Micro Structure Printer with Automated Workflow for Fabrication of Micro Implantable Medical Devices

M. Schwarz and L. Kraaijeveld

Abstract—**In medical industry the development of active micro implantable devices becomes economically important, since passive implants lack many features like self testing, communication or complex control systems. Although adaptive passive implantable systems like accommodating intra ocular lenses are state of the art, the future market will greatly benefit from a new kind of electric active, so called intelligent implant. Those active implants are no longer limited to nerve or muscle stimulation, since they can receive input from complex sensor systems, either from the exterior or from inside the body, and transmit data between separated sensor, control and stimulation units, spanning up an implantable body area network. For prototyping these implants, we designed a microstructure printer including dedicated workflow support software, that will guide the user trough the process of micromechanic and microelectronic design and fabrication. Printer hardware and workflow software have been optimized for design reliability, even when used in an educational environment.**

Index Terms—**Microstructure Printer, Rapid Prototyping, Medical Device.**

I.INTRODUCTION

Mechanical and micromechanical implants are mostly limited to functions like valves, pumps, joints, lenses, passive electrodes and external prostheses. Most of them work fine and everyone knows that in early days pirates equipped with a very simple hook and a wooden leg can greatly benefit from those passive prostheses. Although modern external prostheses are sometimes equipped with electronic and motor-sensory devices, adaptation functionality and superb look and feel, developers are far away from miniaturized implantable systems with integrated neural interfaces, thus that fingers and wrist can be controlled like a normal hand.

On the other hand tetra- and paraplegic patients can have almost intact muscles and suffer - only - from disrupted nerves. With sensory systems and electrical nerve stimulation, we would able to reactivate these affected limbs. The underlying basic principle of functional electro stimulation (FES) is well known from the pacemaker, the pain killer or the deep brain stimulator.

To create and experiment with new types of totally implantable systems, versatile rapid prototyping techniques are required. Therefore we developed a micro structure printer, which is not limited to printing of 3D mechanical microstructures.

As described below, it can be used as a printing system for organic semiconductor materials and thus allows us to also integrate localized microelectronic components whenever a given task can not be solved with solid state electronics, e.g. because of the interconnection problem between solid state electronics and multielectrode systems with very high electrode count.

The high complexity of the designs, combining layered 2D electrically active components with passive 3D components requires a dedicated workflow control system to reduce errors. Therefore we designed as software that controls the micro structure printer and also guides the user trough the complete design and fabrication process. Of cause the software also initiates and controls all verification (DRC) and conversion steps between the different tools, thus interaction with the user has been minimized.

II.GOALS

Since high and medium resolution 2D and 3D printing was our first major goal, we started with the implementation of a micro drop applicator, compatible to a wide range of printable materials. The current version should enable us to print structures with µm resolution on quite large target in the cm range. Designed as a one stop system for manufacturing and testing, the danger of contamination should be minimized. Finally we had to optimize the system according to ease of use, which is important in our context, where the system will be also operated by students. As mentioned above, design and printing process should be controlled by an automated system to guarantee the correct workflow. Besides of the skills for using the graphical and electrical design tools and the knowledge of major design rules, almost no requirements for manual interaction, programming or adjustment for student users or designers should be required.

III.SYSTEM DESIGN AND CONFIGURATION

A.System Architecture

The printing system described here, is able to create micro structures of >10µm at 1µm even on a cm scale target area. Structures printed can be 2D or 3D. The 2D mode is used to create structured layers of conductors, organic semiconductors, e.g. pentacene derivates, dielectric materials and in future also micro-actors and micro-sensor materials.

Although active 3D structures can be build from layers of 2D structures stacked on each other, intermediate planarisation layers are required. Since printing not always is the favorite fabrication method for this and other types of

---

Manuscript received March 5, 2008.

M. Schwarz is with the Niederrhein University of Applied Sciences, 47805 Krefeld, Germany (phone: +49 2151 822 6646; fax: +49 2151 822 6660; e-mail: markus.schwarz@hsnr.de).

L. Kraaijeveld is with the Niederrhein University of Applied Sciences, 47805 Krefeld, Germany (e-mail: l.kraaijeveld@ student.fontys.nl).

layers, spin coating, wafer handling and inspection have been added to form a closed manufacturing and testing system which means, that the processed device always stays inside the systems flow box until it has been finally encapsulated. For sensitive materials like pentacene (Fig. 1), the system can be optionally flooded by an inert gas until the coating layer has been added.

All processes and steps listed above are required to produce relatively simple micro implantable devices, e. g. mechanically flexible nerve and muscle stimulators [1, 2, 3, 4]. Since in near future we also want to focus on non electrical actors and biochemical sensor materials, we will be well prepared for the upcoming market of intelligent sensor and actors in the medical branch.

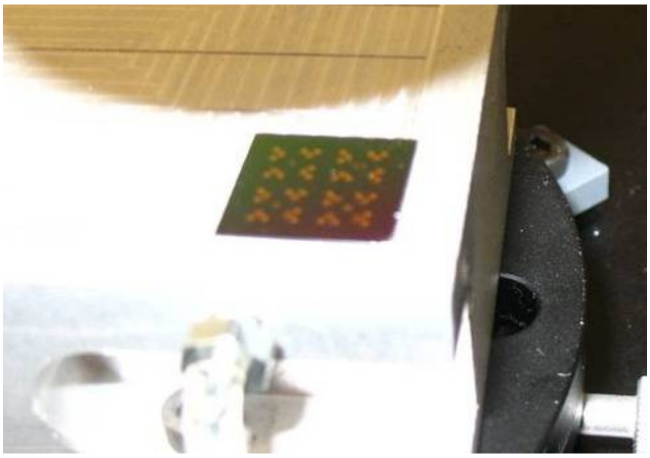

Fig. 1. Substrate for pentacene transistors positioned on vacuum chuck.

Because of the high flexibility of this experimental systems, it is very important to perform all fabrication steps within a closed system under controlled conditions to guarantee reproducibility. Additionally we want to be able not only to test final but also intermediate structures without removing the target from the printer. Therefore the system has been designed in a manner that the structure can be visually inspected through a camera equipped microscope and even electrical parameter test, e. g. resistance, mobility or sensor material sensitivity can be measured by micro positioned probes. Since the whole system, including the test section, is enclosed inside a single flow box, contamination caused by intermediate testing has also been minimized.

B.Software and Control

Building active micro implantable systems is a great challenge, since there is a large number of parameter that can influence the different processes. Even a single parameter outside the parameter window will lead to poor or completely broken devices. So introduction of a controlled workflow is indispensable. Although a workflow can be described by a simple paper guide, a software that not only controls the workflow but also initiates DRC and conversion steps and finally starts and controls the printing and inspection system is required to increase both, usability and safety. The software for our micro structure printer is designed to support the designer and thereby also forces the user to follow a specific workflow. The software is build from independent modules and consists of different tools for 2D and 3D mechanical design, tools for circuit design and simulation, as well as tools for DRC (design rule check) and finally generation of positional data for the printer device, including control parameters. A variety of parameters is supported and most of them are related to the printing heads and the liquid transport, but also include heating, printing speed, drop rate adoption, drop overlap and many more. All these parameters can be predefined and are accessible from a technology file for inexperienced student users.

In more detail, the tool chain, controlled by our software, forces the user to follow given steps for different design modules (mechanical/electrical) and finally after a successful electrical and mechanical DRC it also composes electrical and mechanical designs into a single control file for the printing system. As known from PCB or microelectronic design industry, a DRC is required but not sufficient for a functional device. Tests for distances, overlaps, and other limits of the fabrication process, also have to be performed prior to initiation of the printing process and are considered here.

The control file for the printer system is more complex and quite different from standard microelectronic mask fabrication, since also speed, drop rate, pulse energy, and other material dependent parameters must be included. A dedicated postprocessor has been developed to perform this task, merging design data and technology file data into a data stream for the printer and liquid transport system. When using the postprocessor, most parameters will be set to reliable defaults, relieving the inexperienced users from deep incorporation into technological details.

Expert users can easily modify individual parameters and overwrite the defaults. There are two ways to change parameters without accessing the standard technology file. The first way is to use the CAD postprocessor. It produces a file header with parameters from the technology file, which can be influenced by standard options, given to the postprocessor. Alternatively the expert can use the printer software configuration menu, which allows non standard options, fine tuning and experiments with new materials. The graphical menu offers tuning of almost any printing parameters during printer operation. Parameters like drop diameter, drop overlap percentage and maximum drop rate can be optimized here. Since changes are visualized online using graphical sliders and a camera system with stroboscopic illumination, it becomes easy to understand what happens. For instance, problems from variations in solvent viscosity which do not lead to the results assumed by the technology file can be fixed here. All modifications will be documented in a process log file and can be transferred back to a new technology file version.

Another helpful tool is the direct programming mode. The direct programming mode gives us full control of the printer and can perform operations usually not generated by the postprocessor. It is frequently used, when new materials are introduced or if unexpected problems have occurred. Here, arbitrary polygons and parameters are read from a text file, which allows the operator to find the optimum setup for the given material. Again, all parameters finally can be moved to a new user accessible technology file.

To prevent the printer from damage, especially when operating in the direct programming mode, a syntax checker has been introduced to filter out incorrect or dangerous commands. Besides of filtering, it also detects and highlights inconsistent or dangerous code. Additionally it also controls the parameters programmed by the user and tries to avoid collisions.

The direct programming feature has been extended by a text macros feature that can create additional graphical buttons to call routines from the direct programming mode on mouse click. This enables us to extend the graphical interface (GUI) for commonly used functions and movements even in direct programming mode.

To meet the special needs of a prototyping system, the printing program also offers a simulation mode. During simulation, the simulator not only shows a graphically animated printing process, but also highlights the actual code position inside the printing file from either the CAD-software or a file manually created for the directly programming mode.

C.Printer Hardware

The mechanical part of the printing system is arranged around a high precision xy-table, shown in Fig. 2 (yellow rect.), as its central component. The main advantage of the positioning table is a programmable motion controller, which can be parameterized for printing with different materials. This makes it easy to program the system and allows a fast setup. With the postprocessor described above, we generate a file that can be directly interpreted by the driver software that controls the xy-table motor controller and synchronously triggers the micro drop application system, as the second major part of our system (Fig. 2, red rect.).

This micro drop generator can produce small drops at its nozzle of currently 30-50µm diameter and will be used to structure conducting and semiconducting areas as well as vias between layers. The printing head is piezo-driven and heatable to extend the range of disposable materials. These drops are ejected out of a glass nozzle. The heart of the printing head is a glass capillary that is surrounded by the piezoelectric element. The printing head is connected to a reservoir compartment by a flexible and inert tube.

Droplet generation is preformed by the piezo-element connected to a high voltage driver unit with external trigger input (Fig. 2, large red rect. on the right). The mechanical contraction propagates trough the capillary and forms a shock wave. This shock wave is coupled into the liquid (1000m/s) and produces a small drop at the nozzle of the capillary (Fig. 3). The speed of the drop leaving the nozzle is about 10m/s.

With a trigger and delay function on the controller and voltage-driver unit it is possible to start and synchronize a strobe LED for illumination. This enables us to observe the drop forming and flight phase as well as the deposition and adsorption on and inside different target materials. Thus all stages of during drop forming and flight can be monitored through a trinocular microscope with attached camera device (Fig. 4).

With a drop volume of about 150pl the drops in flight m measure about 5.8µm. A half sphere with the same volume has a diameter of about 6.1µm. With a maximum frequency of 2000Hz the maximum printing speed is 8mm/s for printing a conducting wire structure. Several test structures have been successively printed at highest speed (Fig. 5).

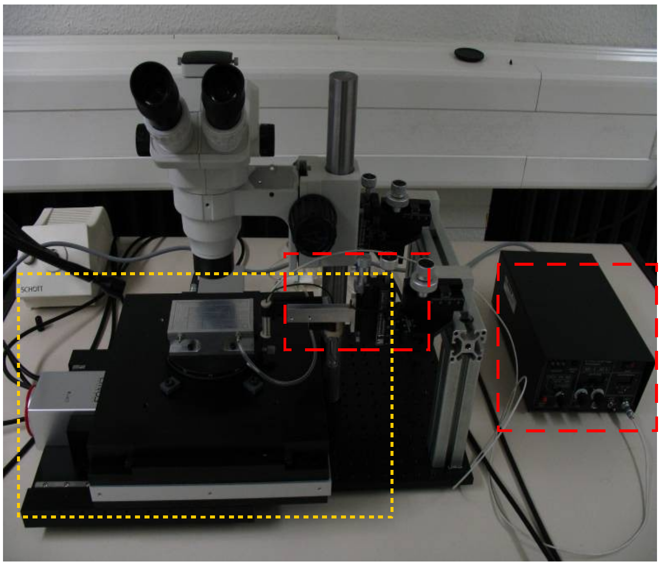

Fig. 2. Components of the printing system.

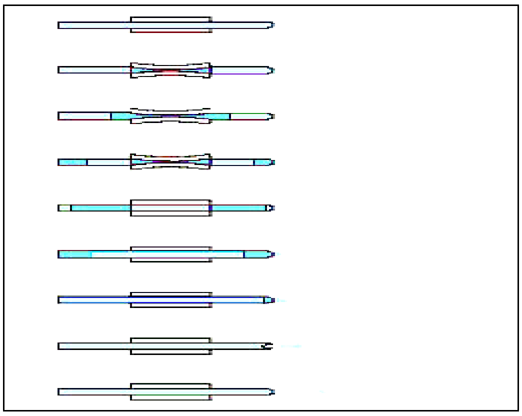

Fig. 3. Piezo contraction for micro drop generation.

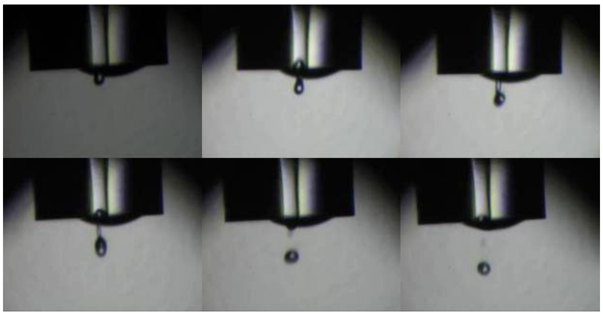

Fig. 4. Drop in flight.

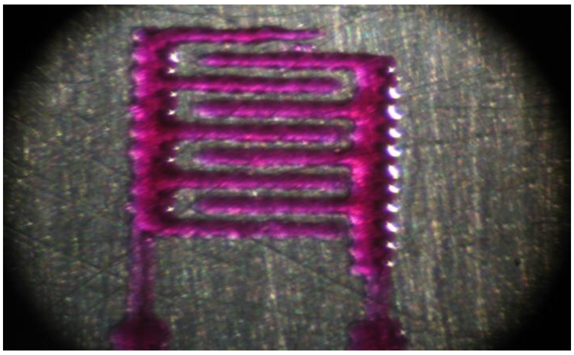

Fig. 5. Test structure printed at highest speed.

One major advantage of the printer driver software described in section B. is the adaptation of the piezo-element frequency against the traveling speed. During acceleration phases the piezo-element frequency is adapted, so that the printed line has the same density, drop overlap, width, and thickness over the whole processable area, although the processable area is quite large and about 60mm wide and 100mm long. The substrate can be clamped on a dedicated vacuum chuck that can hold almost arbitrarily shaped targets.

The complete system is build up on a standard bread board. The high precision xy-table is attached on the breadboard, so that we get a stiff system with negligible resonances. A rotation table mounted on top of the xy-table allows to align prestructured substrates. Also mounted on the breadboard are manipulators for testing, e.g. adjustment of probe needles.

The approach we have chosen almost completely avoids manual handling of target structures and of course minimizes contamination from moving substrates between distant manufacturing and testing sites.

Of cause there are systems on the market performing similar tasks, but most of them are designed for high speed printing of large batches, which results in large and expensive systems and often lower flexibility. Since we want to focus on the needs of a prototyping system, we had to build the machine by our self and thereby also had to optimize the software for our special requirements.

D. Testing Equipment

Inside the testing area, which is located directly aside the printing and structuring components, any final and intermediate structures can be visually inspected and electrically tested. Up to now, electrical test procedures need to be initiated manually. Besides optical inspection (Fig 2), the test equipment includes manipulators with probe needles on the tip (Fig. 6).

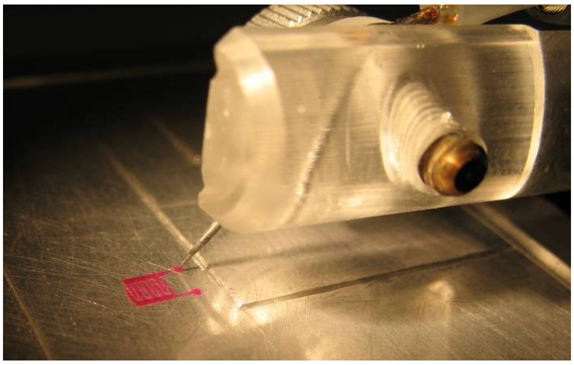

Fig. 6. Test structure contacted with probe needle.

After printing conductive or semiconductive layers, we can activate macro buttons from the GUI, that automatically move the positioning table to the testing spot and afterwards allow to travel back and realign. In some cases also damaged test pads can be repaired by the printing system for use in subsequent testing steps, therefore, additional macro buttons like “reprint test pad” are available.

Adjustment of probe needles and contacting of test pads is performed manually under visual control by the trinocular and camera equipped microscope. All manipulators holding probe needles or other test equipment are fit into a special profile that is fixed on the breadboard (Fig. 2), which allows to coarsely prearrange the micromanipulators.

For electrical testing we currently are using a Labview® based program that fits our requirements as an electrical parameter and transistor tester.

IV. CONCLUSION

Printer hardware and printer control software have been optimized for processing a wide range of materials and are also well suited for operation by non experts and students. Nevertheless default setups, given by the technology file, can be easily modified for evaluation of new or sensitive materials, by changing drop frequency, drop size, and drop overlap, and many more parameters trough an intuitive graphical user interface.

Besides of fabrication of micromechanical structures, the system has been also designed to print conducting and semiconducting materials. In this context we like to refer to FhG-IPMS for provision of their pentacene derivate and all cooperating partners of our medical engineering and our international mechatronics course.

REFERENCES

[1] M. Schwarz, O.R. Hild, U. Todt, J. Amelung, “Solving the Interconnection Problem of flexible Multielectrode Arrays by use of Addressable Organic Semiconductor Stimulation Cells”, European Medical and Biomedical Engineering Conference (EMBEC) 2005 Prag, 21-25.11.05, IFMBE Proc. 200511(1).

[2] M. Schwarz, O.R. Hild, U. Todt, J. Amelung, “Applicability of Organic Semiconductors for Microimplantable Multicontact Arrays”, m2ns2, Krefeld (Germany), 8.11.2005.

[3] M. Schwarz, J. Büddefeld, V. Ortmann, “Organic Semiconductors Providing new Solutions for Future Medical Implants”, IEEE Polytronic 2005, Wroclow/Breslau, 23-26 October 2005 pp.78-81.

[4] M. Schwarz, H. Lohmann, “Evaluation of an Adaptive Waveformgenerator for Microimplantable Multicontact Arrays”, ITAB 2006, 26-28 October 2005, Ioannina (Greece).