# DESIGN CONCEPTS FOR PREVENTING GAS BUBBLE INTERFERENCE IN MICROFLUIDIC DEVICES

**Sebastian Richert, Oliver Peters, Vu Hoa Nguyen and Uwe Schnakenberg**

Institute of Materials in Electrical Engineering 1, RWTH Aachen University, Germany

***Abstract***

*Unintendedly introduced gas bubbles in channels can significantly interfere with performance and behavior of microfluidic systems. Thus, there is a high demand for smart microfluidic system designs which are capable of preventing gas bubbles. In this work, we develop two different bubble interference preventing system designs: a degasser device that actively removes gas bubbles from the liquid based on pressure driven gas permeation, and a passive micro channel design that provides a guiding mechanism based on the gas bubbles' effort to minimize their surface energy. The effective performances of the devices are demonstrated.*

***Keywords***

*microfluidics, gas bubble removal, degassing*

## Introduction

Gas bubbles in microfluidic systems are known for causing functional disturbance. This leads to a direct impact on fluid transport as well as on sensor signals. Different approaches have been proposed for handling with gas bubbles. Skelley et al. introduced a combination of trapping and degassing by capturing gas bubbles with trap structures made in poly(dimethylsiloxane) (PDMS) [1]. The obvious disadvantage of these physical traps is their finite volume capacity which limits the maximal volume of trapped gas bubbles before they flow over. Lochovsky et al. developed an active degassing process to remove gases solute in the liquid, but their approach requires a rather large dead volume, since they only implement a degassing channel interdigitated with the fluidic channel [2].

In this paper, we present two novel design concepts. The first approach comprises an active degasser which removes gas solute in the liquid during continuous flow so that regular device operation is maintained. The degassing is achieved by using pressure driven gas permeation through a porous membrane.

Active degassing devices are not suitable for all microfluidic applications, when e.g. gas exchange through the PDMS is prohibited or extreme pH values of fluids are needed [3]. Therefore, in the second approach a passive guiding channel is proposed which prevents any trapping of gas bubbles within a microfluidic channel.

## Materials and Methods

### Concept 1: Degasser

The degasser design is schematically shown in Fig. 1. PDMS (Elastosil™, Wacker Chemie AG, Germany) is used as gas permeable biocompatible membrane material [4]. The central fluid channel is surrounded by a vacuum channel underneath and two channels on each side. Figures of merit are the required flow distance until the gas bubble is completely removed (as it determines the dead volume) and the maximum bubble volume that can be removed at a given flow rate.

Therefore, the objective was to maximize the gas flux diffusion through the membranes while keeping the length of the degasser channel as small as possible. The gas flux is equal to:



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$$N = \frac{P\Delta p}{h} \quad (1)$$

with $N$ being the steady-state gas mass flux, $P$ the gas permeability, $\Delta p$ the pressure difference along the membrane, and h the thickness of the gas permeable membrane [5]. In general, the gas flux through the membrane increases when the membrane thickness decreases. In our approach, one vaccum channel is placed at the bottom of the fluid channel separated by a PDMS membrane of thickness h and two additional vacuum channels aside the fluid channel separated by membrane thickness w, as shown in Fig. 1. The diameter of the microfluidic and the neighbored vacuum channel was designed to 0.3 mm. The underlying vacuum channel has a height of 0.6 mm and covers the whole area of the fluid channels, as apparent in Fig. 2 d). For mechanical stability reasons this vacuum channel is filled with cloth working as a spacer. The thicknesses of the PDMS membranes were set to w = 0.3 mm and h = 0.1 mm, respectively.

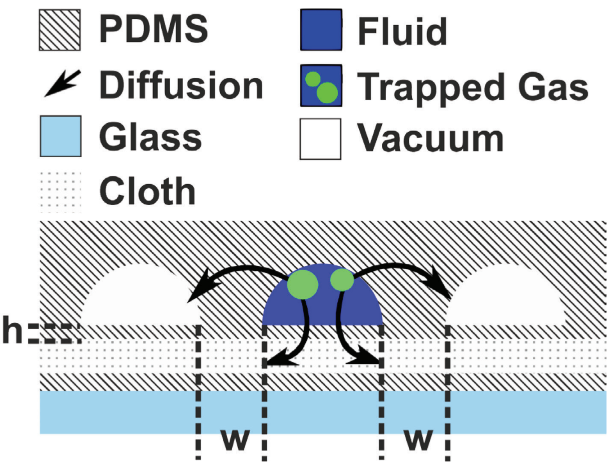


*Fig. 1: Schematic cross-section of the structure and working principle of the degasser design (not to scale). 'h' denotes the thicknesses of the PDMS membrane between fluid and bottom vacuum channel, whereas 'w' denotes the thickness between fluid and neighbored vacuum channels.*

Fig. 2 illustrates the fabrication process of the degasser. The upper degasser body, containing the microfluidic and the neighbored vacuum channels were fabricated by using standard soft-lithography and a mold. Openings for inlet and outlet were punched through the PDMS (a). Then, the PDMS membrane was spin-coated (b), cut and plasma bonded underneath the degasser body (c). The parts were finally plasma bonded onto a glass substrate with a PDMS and cloth layer in between, acting as spacers, thus creating the bottom vacuum channel (d). The casting process was carried out as follows: PDMS was evacuated, poured into the casting mold, and tempered in a convection oven at 60°C for two hours. The spin-coating was performed at 1750 rpm for 30 s followed by a baking step at 60°C for 20 minutes.

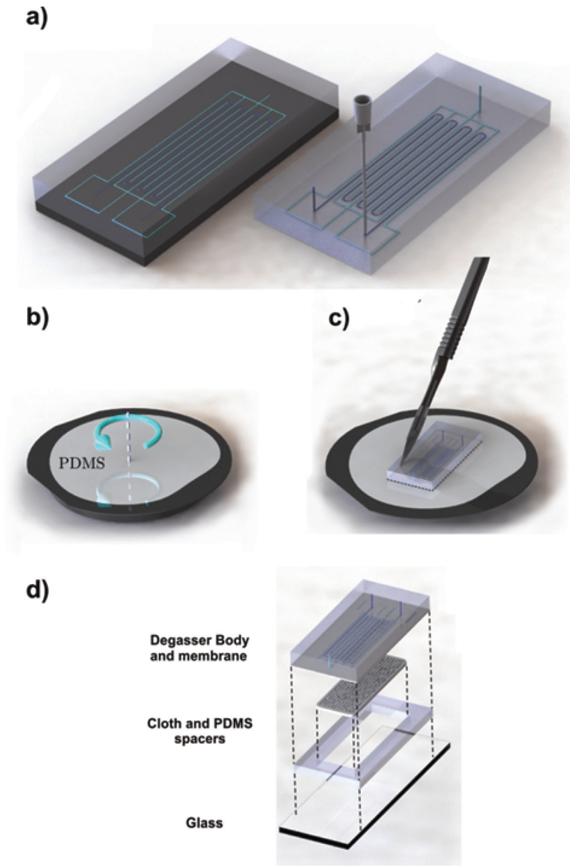


*Fig. 2: Schematic of the fabrication process for the degasser. a) Casting and piercing of upper degasser body. b) Spin coating of bottom PDMS membrane. c) Merging of degasser body and membrane via plasma bonding. d) Exploded drawing of bottom vacuum channel using PDMS and cloth as spacers.*

**Concept 2: Guiding Meander Channel**

In the second approach, a passive guiding channel in meander-type shape was developed that is capable of guiding unintendedly introduced gas bubbles. The working principle is based on the gas bubbles' endeavor to minimize their surface energy [6]. In a microfluidic channel with limited height the bubbles form plugs, while in larger channels the bubbles reduce their surface area, leading to the formation of round shaped bubbles (see Fig. 3).



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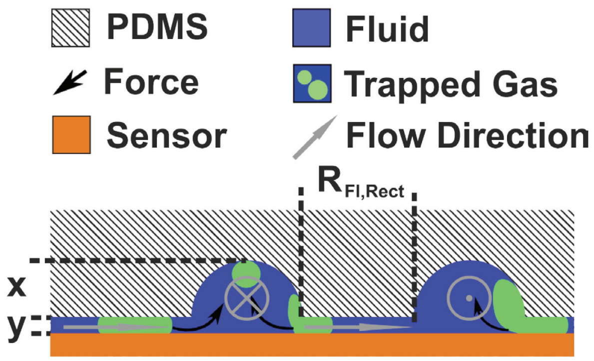


*Fig. 3: Schematic cross-section view of the meander guiding channel concept (not to scale): the gas bubbles' tendency to reduce their surface area forces them into the heightened part of the microchannel. 'x' is the height of the heightened meander channel; 'y' is the height of the rectangular base channel.*

The guiding channel concept was applied to a microfluidic surface acoustic wave sensor chip. In order to achieve absolute performance of the sensor, the rectangular part of the channel overlays the whole sensing surface (gold area in Fig. 4, marked orange). Since the height of this part of the channel is limited, its flow resistance $R_{Fl,Rect}$ is high compared to the one of the heightened part, so that the majority of the flow is guided along the heightened part. To maintain an adequate flow over the entire sensing surface $R_{Fl,Rect}$ has to be reduced. To do so, the heightened part of the channel is designed in a meander shape, so that the effective length of the rectangular part is minimized. The guiding channel was fabricated using PDMS casting as already described in chapter 2.1.

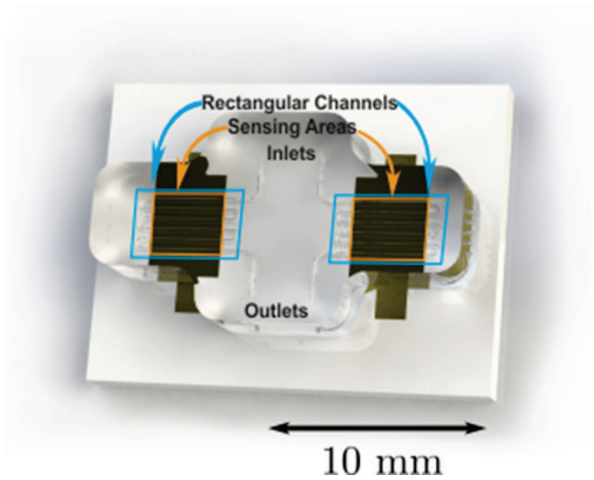


*Fig. 4: Photograph of two guiding meander channels placed above a surface acoustic wave sensor chip. The orange frame shows the sensitive surface and the blue frame indicates the area covered by the microfluidic channel.*

## Results and discussion

### Concept 1: Degassing

Fluid management was carried out by using two syringe pumps (HLL Landgraf LA-110, Germany). One syringe was filled with deionized water and the other one with air, respectively. Their outlets were connected to a microfluidic T-junction followed by the degasser. The flow rate and the bubble length were precisely controlled [7]. Fig. 5 shows the microfluidic degasser at work. The flow rates were set to 5 ml/h introducing 1.5 cm long air and water plugs from the bottom left of the chip. Apparently, the air bubble length decreases with increased progress in the channel, indicating a continuous degassing process.

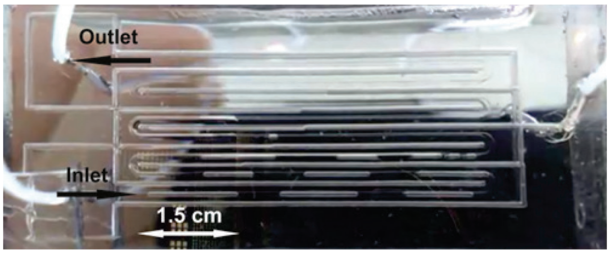


*Fig. 5: Photograph of the microfluidic degasser at work. Water and air plugs enter the degasser at the bottom left side and follow the meander channel to the top. The degassing leads to a continuous reduction of the air plug length.*

The microfluidic channel in Fig. 5 has a diameter of 0.3 mm and a length of 30 cm resulting in a dead volume of about 20 µl. With respect to equation (1) the longest air bubbles that can be reliably removed out of the liquid can have a maximum length of 1.5 cm (volume of 1 µl) at a flow rate of 5 ml/h. Note that this result is highly dependent on the type of solute gas, as the diffusion constants in PDMS differ for different gas types [5]. Therefore, to be representative, this result was obtained for solute air, which is the most frequently occurring gas mixture solute in liquid analytes. Considering the requirements of our own standard microfluidic based experiments the chosen flow rate of 5 ml/h is ten times higher than the actual one and the removed gas volume of 1 µl clearly exceeds the usual occurring ones. Thus, the performance of the improved degasser shows its capability of reliably removing all gas bubbles before reaching any sensitive part of the chip.

### Concept 2: Guiding Meander Channel

The sensor for the following experiments is a surface acoustic wave (SAW) sensor that is typically used to detect mass adsorption processes on its surface.



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Therefore, the SAW sensor is very sensitive to bubble formation on the surface, which would lead to ambiguos results. The output signal of the sensor is the frequency shift of the resonance frequency (about 130 MHz). Fig. 6 shows the correlation of bubble formation inside the (standard, non-guiding) micro-fluidic channel above the sensing area and the corresponding sensor output signal. The microfluidic channel has a rectangular base of 8 mm by 5 mm and a height of 0.3 mm. Gas bubbles inside this channel are marked red. The dotted lines indicate at which point of time the pictures were taken. In the first picture (1 minute), one can obviously see that there are no gas bubbles inside the channel at the beginning of the measurement leading to a stable output signal. At about 5 minutes the output signal starts to change significantly due to an agglomeration of gas bubbles on the sensing area. The gases, solute in the liquid, keep enlarging this agglomeration, until about 31 minutes (see Fig. 6). At this point of time the agglomeration of gas bubbles engrosses the whole channel, so that the fluid flux pushes it out of the channel. This leads to an abrupt decrease in the output signal at 33 minutes to its initial value, because of no further gas bubble disturbance, as apparent in Fig. 6.

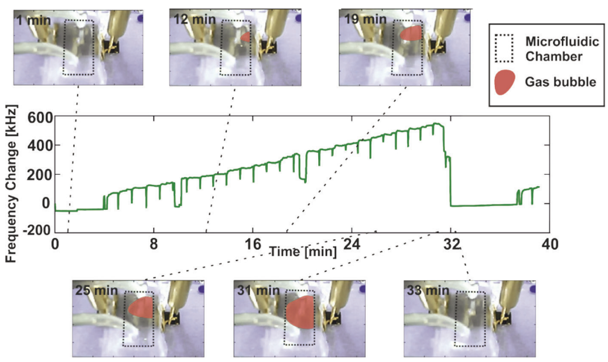


*Fig. 6: Correlation between gas bubble formation in the microfluidic channel (shown by photographs) and its impact on the SAW sensor's resonance frequency.*

Obviously, the presence of gas bubbles on the sensing surface causes an unwanted great impact on the resonance frequency, which would significantly influence the original absorption-based sensor signals. However, when the gas bubbles are guided out of the channel the resonance frequency shifts back to its initial value.

Fig. 7 shows the same measurement performed with the guiding meander channel above the sensing area. The gas bubbles reaching the sensor area still have an impact on its resonance frequency, but the duration of this impact is reduced to a negligible time span of only a few seconds. This is the time the bubbles need to pass the whole channel. Thus, the signal changes expected by mass adsorption processes, which would typically take several minutes, are not significantly influenced compared to prior experiments.

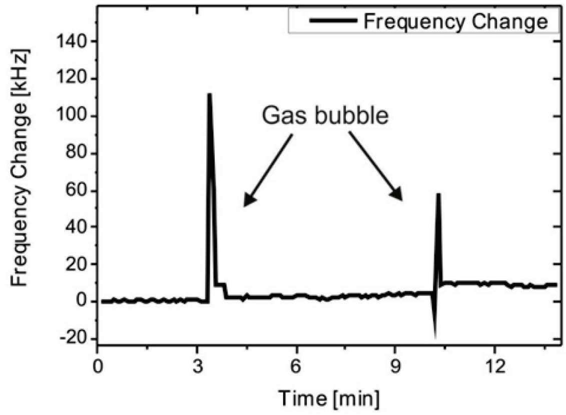


*Fig. 7: The same measurement as shown in Fig. 6 performed with the meander-type guiding channel above the sensor area. The controlled guiding of the gas bubbles through the channel leads to a negligible short interference with the output signal.*

## Conclusion

We have improved an active degasser device by doubling its performance with an additional vacuum channel at the bottom of the fluidic channel. This is eminently important for in-line degassing, since the dead volume within the degasser device was significantly reduced and the possible flow rate considerably increased.

In a second concept, we have developed a new guiding meander structure in order to quickly guide any unwanted gas bubbles away from sensitive areas in the microfluidic device. Compared to the degasser the guiding structure's working principle is not material dependent, so that it can be replaced with gas impermeable or chemical inert materials.

## References

[1] Skelley, M. A., Voldman, J., An active, integrated bubble trap and debubbler for microfluidic applications, 12th International conference on miniaturized systems for chemistry and life sciences, San Diego, CA, USA. 2008, p. 1360-1362.

[2] Lochovsky, C., Yasotharan, S., Guenther, A., Bubbles no more: in-plane trapping and removal of bubbles in microfluidic devices, *Lab on a Chip*, 2012, vol. 12, no. 3, p. 595-601.

[3] Lötter, J.C., Olthius, W., Veltink, P.H., Bergveld, P., The mechanical properties of the rubber elastic polymer polydimethysiloxane for sensor applications. *Journal of Micromechanics and Microengineering*, 1997, vol. 7, p. 145-147.

[4] Jo, B.-H., Van Lerberghe, L. M., Motsegood, K. M., Beebe, D. J., Three-dimensional micro-channel fabrication in poly-



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ISSN 0301-5491 (Print), ISSN 2336-5552 (Online)

dimethylsiloxane (PDMS) elastomer. *Journal of Microelectromechanical Systems,* 2000, vol. 9, no.1, p. 76-81.

[5] Merkel, T.C., Bondar, V.I., Nagai, K., Freeman, B.D., Pinnau, I., Gas sorption, diffusion, and permeation in poly(dimethylsiloxane), *Polymer Physics,* 2000, *vol. 38, no. 3*.

[6] Baroud, C.N., Gallaire, F., Dangla, R., Dynamics of microfluidic droplets. *Lab on a chip*, 2010, vol. 10, p. 2032-2045.

[7] Guenther, A., Manish, J., Thalmann, M., Schmidt, A.M., Jensen, K.F., Micromixing of miscible liquids in segmented gas-liquid flow. *Langmuir*, 2005, vol. 21, no. 4, p. 1547-1555.

*Sebastian Richert, B. Sc.*
*Institute of Materials in Electrical Engineering 1*
*Faculty of Electrical Engineering and Information Technology*
*RWTH Aachen University*
*Sommerfeldstraße 24, 52074 Aachen*

*E-Mail: richert@iwe1.rwth-aachen.de*
*Phone: +49 178 7145069*



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