Design Methodology for Microfluidic Biochips

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Abstract – This paper provides an overview of a top-down design methodology that offers how to solve key issues in the simulation, synthesis, modeling, testing and configuration of digital microfluidics biochips. The top-down design technology will help to integrate the fluidic components with microelectronic component in system on chip.

Key words – Modeling, simulation, CAD, microfluidic, biochip.

I. Introduction

In the past few years, the interest in analysis of even more complex biological systems such as living cells with the use of microfabricated structures has attracted increased attention. Thus, the application of microfabrication techniques has really entered the life science field and has started to serve as a driving force for discovery in cell biology, neurobiology, pharmacology and tissue engineering[1].

The main idea of microfluidic biochips is to integrate all necessary functions for biochemical analysis in one chip using microfluidics technology. These micro-total-analysis-systems (μTAS) are more universal and complex. Integrated functions include microfluidic assay operations and detection, as well as sample pre-treatment and preparation.

II. CAD Modeling and Simulation

Modeling and simulation are very powerful tools and have become an integral part in the design and development of engineering systems[2]. To support a system-level simulation at the start of a design, current design methodologies for microfluidics-based biochips are typically bottom-up in nature. Detailed device simulations are used extensively to design and optimize the component and device, and to help to create custom compact models for this device. Only at this stage, the system-level simulations and optimizations can be carried out. Since the system behavior can only be verified at such a late stage, costly and time-consuming redesign effort is required if the system does not satisfy design constraints.

These bottom-up methodologies have been employed successfully in the past, but they are not usable for the design of complex microfluidic biochips. For this, the top-down design methodology and design tools are called for[3].

III. Top-Down Design Methodology

The structure of the top-down design methodology for microfluidics biochips is shown in Figure 1.

The design starts at the bioassay protocols. A sequencing graph model can be generated to describe this assay protocol.

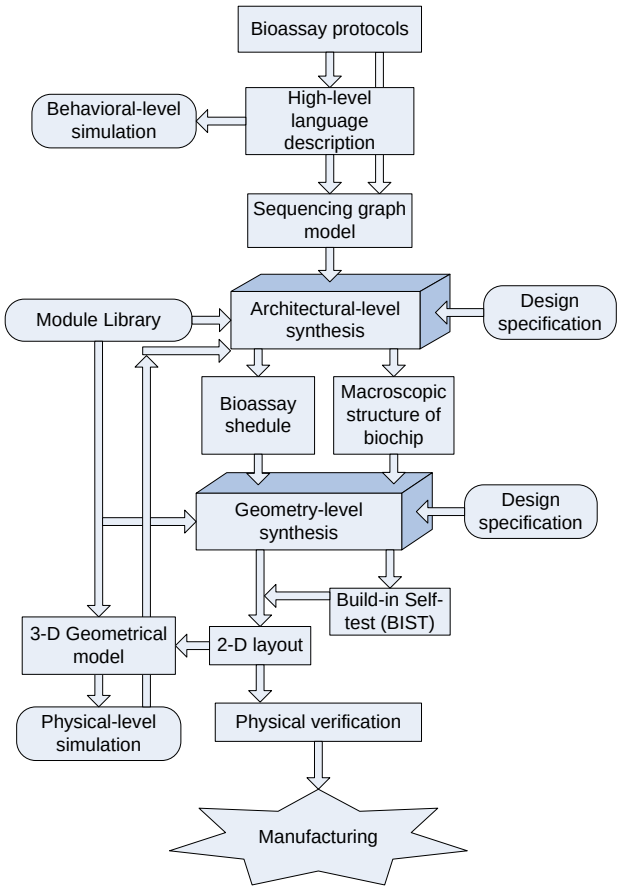

Fig. 1. Top-down design methodology.

This model can be used to perform behavioral-level simulation to verify the assay functionality at the high level[4,5].

Then a synthesis tool is used to generate detailed implementations from graph model. A microfluidic module library is also used as an input of the synthesis procedure. Some design specifications are also given as a constant.

The synthesis process includes architectural-level and geometry level synthesis[6]. The output of the synthesis process includes assay operation to on-chip resources, a table for the assay operations, and a 2-D biochip physical design.

Also two important design issues must be incorporated into the system synthesis procedure:

- Design for testability;
- Design for reliability and manufacturability.

After synthesis the 2-D design of the biochip can be connected with full physical and technical information from the module library to get a 3-D model. This model can be used to perform different simulation and design verification at a low level. After physical verification, the biochip design can be sent for manufacturing.

Conclusion

We have a large number of commercial CAD systems, which contain wide range of models with MEMS-components and oriented on microfluidic biochip technology. There are also many tools for low-level modeling of microfluidic biochip structures which can help to carry out 3D/2D modeling, virtual prototyping and appropriate electromechanical analysis for single microfluidic biochip device. Commercial CAD systems of higher level provide abstract model and carry out design procedures at system-level. We have presented an integrated methodology that helps to solve key issues in the simulation, synthesis, modeling, testing and reconfiguration of digital microfluidics biochips. The top-down design methodology will ease the integration of fluidic components with microelectronic component in systems on chip.

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