mechanism of the gripper is sufficient for high assembling accuracy.

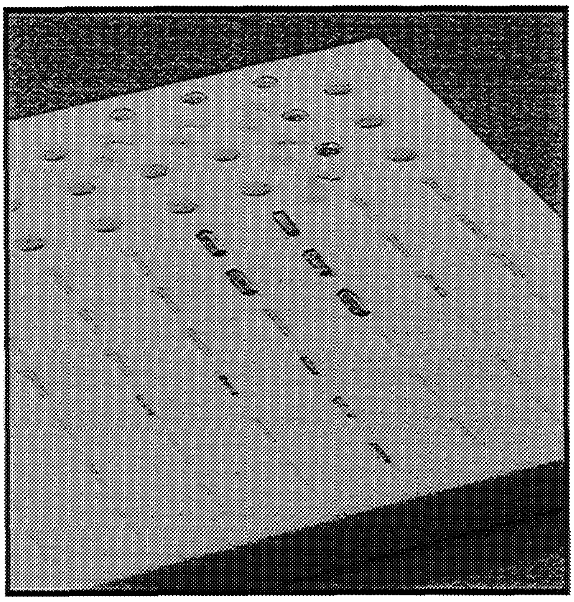

fig. 3 structured magazine containing cylindrical and planar optical lenses

DESIGN OF THE GRIPPERS

The handling capacity and flexibility of the robot system was improved by a modular designed tool-changing-system, a rotating extention of the robot head, which enables changing between seven mounted assembly tools. The design as well allows quick and high accurate changing of the tools themselves based on the principle of a guide slot and a stop. The design of the grippers was based on the following requirements /5/:

- high accuracy in picking up and setting down the microparts,
- avoidance of damage or contamination of the optical surfaces,

- minimization of adhesive forces between surfaces of gripper and micropart,
- possibility to monitor the gripped microcomponents during the assembly process.

As a result a new generation of vacuum grippers was developed, based on the principle to pick up the microparts by a self-centring process (fig. 4). The accuracy achieved by the gripper in picking up and setting down the parts is <2µm depending on the position tolerance of <0.1mm of the components in the magazine.

- After picking up the parts, they are positioned in the gripper by vacuum channels, integrated in the gripper body, precisely pre-adjusted for assembly. To adjust the components of the optical system described here the directions of optical function are the z- and y-coordinate. For optical function the x-coordinate did not necessarily need to be centred but it is possible as well.
- To avoid damaging or contaminating the optical surfaces, the geometry of the gripper was designed to touch the non-active areas of the optical surfaces of the microoptical components. Two possibilities exist to achieve this. First, depending on the geometry of the micropart there may already be enough space between or beside the non-active areas for the gripper to grip. But more commonly there is a need to realize: „assembly adapted design of subassembly components“. This requires that during designing of the single components not only their functionality, but, their ease in gripping and handling as well should be considered; for example, the GRIN-lenses of this microoptical system are overdimensioned in one direction to leave gripping space adjacent to the optical surface of the components. Combined with the special design of the gripping surface, consisting of two bars touching the micropart, there is no danger damaging or contaminating it.

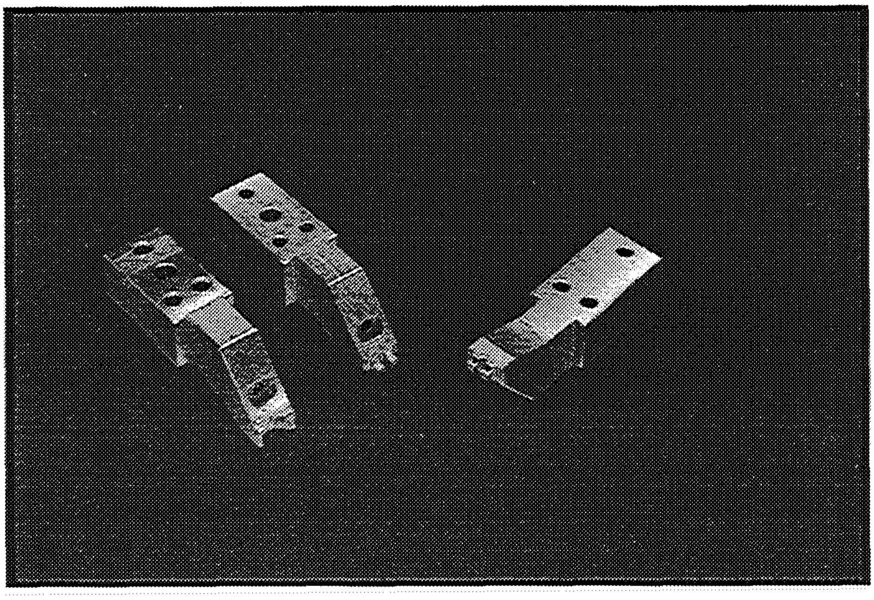

fig. 4 geometrically adapted vacuum gripper for the microassembly process

- Additionally, in touching the surface minimally, the gripper design fulfills further requirements. To guarantee viewing access for position monitoring during the assembly process and to enable 3D-imaging or an optical alignment process. To minimize the adhesive forces between gripper and microcomponent, which can cause undefined setting down of the components.
- In addition to vacuum grippers, piezoelectric grippers were developed to grip cylindrical parts at the cylinder surface. The gripper holds the cylindrical lens, clamping it from three points. A machined V-slot constitutes two of the points and is stable, the third point is realized by a piezoelectric bending bar to clamp the component.

DESIGN OF THE ASSEMBLY PLATFORM

Assembling of microcomponents and subassemblies with the accuracies required, needs a defined point of reference represented by an assembly platform. The requirements given for this device are the following:

- a defined fixation of both the SELFOC-lense and the mount of the subassembly
- and a protection from contaminating and damaging of optical surfaces of the microcomponents.

Depending on the similar requirements of grippers and magazines, the working principles of these devices were tranfered to the design of the assembly platform (fig. 5). The design includes the following solutions:

- to avoid damage to the optical surfaces the SELFOC-lens is placed on a circle touching only non-active areas of the optical surface.
- The clamping principle which fixes the SELFOC-lens is transfered from the piezoelectric gripper using a V-slot fixing two points combined with a third clamping point, moved by a pneumatic cylinder and a solid state hinge.

The developments decribed in this paper are suitable for passive assembly tasks; i.e. the manufacturing tolerances of the assembly components contribute to the tolerances of the assembly process, especially in the z-direction, involving taking off the microparts from the magazine, placing them on the assembly platform and joining them to each other. This problem can not be solved by the integration of passive adjusting elements, however, one solution to improve process accuracy will be the integration of a 3D-imaging system next year.

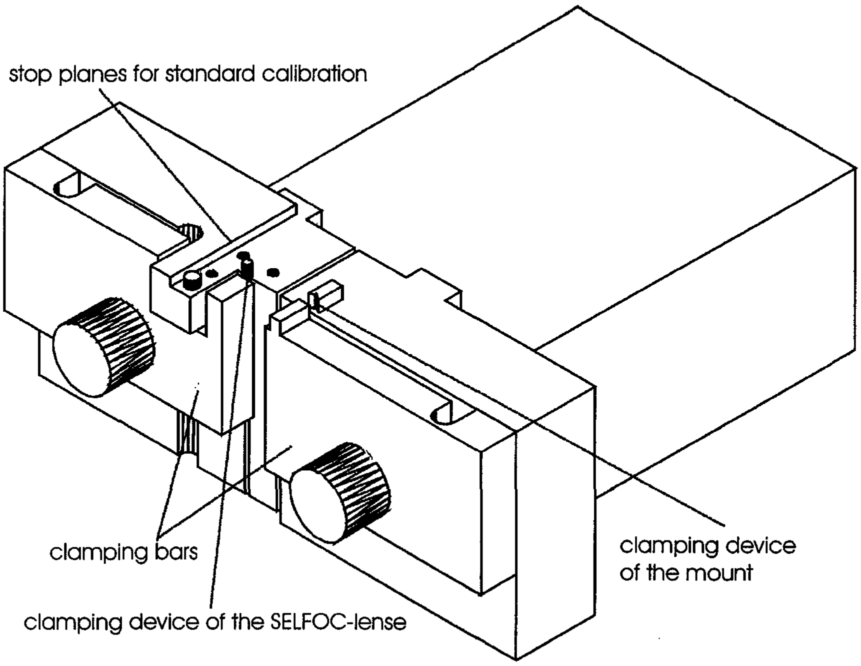

fig. 5 schematical view of the assembly platform

THE ASSEMBLY PROCESS

The assembly of the described beam forming system (fig. 1) is realized by a 6-axis-precision-robot µKRoS 316 following these assembly steps (fig. 6):

1. The SELFOC- and both GRIN-lenses are picked up from the magazine in a pick-and-place process by self-centring vacuum grippers.
2. Equiped with the assembly components, the robot moves to the assembly platform to insert the SELFOC-lense in the clamping device. Following the assembly process, the tool-changing-system turns in the next tool to the assembly position very quickly.
3. A dosage device, integrated in the tool-changing system, is positioned over the SELFOC-lens to apply a defined volume of adhesive on its surface. The volume needed depends on the joining surface and the defined thickness of adhesive given by the optical design.
4. The larger GRIN-lens is pressed into the adhesive with accurate position and cured by UV-irradiation.
5. The adhesive bonding, the joining process and the curing of adhesive will then be repeated for the smaller GRIN-lens. To realize the optical function the smaller lens has to be joined rectangular to the larger one.
6. The completely joined subassembly is taken off again by the gripper of the smaller GRIN-lens and placed on another magazine.

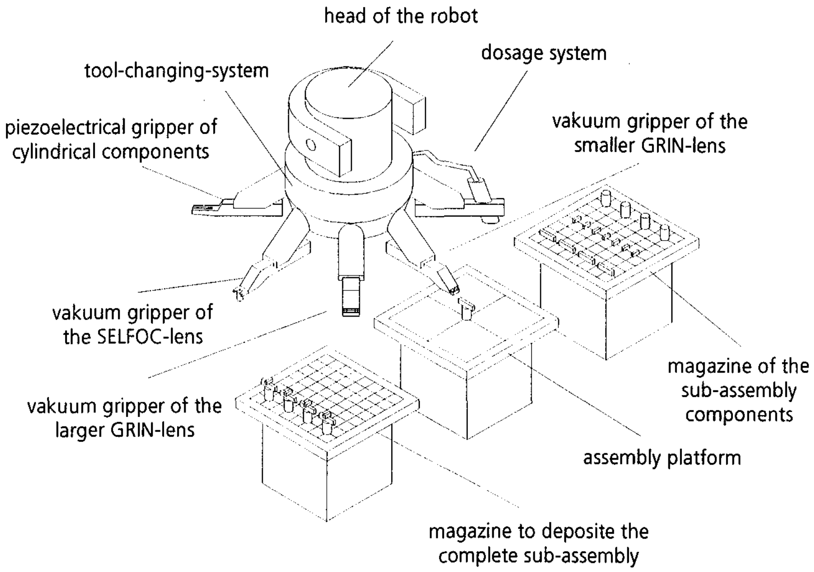

fig. 6 schematic view of the assembly process

The total accuracy of the assembly system will be improved by the integration of a 3D-imaging system, able to monitor the position and orientation of the assembly components and send correcting data to the assembly control system. Correcting movements are calculated to increase the accuracy of the robot, realized with minimized steps. The result will be an optimization of the joining process down to an accuracy of <2µm.

CONCLUSIONS

The microassembly system described in this paper allows to solve the requirements in hybrid integrated microsystem assembly. The mechanical units like the precision robot, the tool changing system, the adapted grippers and the assembly platform combined with the developed vision system guarantee the required accuracies of microassembly down to few µm. A high degree of modularity was included during development of the assembly system and the peripheral devices to allow ease of switching the system to further tasks of automated microsystem assembly. Depending on the number of pieces, the needed flexibility and accuracy either a robot system or a high precise handling system, based on five axis, can be used to achieve the highest productivity and economy compared to the momentous state of art.

ACKNOWLEDGEMENT

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