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Concept for processing of silicon check valves by proton beam micromachining

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Abstract

In this work, we present alternative methods for the formation of a simple a check valve for microfluidic applications. In two different approaches we exploited the characteristic features of the proton beam micromachining (PBM) technique and the selective formation and dissolution of porous Si around the implantation damaged areas.

In the first case, we implanted 10 μm thick cantilever-type membrane of the valve normally to the crystal surface and at 30–60° to the sidewalls of the flow channel, which were also implanted at the same irradiation. During the porous Si formation we developed the sample 6–8 μm deeper than the implanting ion range damaged the crystal. Due to the isotropic nature of the porous Si etching, the thick sidewall blocks are still connected to the crystal while the thin membranes detached from the bottom, and they are only connected to one of the sidewalls.

The other construction utilized the goniometer facility mounted on the microbeam chamber. We implanted the samples at 43° tilt, and developed the samples not as deep as the ion range. This way both the sidewalls and the membranes are attached to the bottom of the sample.

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1. Introduction

The increasing demand for chemical or biochemical microsystems, e.g. Lab-on-a-Chip inspires the development of integrable microfluidic components. Although glass and plastics are obviously the best materials for cheap, disposable fluidic devices, crystalline silicon is still a promising candidate for realization of complex systems containing passive and active components in integrated form. The elaborated IC processing technology supplemented by appropriate three-dimensional structuring techniques offers the possibility of exploitation the outstanding mechanical properties of crystalline Si by forming flexible elements (membranes, cantilevers) and sensory functions.

The most commonly used 3D structuring methods are the preferential alkaline etching, the high density RIE process (deep RIE or HDRIE) and recently, the isotropic porous Si micromachining technique. While the applicability of the alkaline etching process is limited by its anisotropy, which results in tapered walls, the HDRIE is capable to form vertical-wall, high aspect ratio structures at a cost of low throughput, expensive process with relatively limited capabilities.

The membranes of microvalves and pumps have been demonstrated so far are formed from TiNi shape memory alloy [1–3], elastomers [4–6], single-, or polycrystalline

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silicon [7,8]. Regardless the material of the membrane, all the devices has similar construction, i.e. the moving membrane is parallel with the surface while the flow channels are perpendicularly formed.

In this work, we propose a novel approach for the formation of check valves by combining direct proton beam implantation with porous Si etching technique. Although P-beam writing requires expensive tool, the ion microbeam system can also be used for different purposes, i.e. micromachining of other materials (SU-8, PMMA, Foturan, etc.) or various microanalytical methods. The advantage of the porous Si technique lies in its simplicity, flexibility in design by inserting of in-line check valves in flow channels of almost arbitrary shape and the compatibility with CMOS processing. Nevertheless, the sealing properties of the proposed structure is still to be improved in order to show similar performance of the discrete devices mentioned above [7,8].

2. Model calculation

Two types of check valve structures were considered: the first group is called "horizontal". The membrane is attached to the flow channel at one of its side or by a reduced cross-section neck at the side. The flexible membrane is vertical to the surface but tilted with the sidewall of the channel by an angle of 30–60°. Therefore, flow from the two directions has different effect, may open the valve membrane more or close it, the valve works like a door.

In the "vertical" versions both the sidewalls and the membranes are attached to the bottom of the channel but there are no contacts at the sides. The membrane is not perpendicular, it has an angle of 40–60° to the bottom of the channel. The operation is similar to the other versions.

The mechanical conditions of the structures deposited in flow stream were analyzed by using finite element method (FEM) simulation. The applied COSMOS/M code is capable of modeling linear and nonlinear static and dynamic structural problems in complex 3D structures by solving numerically the mechanical equations in combined volume meshes. In this case eight-node SOLID elements were applied for 3D mesh generation with material properties of silicon (Young-modulus: 160 GPa, Poisson-ratio: 0.278), and an average pressure (10 kPa) as boundary condition in the surface perpendicular to the flow direction. The adequate deformation could be observed in case of the horizontal valve structure (*ca.* 20 μm) considered the tensile strength of the silicon material estimated to 7000 MPa, and the safety factor of 30. The maximal displacement and stress values of different structures and dimensions are summarized in Table 1. By forming thinner

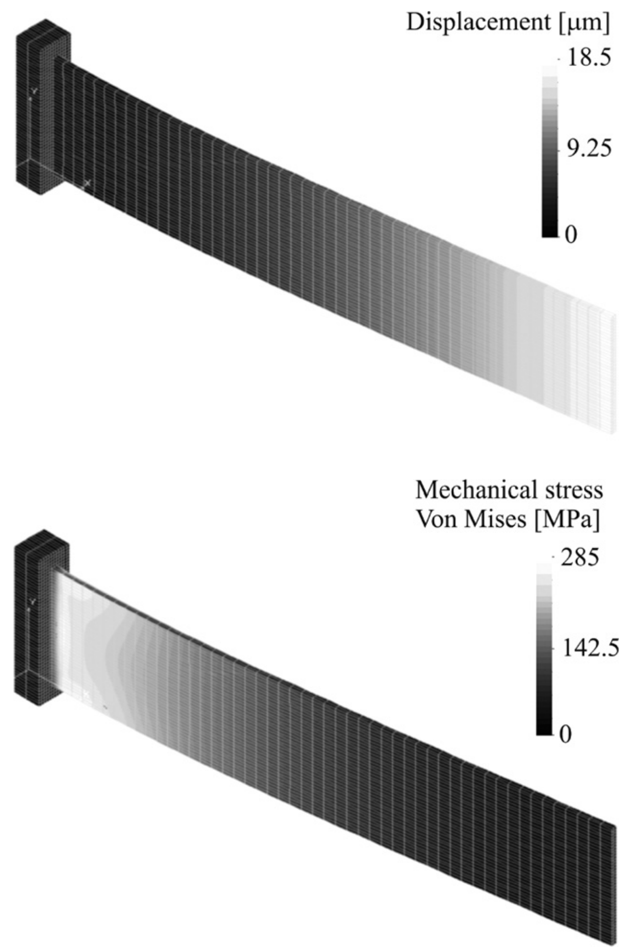

Fig. 1. Deformation and stress distribution of the horizontal valve structure under 10 kPa average pressure applied in the surface perpendicular to the flow direction.

Table 1
Maximum displacement and stress rise in membranes of different geometry

Value type	Value membrane dimensions (μm)					Maximum displacement (μm)	Maximum stress (Von Mises) (MPa)
	Length	Height	Thickness	Neck length	Neck height		
Horizontal	200	40	2	–	–	18.53	285.40
	200	60	2	–	–	18.38	287.40
	100	40	2	–	–	1.15	72.00
	100	40	1	–	–	9.16	295.60
Horizontal with neck	200	40	2	20	10	62.35	1938.70
	100	40	2	20	10	7.54	500.70
Vertical	200	30	0.5	–	–	1.80	157.70
	200	60	0.5	–	–	9.10	367.95