Fabrication method for nearly-perfect circular channel structures using Buried Channel Technology and HNA etchant

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Abstract
A novel fabrication method for microfluidic channels with a nearly-perfect circular cross-sections and low surface roughness in a silicon substrate is presented. The method is based on Buried Channel Technology and uses a modified HNA etchant with a low etch rate for silicon-rich silicon nitride mask material. A dedicated reaction vessel is designed which enables horizontal wafer rotation during the etch to reduce the non-uniformity of HNA etchant. Channels with a near-perfect circular cross-section of diameter of 100 µm are fabricated for micro Coriolis mass-flow sensor applications.

Introduction
Buried Channel Technology (BCT) was invented in the MESA+ Institute [1,2]. This technology makes it possible to fabricate microfluidic channel structures with a circular cross-sectional area in a silicon substrate. The outline of the fabrication process of BCT is described in Figure 1. BCT with different etchants were studied in previous works and showed that channels with non-circular cross-sections were fabricated by etching with vapour-phase XeF₂, reactive ion etching using SF₆ plasma and wet chemical etching using the HNA etchant [3,4].

In this work, the HNA etchant is used to etch the microfluidic channel. The HNA solution is made by mixing hydrofluoric acid, nitric acid and acetic acid and it can etch silicon isotropically. By changing the composition, i.e., the ratio between the acids, the etching kinetics changes as well, resulting in changes to the etch profile. This was studied in detail by Schwartz et al. [5]. Further studies proved that by adding the rotation of substrate during etching, the etching uniformity can be optimized [6].

Experimental results
The starting point of etching of the channel is defined by the opened bottom of the trench in step (g) in Figure 1, which results in a channel buried within the silicon substrate. The shape of the etched channel cross-section is mainly determined by the type of etchant used in step (h). The maximum diameter is determined by the etched trench depth in step (e), the etch rate of mask material on the substrate surface and the trench sidewalls in the etchant used in step (h). Figure 2 shows an etched trench with silicon-rich silicon nitride (SiRN) deposited and the opening after the trench bottom removal step. The trench has a depth of 65 µm and width of 10 µm.

A dedicated reaction vessel was designed for channel etch, as shown in Figure 3. The wafer is mounted horizontally in the wafer carrier, which can rotate by a motor on top of the lid. The chemicals used are 50% hydrofluoric acid (H), 69% nitric acid (N) and 100% acetic acid (A). Two different compositions were used, i.e., 2:7:1 and 3:6:1. The etch time was 90 minutes for both compositions. Both wafers were rotated with 25 rpm during etching. Figure 4 shows the SEM image of the cross-section of the etched channels. For composition 2:7:1, the cross-section is nearly perfectly circular, and the diameter of the circle is approximately 100 µm. For composition 3:6:1, on the other hand, the channel is over-etched in 90 minutes and the surface roughness is high. The hanging walls are the deposited SiRN sidewalls of the trench. For both compositions, the etch rate of SiRN mask is 3 nm min⁻¹. The non-uniformity is reduced from 1.41% to 0.9% by adding the rotation with composition 2:7:1.

Conclusion
We demonstrated that the HNA etchant can be used to fabricate large (100 µm) microfluidic channels with near-perfect circular cross-sectional areas in a silicon substrate. The obtained channel is fully integrated in single silicon substrate. The selectivity of this etchant between silicon and SiRN is high enough so the maximum diameter of the channel is mainly determined by the depth of pre-etched trenches, therefore channels with an even larger dimension can be achieved by this method.
References

Figure 1. Overview of fabrication steps of BCT
(a): Bare silicon wafer. (b): 500 nm SiO₂ thermal oxidation. (c): Patterning oxide layer. (d): Bosch-based trench etching. (e): Stripping of oxide layer. (f): LPCVD of SiRN. (g) Trench bottom removal. (h): Channel etching by HNA.

Figure 2. Etched trench and the bottom opening of the trench after bottom removal step.


Figure 4. SEM image of the cross-section of the etched channel. (a) Composition 2:7:1. (b) Composition 3:6:1.