A SINGLE-MASK SINGLE-ETCH PROCESS FOR CONSTRUCTING THREE DIMENSIONAL MICRO TOTAL ANALYSIS SYSTEMS

Phillip Zellner and Masoud Agah
Virginia Tech MEMS Laboratory, The Bradley Department of Electrical & Computer Engineering, Virginia Tech, Blacksburg, USA

ABSTRACT

This paper reports a single-mask, single-etch process for fabricating silicon microchannels with control in all three dimensions to form complex three dimensional (3D) micro total analysis systems (µTAS) comprising microchannels and cavities with varying depths and width and with symmetric and non-symmetric cross-sections as well as junctions with controlled transitions.

KEYWORDS: 3D microfabrication, silicon micromachining, isotropic etching, RIE lag, micro total analysis systems

INTRODUCTION

Microfluidics has found numerous applications ranging from the life sciences industries for pharmaceuticals and biomedicine to industrial applications of combinatorial synthesis [1]. The core element of a microfluidic system is micron sized channels. The capability to create a high performance microfluidic system is often limited by the achievable geometries of the chosen fabrication process. Some of the common methods for creating microchannels include anisotropic wet etching, isotropic wet etching, ion milling, and reactive ion etching (RIE).

RIE is a microfabrication process that utilizes a chemically active plasma to remove thin film material deposited on a wafer or etch the wafer itself. It has been shown that for RIE, the etch rate varies with the aspect ratio of the structure. This phenomenon, know as RIE lag, has already been utilized as a 3D silicon micromachining technique for the fabrication of micro lenses [2] and 3D electrodes [3]. Our group, however, has been the first to utilize RIE lag in microfluidic applications and has demonstrated that different geometric features of the photomask layout can be used to tune the width and depth of microchannels formed in silicon by isotropic deep reactive ion etching (DRIE) process [4]. This paper reports the flexibility of the RIE-lag-based silicon micromachining technique to fabricate complex 3D microchannels and to control the transitions between different depths of the microfluidic system using a sinlge-mask single-etch process.

FABRICATION

Figure 1 shows the fabrication process and photomask layout for some of the designs. By changing the size, spacing, and the number of openings in the photomask, the RIE lag effect can be tuned and the silicon etch rate can be varied to achieve different depths and widths in a single-etch process. The process starts by first depositing silicon dioxide on a silicon wafer and patterning the oxide layer. Photoresist and oxide layers are striped.
and the wafer is diced to characterize the etch process and its dependence on the geometric features of the layout.

RESULTS AND DISCUSSION

The fabricated structures were observed with scanning electron microscopy (SEM). The depth resolution was limited by the minimum feature size present on the mask and the etch time. For a 10 min etch time with 2 µm square openings, channels as small as 20 µm can be obtained. In order to tune the profile of the transitions between different depths, channels of different depths were connected by a varying number of mask openings. The sharpness of the transition depended on the configuration of the mask openings and the rate that the openings varied. When connecting two channels with different dimensions, a sharp transition in depth would occur with little or no incrementing of the openings (Figure 1-A1). Conversely, a gradual depth transition would occur with a gradual increment in the number of openings in the mask (Figure 1-A2). Images of two such junctions between 40 µm- and 200 µm-deep channels are shown in Figure 2. This technique can be extended to create structures having varying depth with extremely smooth transitions. For example, by gradually varying the number of 2 µm square mask openings from 1 to 10 with a constant 2 µm spacing (Figure 1-A3), a spiral (Figure 3) was fabricated that increased in depth from 20 µm to 45 µm and in width from 20 µm to 85 µm. By increasing the number of openings and their sizes, the depth of this channel can increase to more than 150 µm. Non-symmetric channels were also achieved by changing the size of the openings in the

![Figure 1 Process flow for creating 3D structures (A) mask patterns, (B) silicon substrate with oxide layer deposited, (C) photolithography and patterning oxide, and (D) silicon isotropic DRIE.](image1)

![Figure 2 Cross sections of (top) gradual transition and (bottom) abrupt transition.](image2)

![Figure 3 Microfluidic spiral: (center) top view, (bottom) cross section, and (upper right) 45° angle view.](image3)
mask from 10µm to 2µm while keeping the spacing between the openings constant (Figure 1-A4). Figure 4 shows such a structure which is 1mm-wide and 190µm-deep at its deepest point.

To prove the versatility of this technique, different microfluidic devices for cell handling and analysis were fabricated on a single wafer, some of which are shown in Figure 5. It is worth mentioning that these microstructures include channels with different depths and that the slope of the transition at the junction of different channels varies.

CONCLUSIONS

The presented single-etch process is a novel, low-cost, high-yield alternative process to conventional multiple lithography and etching steps for developing microchannels comprising different depths while having this unique capability to form microchannels with asymmetric cross sections and with varying depth along their length. Moreover, a higher degree of miniaturization and integration can be achieved since these complex µTAS are made of silicon.

ACKNOWLEDGEMENTS

This work has been supported primarily by the National Science Foundation under award number ECCS-0747600 and the Virginia Tech Institute for Critical Technology and Applied Science (ICTAS). The authors would like to thank Mr. Mehdi Nikkhah for his technical assistance.

REFERENCES