A Modular Flexible Scalable and Reconfigurable System for Manufacturing of Microsystems Based on Additive Manufacturing and E-Printing

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ABSTRACT

Generative manufacturing technologies are gaining more and more of importance as key enabling technologies in future manufacturing, especially when a flexible scalable manufacturing of small medium series of customized parts is required. The paper describes a new approach for design manufacturing of complex three dimensional components building on a combination of laminated objects manufacturing and e-printing technologies. The micro component is made up of stacks of functionalized layers of polymer films. The concept is currently developed further in the project SMARTLAM, funded by the European Commission. The manufacturing system is based on a modular approach which enables the manufacturing of different small size batches with different modules. Different modules can be combined by defined Hardware and software interfaces. Avoiding time consumable and difficult programming caused by manufacturing a new product a Function-Block Runtime (FORTE) executes generated control application platform-independently and coordinates component module functionalities. The control system will integrate all processes as well as the base platform with features far beyond ordinary PLC systems. One aspect is the use of process data out of the data acquisition system to simulate and optimize the processes. These results are incorporated into the main machine control system. Another aspect is the vision system for flexible quality control and closed-loop positioning control with visual serving. The paper shows the first example of manufacturing technologies and demonstrates the control system approach by the example of the control system for alignment of different stacks.

1. INTRODUCTION

Today´s fabrication methods for micro and nanotechnology enabled devices require expensive tooling and long turnaround times, making empirical, performance-based modifications to the product design expensive and time consuming. Thus till to date products are often limited in their flexibility, so that complex devices, that incorporate on-board valves, membranes, discrete parts, or electrodes, cannot be developed or adapted without considerable expense in molds and assembly fixtures.

This again creates a barrier to the development of small to medium series of complex and higher functionality devices, where the cost-benefit ratio of incorporating functionality is too risky for the typical laboratory, diagnostic or medical device developer. To bridge the gap between high volume production with specialized equipment and a - until today - not efficient production of medium series, especially SME´s need to find other, more flexible and scalable approaches to produce microsystems in high volumes.

A manufacturing concept for this is proposed by the EC-funded project SMARTLAM. SMARTLAM builds on a modular, flexible, scalable scenario combining state of the art developments in technologies and materials (fig. 1):

Rapid prototyping technologies in a wider sense and laminated object manufacturing (LOM) in the narrow sense - an established rapid prototyping technology building on layer by layer lamination of functionalized film sheets with different material properties is in the focus of the activities [1].

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Printing technologies, where aerosol-jet printing is in the specific focus of the project allowing for an efficient and precise manufacturing of conductive tracks, electrodes, etc.

Novel polymer film materials with advanced material properties such as anisotropic conductive film or effects arising from combinations of composite sheets will be combined with state of the art, scalable 3D printing, structuring and welding technologies.

Fig. 1. SMARTLAM enabling technologies.

The above mentioned technologies will be integrated in a modular manufacturing environment allowing for a production of complete 3D Microsystems in one machine setup.

The SMARTLAM design approach builds on the assumption that most applications can be designed using modular building blocks with dedicated process sequences for each functional element – the 3 dimensional integration (3D-I) approach.

2. Application oriented modeling elements of the SMARTLAM 3D-I approach

To facilitate the development of new applications the SMARTLAM consortium introduced a modelling hierarchy (fig. 2), allowing for structuring of the different levels of detailing and the mapping of technological capabilities, after the initial function requirements have been clarified and a first decision for a specific design has been made.

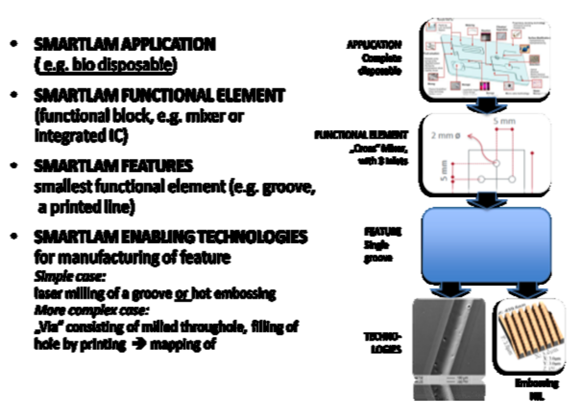

Fig. 2. SMARTLAM modeling hierarchies.

Over the first months the focus of the activities was on the identification of an initial set of functional elements which will become expanded during the project. Sets of process step sequences for manufacturing of these functional elements had been identified for each of these elements. While in most of cases specific functional elements are triggering the development (and later adaption) of application specific process chains process sequences shall be a priori described in a more application independent manner and then instantiated for a specific user request.

2.1. MODELLING OF GENERIC SMARTLAM FUNCTIONAL ELEMENTS

Such an initial set of functional elements shall have the potential to cover a broad variety of potential applications without being limited to the two main application fields, which are in the focus of SMARTLAM.

The requirements to the functional elements have to address the manufacturing methods inherent to SMARTLAM: They should either

- have the potential to become realized by a combination of the technologies available in one level (grooves, conductive tracks,…), or
- can be manufactured by a combination of layers with different properties, e.g. a valve, realized by an elastomer layer in between two rigid layers with circular cut outs.

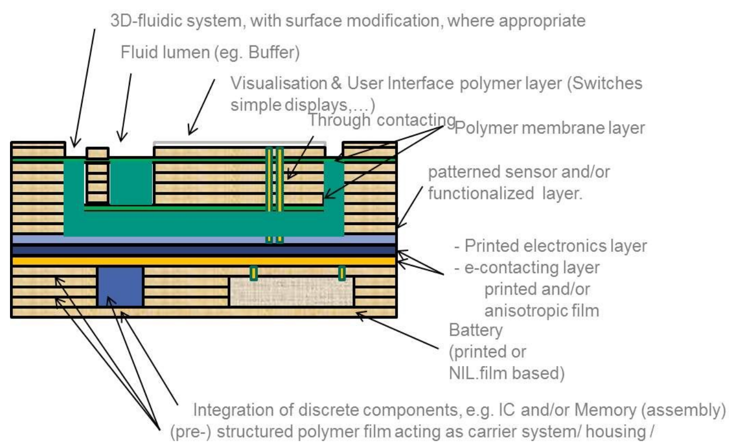

Fig. 3. SMARTLAM demonstrator for "intelligent combination of functionalized" polymer layers.

Positioning and contacting of a discrete chip or a battery widens the capabilities of the additive manufacturing capabilities.

In SMARTLAM the following types of functional elements for printed electronics had been identified over the first months and are currently subject to further investigations and discussions with respect to fulfill the application requirements as well as to meet the technological constraints:

Printed electronics

- electrode structures [line, interdigital]
- MR Sensors
- Capacitive switches
- Functional elements for the energy storage
- Printed batteries
- NIL-based Batteries
- Components for electronics
- Resistors
- Switches

Functional elements for micro fluidics

The concept allows for a broad range of fluidic functional elements to be investigated in a more detail in later stages of the project:

- Microfluidic channels
- Membranes
- Valves
- Mixers
- Storage
- Actuators

Functional elements building on surface modification

The SMARTLAM technologies selected for integration in this first demonstrator basically allow for an active treatment of surface properties. Active control of wettability by laser processing is just an example to demonstrate the capabilities of the generative technologies currently being integrated in the system setup.

Composite functional elements

The SMARTLAM functional elements again can be combined to sequences, representing "composite" functional elements of a "higher" integration level. The functional element "positioning and integration of a chip" may consist of two functional elements "milling of a pocket" and "e-contacting",

Implementation strategies

Many of the functional elements mentioned above can be realized in a single manufacturing step, where the function can be realized by manufacturing of a single geometric element, which will be covered in more detail in the next paragraph. In most cases even more complex functional elements can be described as a combination of such features. From a process perspective however, there are typically multiple solution strategies for implementing functional elements. The "Via" functional element may serve as an example, as technological as well as chemical solutions are feasible and will have to be selected depending on the application boundary conditions. These solutions include but are not limited to:

- Realization of a "mechanical" contacting between film layers consisting of a through hole filled with electronic ink.
- Physical realization of a contacting using the special material properties e.g. of "anisotropic conductive films"

2.2. Features

"Features" represent a kind of intermediate between the application-oriented function element and the "manufacturing output", mostly resulting in a set of geometric primitives that can be micro milled or cut, coated, printed, welded, etc...

The following examples may illustrate underlying concept:

- A single hole can be a vertical microfluidic channels well as a pocket for integration of discrete parts.
- An array of such micro might represent a "micro sieve" for blood separation in the bio disposable application areas.
- A combination of the "hole"-feature with other features such as the filling of a hole with e-ink can result in a contacting for manufacturing of "vias", know from printed circuit board technology.

Typical features:

- Channels (for fluidic or optical properties)
- Pockets (cavities, lumen or locating holes)
- Printed lines (conductive tracks, sensors, "via")
- Material layers with properties, different from polymers (realization of batteries, realization of membranes (elastomers)

Evaluation tests could demonstrate the validity of this approach and similar concepts on feature level had been successfully tested in other micro related contexts [2]. A thorough evaluation in order to validate the principles of this concept will be performed over the course of the project.

3. TECHNOLOGIES AND MATERIALS OR RELEVANCE FOR THE SMART MANUFACTURING APPROACH

As mentioned earlier, the SMARTLAM 3D-I concept aims at attaching single manufacturing processes or process sequences to each feature (and with that indirectly to each functional element).

Modelling of process sequences

Especially for more complex functional elements one can expect more complex process hierarchies for description of the respective process chains allowing for a modelling of the technical processes on different abstraction layers (similar to modelling approaches having been elaborated and realized in CIM or STEP [3][4]) see Fig. 4.

Due to the introduction of different abstraction layers of abstractions within the process chain, a reduction of overall complexity can achieved. The first layer is usually comprised of sequential high level technology classes such as Structuring, Printing, Laminating or Handling. These basic classes are refined in lower layers of the hierarchy. On this layer, decision nodes capture criterions to decide between alternative process subsequences. On a successive third layer, the actual laser technology such as an excimer laser or a CO2 Laser can be specified in more detail.

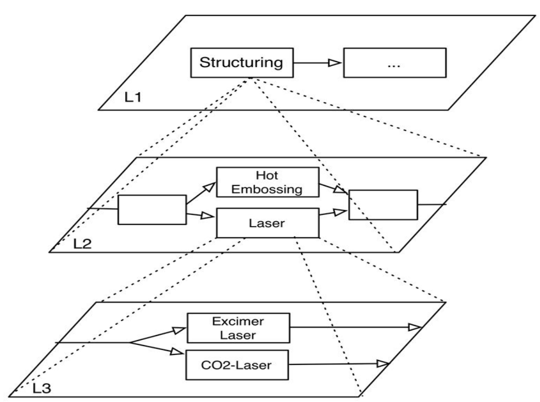

Fig. 4. SMARTLAM process sequence hierarchies.

Each activity consists of a set of input and outputs and an optional functional description of the process step. Additionally, each step has a set of preconditions that are required to be fulfilled for it to be insertable into a process chain. Post conditions of an activity describe constraints that shall not be invalidated in the subsequent process flow. As an example for this may serve technology-related parameters such as temperature or pressure, whose values shall not exceed a certain range within the rest of the process chain.

Technologies of relevance for smart manufacturing

Representing the smallest building blocks in modelling of process chains three different types of technologies are currently under evaluation regarding their integration in the system setup:

- Technologies for additive manufacturing and e-printing aerosol jet printing. In SMARTLAM the e-printing functionality is realized by aerosol jet printing, offering good results for manufacturing of line-based geometries such as conductive paths [5]
- Handling assembly and bonding technologies [6]
- Technologies for direct and indirect milling and cutting of polymer films [laser milling, cutting, nano imprint lithography, hot embossing], [7]

4. OUTLOOK AND CONCLUSIONS

The paper presented a novel conceptual approach for flexible scalable manufacturing of micro components To allow for an easier design of applications, design elements on different aggregation levels have been introduced building on a combination of laminated objects modelling technologies, integration of laser technologies for structuring of films and printed electronics for e-contacting and printing of electronic components.

Over the next months the consortium will continue adapting the respective equipment system demonstrator and continue developing the process chains required for the manufacturing of the two project demonstrators in the field of lighting and microfluidics

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