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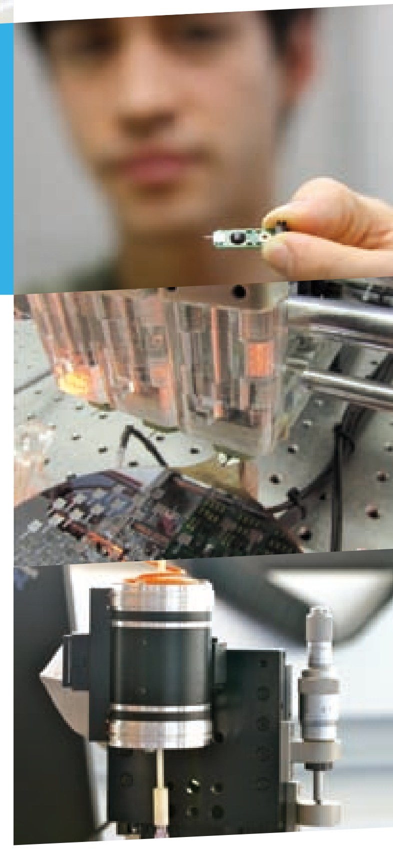
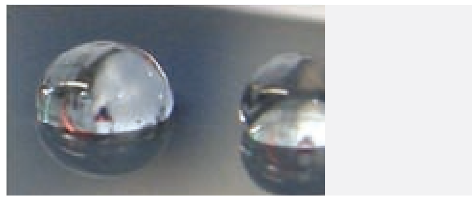


Acknowledgement

Supported by the European Commission through the Sixth Framework Programme for Research and Development at a level of 8 999K€ out of a total budget of 13 870K€. The Hydromel project addresses the area "Nanotechnologies and nano-sciences, knowledge-based multifunctional materials and new production processes and devices". The project finished on 30th September 2010 after 48 months.



hydromel
Microrobotics & Self Assembly

www.hydromel-project.eu

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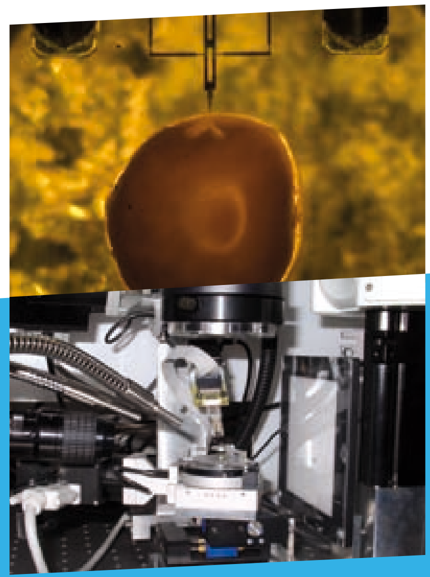
hydromel
Microrobotics & Self Assembly

A European Integrated Project supported through the Sixth Framework Programme for Research and Technological Development

Introduction

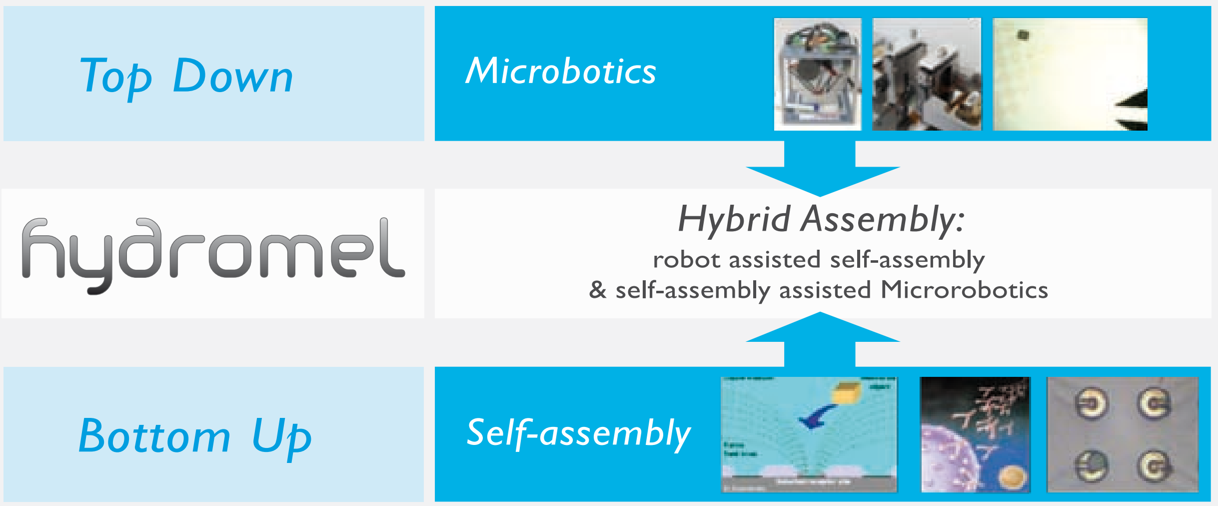


The HYDROMEL framework

Emerging hybrid and complex micro-devices as realized in the areas of mechanics, electronics, biological engineering, microfluidics and IT request challenging manufacturing processes. A need becomes apparent to develop next-generation **high precision flexible** and **cost-effective** manufacturing processes for such **complex micro-products**.

Hybrid assembly has been identified as promising, innovative production technology. It is defined as the synthesis of two production approaches: (i) *positional assembly* where objects are mechanically manipulated and positioned one by one; and (ii) *self-assembly* where objects arrange themselves into ordered structures by physical or chemical interactions. Such hybrid assembly has not yet been achieved and implemented at the industrial scale.

The European integrated FP6 project HYDROMEL addressed exactly this ambitious goal. Experts from academia, R&D and industry contributed. 22 partners from 9 European countries were involved. Selected industrial partners acted as end-users demonstrating various applications generated by the project.



Combination of microrobotics and self-assembly results in hybrid assembly.

Project Goals

Technical goals

Hydromel closed technology gaps identified in the enabling disciplines for **(i) microrobotics, (ii) *self-assembly*** and finally combined them to realize **(iii) *hybrid assembly* methods**. Two hybridization scenarios have been investigated: first, robotics assisted by self-assembly: here, a primary pure robotic process is supported and optimized by self-assembly; and secondly, self-assembly assisted by robotics: here, a self-assembly or self-alignment process is supported by robotics.

Hybrid assembly will penetrate a broad range of manufacturing applications on the industrial scale with very different demands in terms of component size, accuracy and throughput.

Five application cases are demonstrated in HYDROMEL:

- (i) hybrid assembly for packaging of high-value MEMS parts;
- (ii) hybrid assembly for mass-production of RFID tags;
- (iii) self-alignment assisted highly reliable manipulation of biological cells;
- (iv) future technologies: Hybrid assembly for emerging nanophotonics, nano-electronics and nano-electrochemistry;
- (v) self-alignment in high-precision quality inspection.

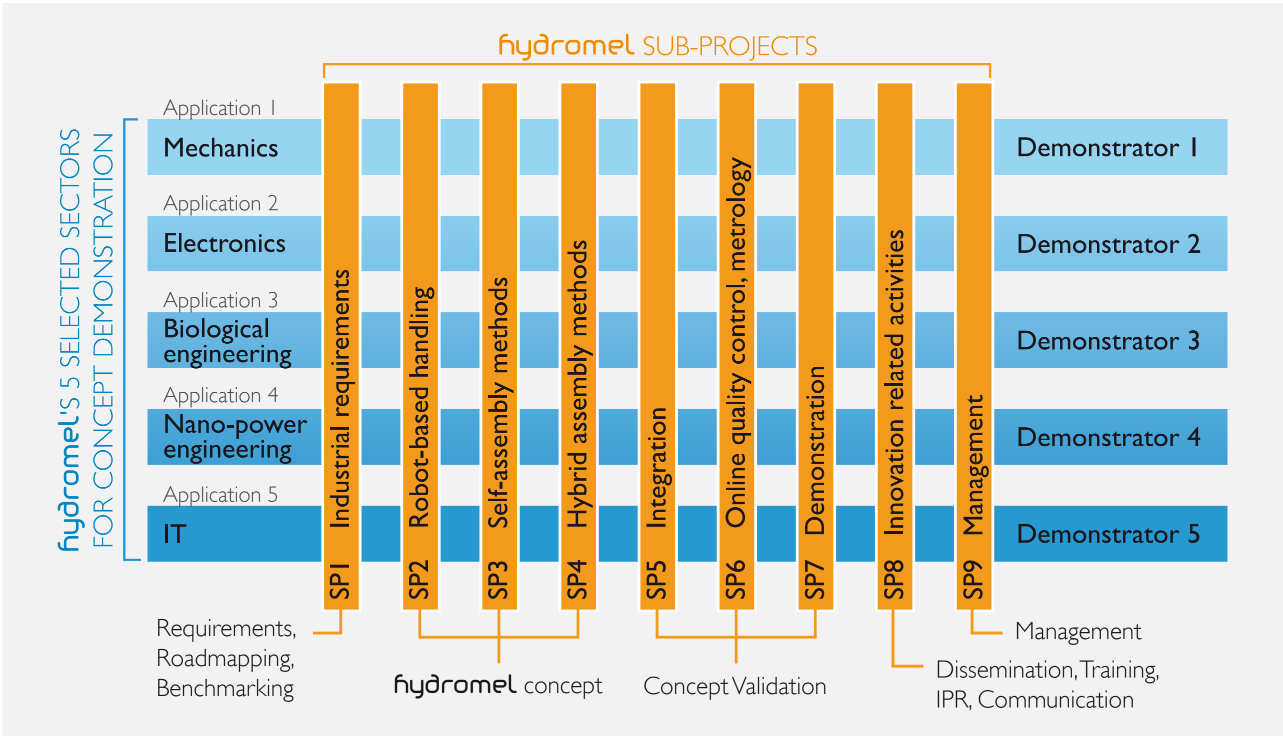
European industrial impact

The goal of HYDROMEL was further to implement hybrid assembly in an ***industrial*** environment. Therefore, measures have been implemented to support penetration of such innovative manufacturing approaches in assembly industry.
HYDROMEL established a highly qualified industrial interest group of external experts to monitor the project progress. The group met regularly and provided feedback during the lifetime of the project.

Strong emphasis in the project was put on the support of industrial exploitation and implementation. Hybrid assembly methods have been benchmarked and compared with traditional approaches. Their life-cycle impact has been analyzed.

Concept Technologies

The overall structure of the project with its sub projects (SP) is shown in the figure below. The scientific concept of robotics, self-assembly and their hybridization has been developed in SPs 2-4. The validation of the concept and industrial demonstration was core of SPs 5-7. The generation of industrial impact beyond the consortium project was supported by benchmarking and roadmapping activities (SP1) and by accompanying measures (SP 8) for dissemination and exploitation.



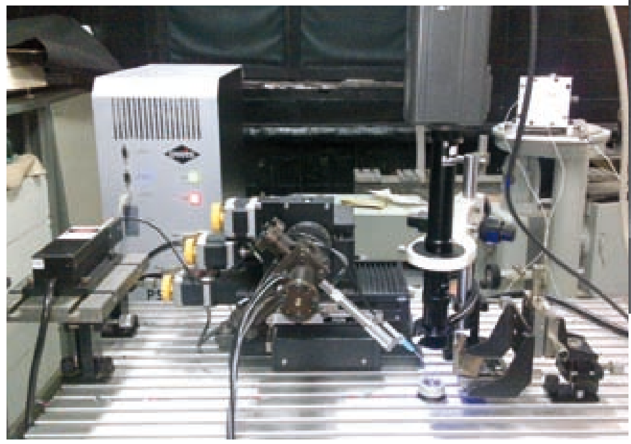
Structure of HYDROMEL sub projects and demonstrator activities.

Robotics

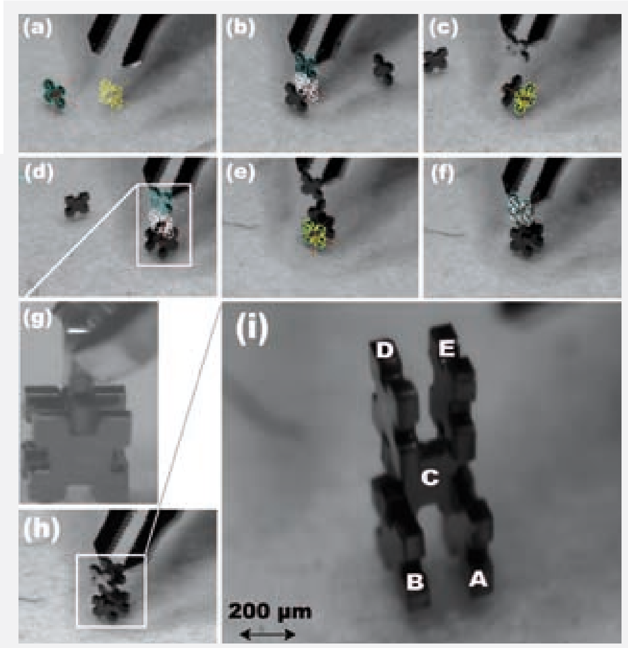
Robotics is a well established industrial technology. Nevertheless, if high throughput and high accuracy are aimed - especially in the microrobotics area - several bottlenecks have been identified that were addressed within HYDROMEL: (i) High-speed and long-range nano-manipulators can only be achieved by combining fast conventional robots and precise nano-robots. (ii) Tools and handling strategies for microhandling have to be revised. (iii) Control and sensor fusion for microrobotics is required for closed-loop secure operation.

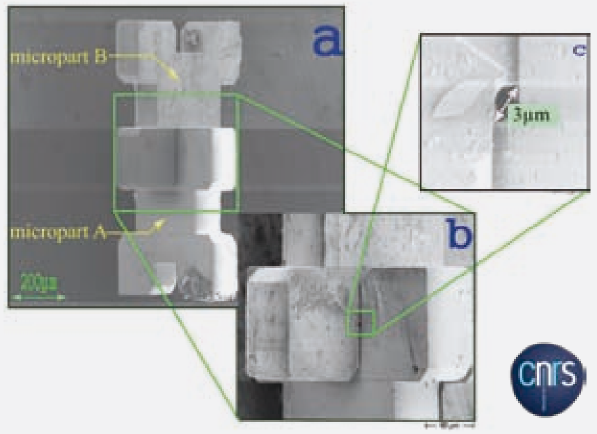
HYDROMEL delivered essential improvements for reliable microhandling: concepts for the combination of macro- and nanorobots, realization of innovative, multidimensional vision sensing for closed-loop robot operation with nanometer precision; development of tools such as grippers and part feeders for efficient handling of microcomponents.

The Hydro-MiNa robot with 7 DoF for cell injection with force sensing is presented here as an example utilizing the enabling robot technologies developed (courtesy of BAS).



Innovative and full automatic MEMS manipulation and assembly have been developed based on 2D and 3D multiple scale visual servoings.

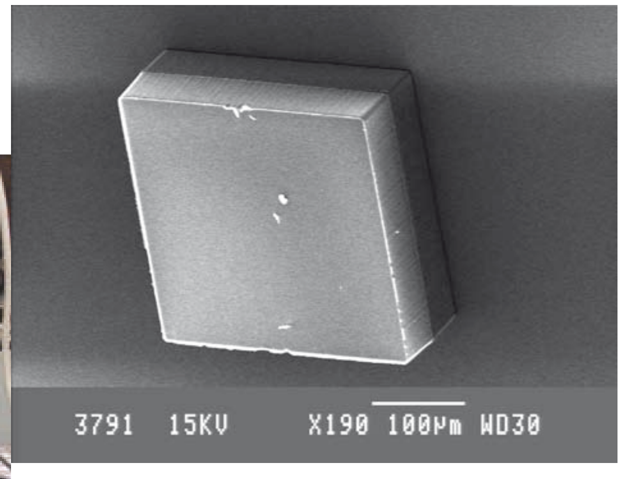




3D MEMS assembly using 3D CAD model-based tracking and 3D visual servoing ((courtesy of CNRS)

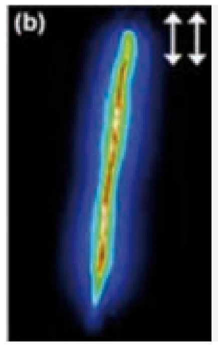
Self-assembly

Self-assembly is a powerful bottom-up production approach for nano- and microfabrication. It enables massively parallel throughput of parts. A drawback of pure self-assembly is the lack of reliability due to its stochastic character and the lack of process control.
HYDROMEL focused on the development of methods for reliable self-assembly of components with dimensions ranging from several millimeters down to nanometers. As one important aspect, programmable self-assembly enabling spatial and time process control has been investigated.



High precision fluidic self-assembly of a chip on a substrate (courtesy of Aalto University).

HYDROMEL provided results in key domains: (i) Surface treatment and patterning for different self-assembly cases - cells, chips, nanowires - (ii) chemical and physical switching of surface properties for controlled adhesion and release of parts; (iii) directed self-assembly of micro- and nano-objects by application of external fields; (iv) modeling and measuring of bonding forces in self-alignment.



Controlled synthesis and characterization of polymer nanowires (courtesy of Tyndall)

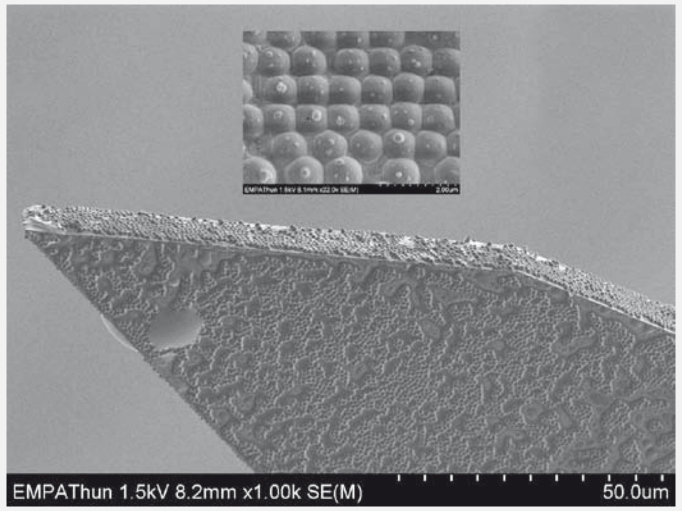
Hybrid assembly

Hybrid assembly is bringing together robotics and self-assembly. HYDROMEL investigated the following complementary approaches: (i) robotics assisted by self-assembly and vice versa (ii) self-assembly assisted by robotics.

Improvement of robotics by using self-assembly techniques

Classical robotics can be improved by means of self-assembly in different ways. Structuring techniques can be applied to grippers in order to improve picking, reliable positioning and releasing of micro-objects. Feeding - a classical robotics task - can also benefit from controlled and switchable self-assembly by concentrating objects in desired position and thus facilitate an efficient pick- and place process.

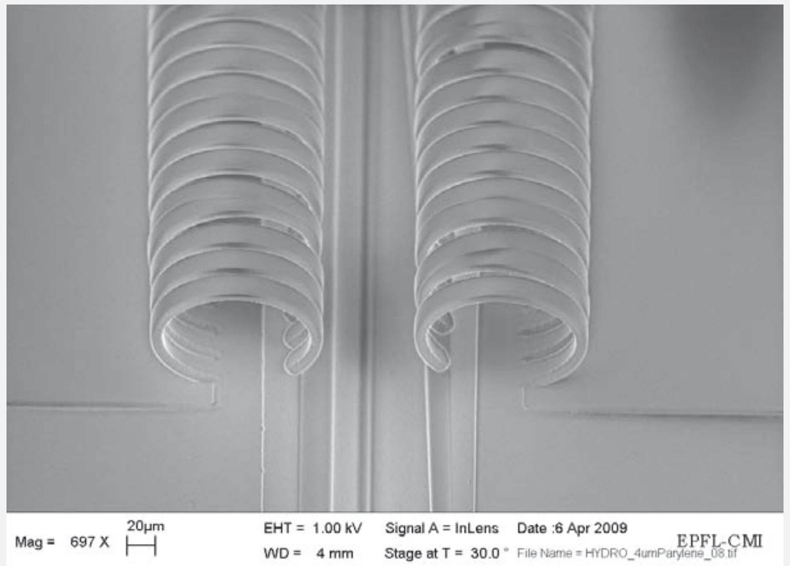
CNRS and EMPA have worked on the adhesion force between a structuring surface, with microbeads, and micro-object. They measured and modelled these forces. Using this model, the size of PS particles deposited on the grippers can be optimized in order to reduce adhesion wathever the size and the material of the handled micro-objects.



A working prototype of microfabricated capillary gripper with self-alignment capability (courtesy of Aalto University).

Improvement of self-assembly by using robotics

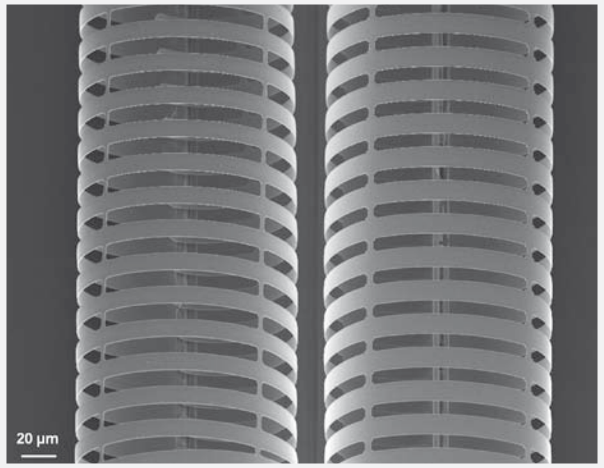
Using robotics to assist or to improve self-assembly is useful in various application scenarios. Micro- or nanorobots can be used in processes where the result of a self-assembly process has to be error corrected or characterized. Robust and fast coarse robotics will be used to place meso-scale objects close to self-alignment attractors.



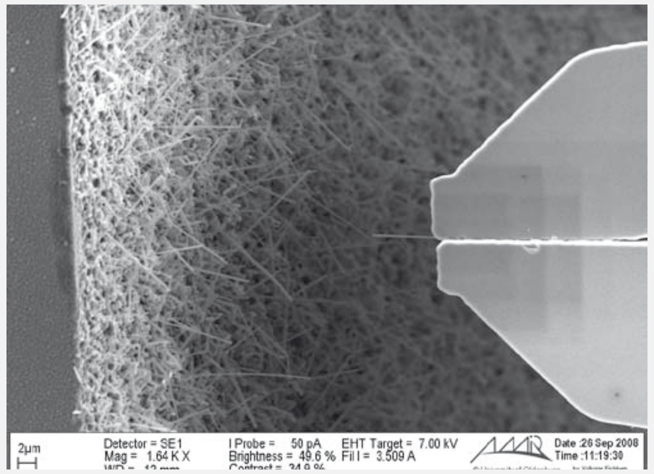
Clipping structures conformally coated in order to increase their strength (courtesy of CSEM).

The final alignment in position and/or orientation that extends the targeted accuracy by an order of a magnitude is carried out by unsupervised self-alignment. Therefore parallelization can be achieved as well as a reduction of investment of equipment.

The implementation of hybrid assembly and integration into dedicated systems has been realized by HYDROMEL. The functionality of modules and sub-systems has been proven for various application cases with industrial relevance as described in the following section.



Clipping structures that allow precise fiber positioning with coarse robotic approach (courtesy of CSEM).



Individual self-assembled nanowires can be accessed and manipulated (courtesy of UNIOL).

Technology Demonstrators for Industrial Applications

The industrial integration of the core technologies that have been presented in the previous section was demonstrated in selected applications. Benchmarking of the economical benefit of the hybrid integration compared to conventional solutions was a key point of the demonstrators. The technology demonstrators are addressing complementary assembly cases with very different system specifications and application areas.

Advanced Micromechanics: Hybrid assembly of fragile MEMS parts

MEMS parts for measuring micro forces and for force controlled microgripping have to be assembled into a package. A mechanical and electrical connection between MEMS and a printed circuit board (PCB) has to be realized. The MEMS components consist of fine mechanical structures and are very brittle.

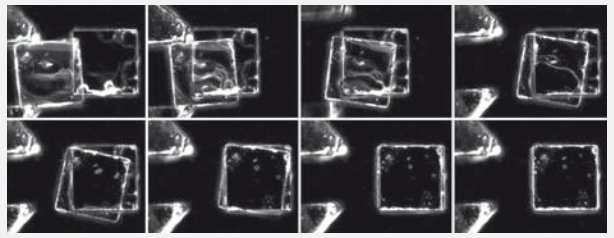
HYDROMEL provided a method to overcome tedious one-by-one processing by a parallel process. Coarse robotics have been combined with precise self-alignment to achieve high throughput and high alignment accuracy of the MEMS components with respect to the PCB. Self-alignment resulting in mechanical and electrical contact of the MEMS parts has been achieved by using capillary forces from melted low-temperature solder.

The flexible integrated system is cost effective, reduces assembly effort and increases the process yield targeting mid- to high-production rates.

MEMS force sensor. Packaging of MEMS component on circuit board has been realized by hybrid assembly. System overview (left) and close-up view (courtesy of FemtoTools).

Opto-electronics: Hybrid self-alignment in optical inspection

A high-speed handling and inspection solution for laser diodes has been developed that overcomes precise pure robotic pick-and-place approaches. A hybrid inspection system has been implemented for handling of diode chips with sizes down to 0.1 mm. The system combines coarse handling robotics with high precision self-alignment and self-positioning of the chips.

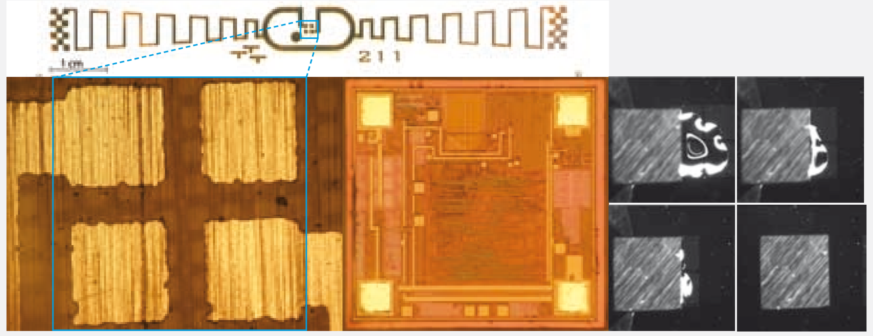


Self-alignment of sub-millimeter microparts (courtesy of Aalto University).

Electronics: Hybrid assembly of RFID tags

A hybrid assembly solution for high-precision and high-speed assembly of RFID chips on an antenna web has been investigated. The state-of art production process for RFID tags is a pick-and-place procedure with dedicated and highly optimized die bonding equipment. An alternative industry compatible approach will offer the opportunity for parallelization and cost reduction by an optimum combination of coarse placement and precise fluidic self-alignment.

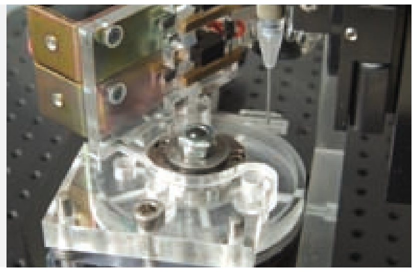
By parallelization of the process high-speed and high-throughput processes will be enabled. A route towards industrialization of the technologies has been provided by HYDROMEL.



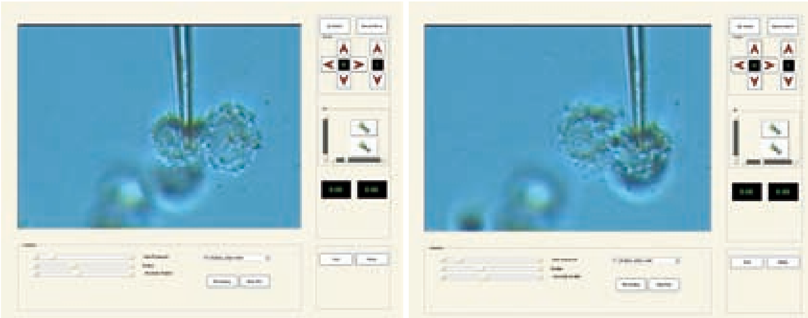
RFID antenna (top) with enlarged contact pads (bottom left) and chip (bottom right). Droplet self-assembly of chip and matching pads proven (alignment sequence right) (courtesy of Aalto University).

Bio- and life sciences: Self-alignment assisted handling of cells

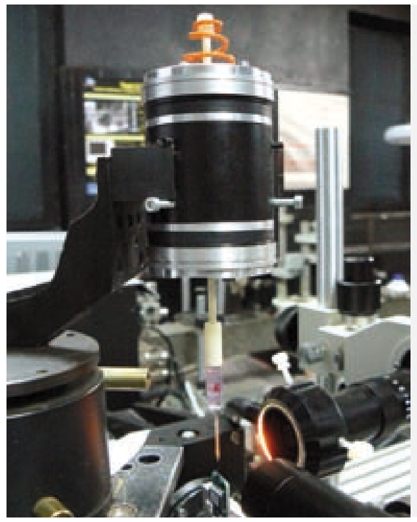
A system has been integrated that combines several aspects of cell handling for life sciences. It includes automated cell selection, immobilization, and a microinjection process by combining microfluidics for prior cell sorting and individualization, self-assembly for reversible immobilization of the cell, and microrobotics for cell injection and automation of the complete process by feedback loops. The complete system offers an automated, high throughput cell injection system. Different components have been developed that allow to process cells with sizes between 1.5 mm and 5 µm.



Device for automated cell injection used as sub-system in a robotic set-up for micro-handling of cells (courtesy of CSEM).



Screenshots of the injection process of single HTC using the Hydro-MiNa robotic system (courtesy of BAS)

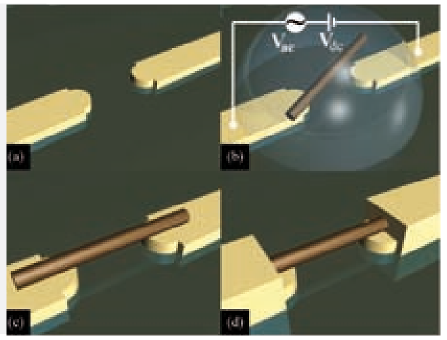


Callibration of the Force sensor for cell injection (courtesy of BAS)

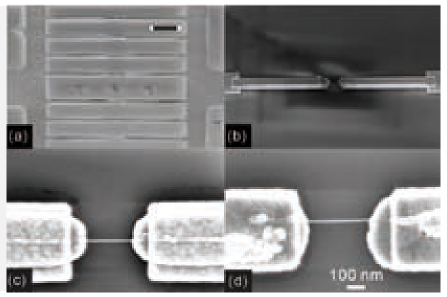
Future Technologies: Self-assembly for emerging nanophotonics, nano-electronics and nano-electrochemistry

To address the current limitations associated with top-down fabrication approaches, a palette of self-assembly techniques has been developed and applied to the configurable assembly of a variety of nanostructures that have been selected so as to enable demonstration of not only the assembly methodology but also of resulting nanoscale functionality. Self-assembly of nano-objects allows the organization of nanoscopic objects much smaller than those that can be defined with classical top-down approaches. This approach is mandatory for Systems on Chip or even in future 3D circuits.

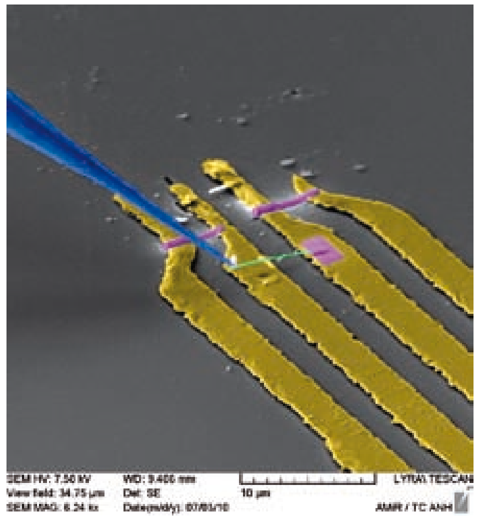
Hybrid approaches have been investigated involving production and characterization of self-assembled nanostructures combined with robotic quality control and error-correction measures.



Hybrid nanofabrication approach. (a) Definition of lower nanoelectrodes by E-beam lithography (EBL), metal deposition and lift-off. (b) Dielectrophoretic (DEP) assembly of nanomaterials performed by immersing the nanoelectrodes in the multi-walled carbon nanotubes (MWCNTs) suspension and applying a composite (AC+DC) electric field. (c) Assembled MWCNTs after blow-drying the suspension with a nitrogen gun and (d) Top metal definition using EBL, metal deposition and lift-off(Courtesy of ETHZ).



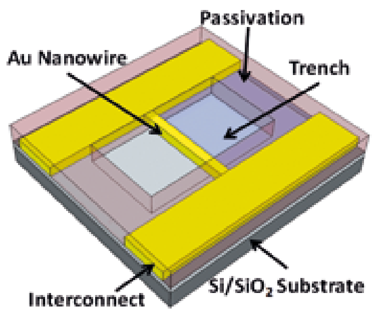
DEP assembly of MWCNTs using the composite-field (AC+DC) method (a) Nanoarray design with the scale bar representing 10 microns. (b) An SEM image of an assembled MWCNT taken at a stage tilt of 30 degrees. (c-d) illustrate high magnification SEM images of representative individual NTs. (Courtesy of ETHZ).

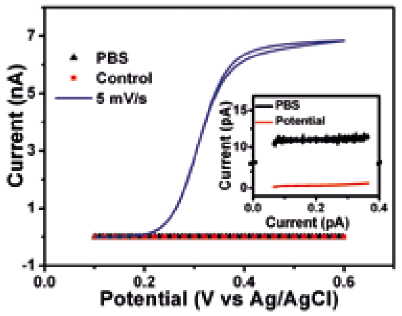


Handling and electrical characterization of doped silicon-nanowires inside a scanning electron microscope. A tungsten tip (blue) carries the nanowire (green), which is attached to the electrode (yellow) by a electron beam based tungsten deposition (pink)(Courtesy of UNIOL).

Self/hybrid assembled functioning nanowire device fabricated and tested by Tyndall.

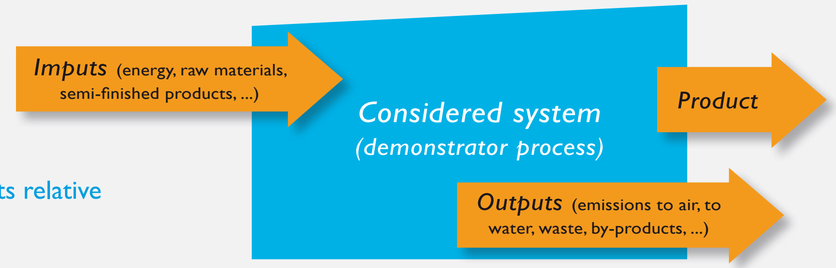
(a) a Device schematic of a gold nanowire device. The contact electrodes are passivated using a photoresist insulating passivation layer. A trench in the photoresist is opened over the nanowire electrode to allow direct contact between the nanowire and the external electrolyte. (b) CVs obtained for a nanowire electrode device in the presence (navy line) and absence (black triangles) of 1mM FcCOOH in PBS from 0.1 - +0.6 V, at 5 mV s-1. Data for a control device are also shown (red squares). Inset: the measured current for a control device and a nanowire in the absence of FcCOOH were less than 1 and 12 pA, respectively.



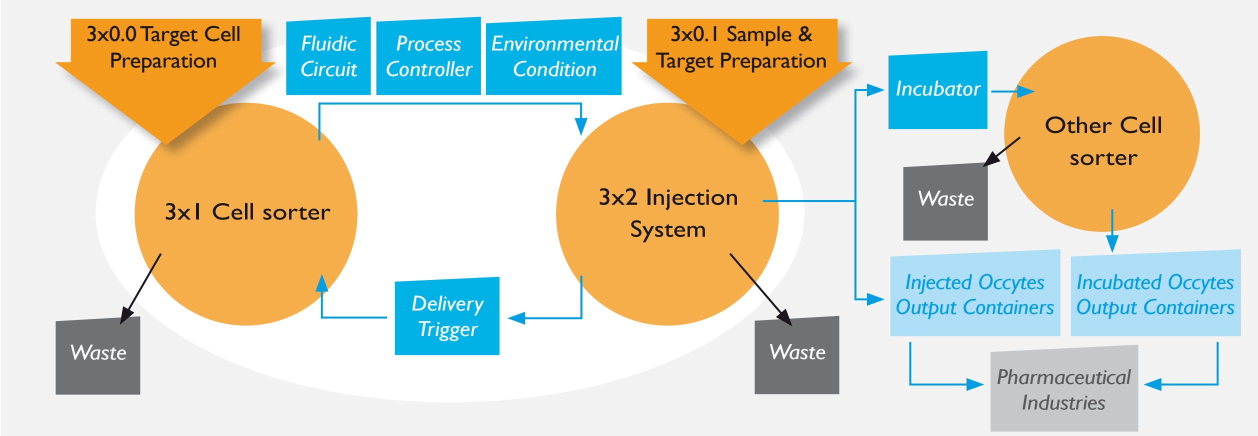


Life Cycle Assessment (LCA)

HYDROMEL Demonstrators have been analyzed also according to their environmental impact point of view following the ISO 14040 standards, by providing a dedicated LCA. This allowed realizing a sustainable development of demonstrators assessing the most critical processing steps. Given the innovative topic a specific methodology has been devised in order to assess the environmental burden properly, considering primary energy, raw materials, air and water emissions and solid wastes.



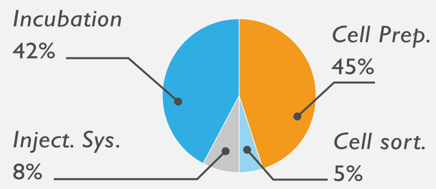
Simplified sketch of inputs and outputs relative to the system boundaries



Example of system and system boundaries definition for one of the Hydromel demonstrators: all LCA results are referred to the functional unit and to the defined inputs entering the system and the outputs from the defined system boundaries.

Direct energy distribution

Example of direct energy allocation in one of the demonstrators, showing the relevant sub process impacts.



Summary and Outlook

The HYDROMEL project developed a set of technologies for hybrid assembly of microproducts. The proof of feasibility and a demonstration of hybrid assembly of various selected systems have been given.

The economic benefit of HYDROMEL has been confirmed by detailed analysis: industrial compatibility of selected processes, economic benchmark of integrated assembly solutions and a life cycle analysis for production cases have been investigated.

Industrial exploitation of the technologies has started and will be carried out beyond HYDROMEL.