Self-rolled microsystems: A promising route toward fully functionalized and low cost micro-capillaries

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Summary

We present a new route for the fabrication of highly specialized micro-capillaries, based on the phenomenon of thin polymer films self-rolling. Using effects of solvent swelling or embedded stress, instability in polymer films are generated, leading to the spontaneous formation of capillaries. Before rolling, the surface can be patterned (chemically, topographically), permitting the fabrication of inexpensive fully functionalized capillaries.

Keywords: microfluidics, self-assembly, micro-capillaries, polydimethylsiloxane, rolled-up microsystems

Introduction

Spontaneous curvature is a well-known instability, first theorised by Timoshenko in 1925 [1], which occurs in films with gradients of stress along the normal axis. It was first studied as a potential source of defects in lithographically designed system, where the densification of the photoresists could lead to curving of the system. More recently, this effect was used to fabricate tubes as a self-assembly process. Those self-rolled systems have often been cited as object with great potential of application [2].

We focus on the application of those self rolled microsystems to lab-on-chip technology. Hence, we propose new methods to induce the spontaneous rolling of polymeric films, more precisely polydimethylsiloxane (PDMS). The advantage of such system is three-fold : i - Those systems are inexpensive to design. ii - The inner surface of the capillary is accessible before rolling and can be properly functionalized and characterized. iii - The formation of the channel itself is not a lithographic process. Thus the fabrication of patterned channel can be done with only one lithographic step, which implies a great economy in terms of means and efforts.

We believe that those systems are a great alternative for the fabrication of cheap and highly specialized capillaries.

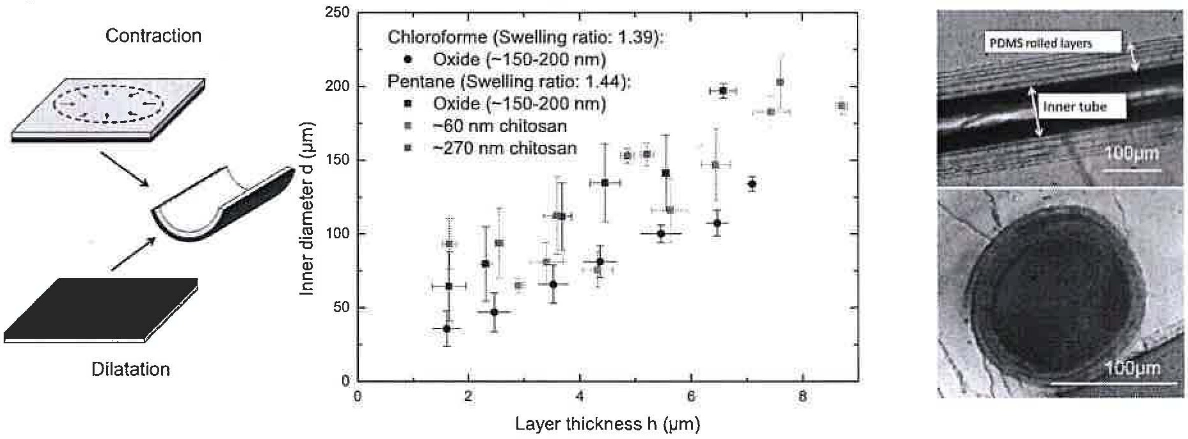

FIGURE 1: *Left* : Two types of rolling of a bilayer systems. Either the top layer shrinks (top) or the bottom layer is swollen by a solvent (bottom). The flat position is not equilibrium anymore so that a spontaneous curvature occurs. *Center* : Inner diameter as a function of film thickness for different types of capping and solvents in the case of the swelled PDMS process. *Right* : Optical images of rolled systems embedded in PDMS, side and front view.

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Self-rolling of polydimethylsiloxane based systems

Spontaneous rolling occurs when there is a stress inhomogeneity in a thin film. A first method is to harden the surface of a PDMS thin film, either by adding a capping of material (e.g. 60 to 200nm of chitosan) or by hardening the surface by plasma oxidation (some tenth to 100nm of glass like material [3]). The film is then cut to define the final shape of the system, which is then exposed to solvents in liquid or gaseous phase[4] (figure 1). As the swelling of PDMS occurs, the flat configuration of the film is not an equilibrium anymore and spontaneous rolling occurs. A second method is to add a layer of a mixture of PDMS and oil which can be extracted by solvent bath. The collapse of the PDMS matrix when the oil is removed provokes a permanent and embedded shrinking stress in this layer, thus generating a spontaneous rolling [5]. The inner diameter of such systems can be controlled by changing the solvent, the nature of the top layer or the thickness of the whole system. Capillaries of inner diameter between 10 and 1000 microns can be obtained.

Inner surface specialization

In order to illustrate the potential of the method, we propose the geometrical patterning of surface before rolling obtained with simple embossing-like methods (figure 2). We obtained capillaries as small as 70 microns with 13 microns deep patterns *over the whole inner surface of the tube*, which typically cannot be obtained with standard techniques. Other types of patterning such as chemical functionnalization or electrode deposition are currently in development.

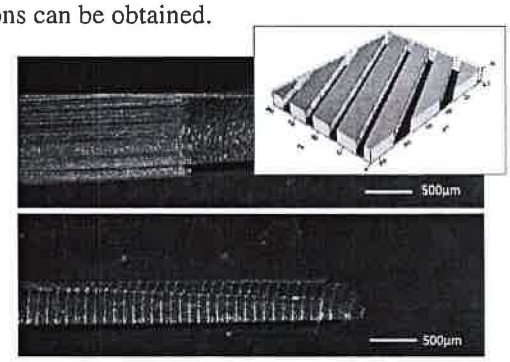

FIGURE 2: *Inset* : Pattern of a PDMS film before rolling. The grooves depth is 11.2 microns. *Main* : Patterned rolled systems with different rolling directions. *Top* : Grooves parallel to axis.

Conclusion and perspective : Toward chip technology

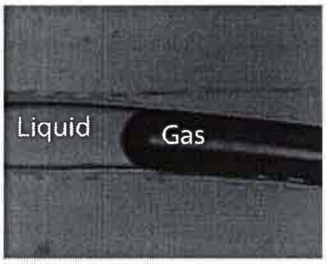

FIGURE 3: Optical image of a fluid front in a 300 microns rolled up system.

Spontaneous curvature effect can be used for the inexpensive auto-assembly of micro-capillaries. The inner surface of those is fully accessible before the rolling occurs and can be easily functionalized.

The main remaining challenge of this technique is the integration of the rolled-up system in a larger microfluidic systems. Methods are developed to obtain soft lithographic / self-rolled hybrid systems in order to make use of the advantages of both processes.

We believe in the potential of this method for the design of cutting edge microfluidic technology.

Acknowledgements

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