THE PHASEGUIDE PARADIGM: PRIMING AND EMPTYING OF MONOLITHIC POLYMER CHIPS

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ABSTRACT

Phaseguide technology gives complete control over filling and emptying of any type of microfluidic structures, independent of the chamber and channel geometry. The technique is based on a step-wise advancement of the liquid–air interface over passive capillary pressure barriers, typically in the form of ridges in the channels or chambers. The fluid will align itself to a phaseguide and completely fill the deligned area before jumping over to the next area. Phaseguides control fluid flow for complete filling and emptying of glass-hybrid or monolithic polymer chips.

KEYWORDS: Phaseguides, priming, fluid handling, capillary pressure

INTRODUCTION

The complexity of conventionally designed microfluidic chips is limited by the ability to properly prime them and eventually recover their content. Particularly non-hydrophilic materials, such as most plastics in their native state, give rise to filling complications, such as air bubble trapping. Complex surface treatments are typically needed to make the surface more hydrophilic [1] and the geometry is compromised to accommodate complete filling. In this paper we propose a passive geometry based fluid handling technique that is applicable to monolithic hydrophobic polymeric chips without the need for any surface modification or active fluid manipulation.

Recently, we introduced phaseguide technology that gives complete control over filling and emptying of any type of microfluidic structures, independent of the chamber and channel geometry [2]. Phaseguide design adds a new level of engineering complexity to microfluidics that enables to create simplest possible, black box type, microfluidic chips. Geometries are not compromised by handling issues anymore and become fully supportive to the functionality of the chip. So far, we have demonstrated phaseguiding behavior for glass chips with phaseguides patterned in photopolymer. Here we demonstrate the potential of phaseguides for monolithic polymer chips.

Phaseguides are patterned capillary pressure barriers that induce the liquid-air meniscus to align itself with the boundary before jumping over and aligning with the next phaseguide (see figure 1a and b). Typical phaseguiding behavior is based on the meniscus-pinning effect (see Fig. 1c). For phaseguides patterned in monolithic chips having side wall profiles of 90°, efficient pinning occurs for contact angles that are larger than 45°, which is the case for most plastic chips.

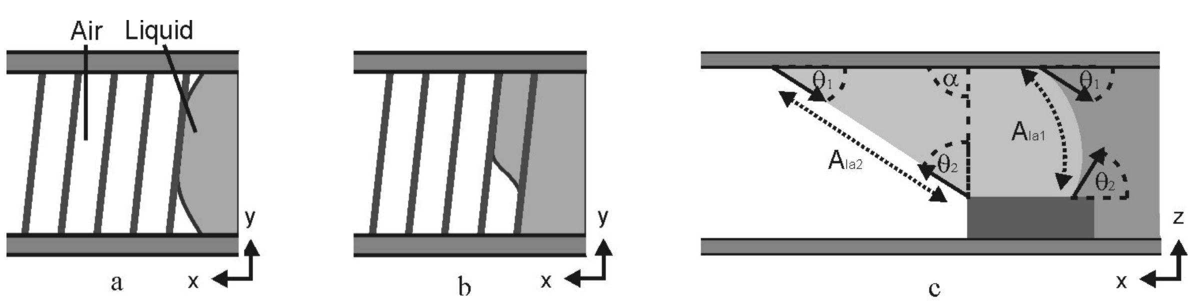


Figure 1: Principle of phaseguiding. (a) An advancing liquid aligns itself along a phaseguide before (b) jumping over. (c) Meniscus pinning effect makes the phaseguide acts as a pressure barrier. Complete pinning occurs when the angle α between the vertical side of the phaseguide and the top material is larger than 180° minus the contact angles $\theta_1 + \theta_2$ of the two materials. The increase in liquid–air surface from A_{la1} to A_{la2} contributes to an increase in Gibbs free energy and thus counteracts the capillary

EXPERIMENTAL

Glass-photopolymer chips were fabricated by patterning phaseguides in the dry film resist Ordyl SY 312/355 using a two mask process. Thermal bonding was used to cap these chips with a second glass layer. Polymer chips were fabricated using PDMS for replication molding of an Ordyl SY 312/355 patterned master. After casting and cross linking, PDMS is treated with oxygen plasma to enable bonding to a second PDMS layer. Chip filling was tested after the PDMS had returned to its native non-hydrophilic state.

Chips were filled with food dye colored water using a pipette or a syringe pump. Inlets were punched into the polymer chips and a conformational seal was easily acquired when inserting either the pipet tip or the tubing connected to the syringe pump. Emptying was either performed by sucking the fluid out using a pipette, or by pumping in air using the syringe pump.

RESULTS AND DISCUSSION

An important application of phaseguides is the filling of dead angles. Dead angles are corners at the extremes of a chamber that would normally not be reached during the filling process as air would be trapped there. A phaseguide originating from this extreme corner allows complete filling of the structure. Figure 2 shows a monolithic polymer chip with a square chamber having four so-called *dead-angle phaseguides* and three *supporting phaseguides* [2]. Fig. 2 b, e, f, and i show that the dead angle phaseguides ensure complete filling and emptying of these corners.

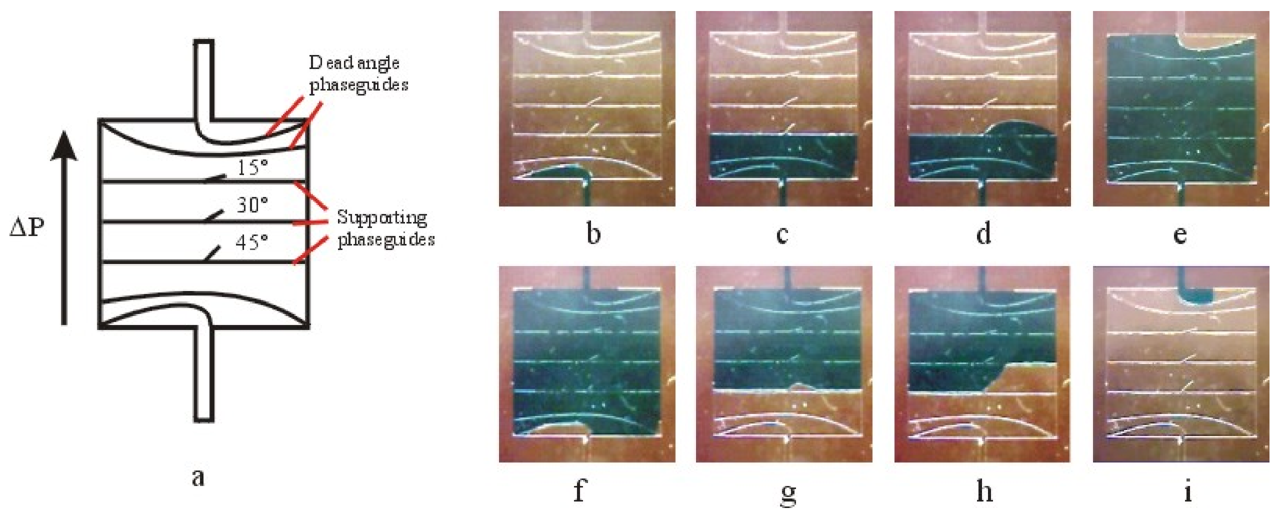


Figure 2: Controlled filling and emptying of a non-hydrophilic monolithic chip: a) Schematic showing the layout of the chip with dead angle phaseguides and supporting phaseguides. The dead angle phaseguides ensure complete filling (b,e) and emptying (f,i) of corners. Branches of supporting phaseguides enforce a central overflow (c,d,g,h).

In addition to dead angle filling, phaseguides can also be designed to ensure a controlled flow pattern by introducing specified overflow points of the phaseguides. When build-up of pressure over a pinned liquid–air interface is high enough, phaseguide overflow will occur. This occurs at the ‘‘weakest point’’ along the phaseguide, i.e. the place where least energy is required for the meniscus to advance. This is the point where minimal meniscus stretching is required and maximal surface wetting is achieved. Typically, this occurs at the position where the meniscus faces a V-shaped solid surface (V-groove). Such a V-groove can be designed in various manners:

1. A sharp angle between the phaseguide and the channel wall
2. A sharp V-shape bend of the phaseguide
3. A branch of the phaseguide resulting in a sharp V-shaped groove

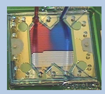
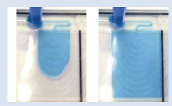
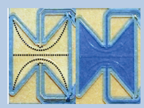
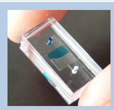
Supporting phaseguides are used to gradually manipulate a liquid front in the required shape or direction. The design of these supporting phaseguides incorporate a “weak spot” at a predetermined position where overflow is required. The chip show in Fig. 2 contains three supporting phaseguides. Each supporting phaseguide has a branching line at its center defining the pre-determined overflow point. Combining dead angle phaseguides with supporting phaseguides, Figures 2b-e show the filling sequence, including dead angle filling and controlled overflow at the branches. Figure 2f-i show complete emptying. Also here, dead angles are emptied and overflow is enforced at the branches in the center.

CONCLUSION

In general, we believe that phaseguides represent a paradigm shift in microfluidic design thinking. Phaseguide design adds a new level of engineering complexity to microfluidics that enables to create simplest possible, black box type, microfluidic chips. Geometries will not be compromised by handling issues anymore and become fully supportive to the functionality of the chip.

Implementation in monolithic chips is a crucial development in the evolution of phaseguide technology. Table 1 summarizes operations and applications that have been developed so far. Monolithic chips add the dimension of low cost mass fabrication to the portfolio, thus enabling the phaseguide paradigm to extend its impact also to a commercial setting. Applications that have been demonstrated to date are only the very first steps taken in these directions, leaving the true potential of phaseguide design still largely unexplored. Phaseguides will prove a leap forward towards more simple, flexible and reliable microfluidic systems.

Table 1. Overview of phaseguide operations developed so far and their envisioned applications

Operation		Application
Selective buffer recovery [3]		Particle & cell separation
Gel patterning [4]		Electrophoresis, salt bridges
Complex and square chamber filling & recovery [2]		Microarrays, inkjet printing
Selective phaseguide overflow [2]		Multi-reagent assays
Monolithic chip filling		***Mass production of low cost chips***

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