University of Twente Case Study: Fabrication of mechanically stable & thermally isolated microfluidic channels

We are very pleased to present a research project from Henk-Willem Veltkamp, M.Sc., researcher and process technologist at the University of Twente (Enschede, the Netherlands), focusing on microfluidic channels for high-temperature applications. Henk-Willem et al. successfully fabricated mechanically stable, thermally isolated microfluidic channels with silicon sidewall heating elements (SHEs) embedded in the sidewalls. ▶

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During his PhD, Henk-Willem gained a lot of hands-on cleanroom experience, using various Oxford Instruments' etching and deposition tools extensively for his research project. As Henk-Willem states "one of the benefits using Oxford Instruments systems is that they are robust, the user interface straightforward, and you can easily change the recipe settings".

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Research purpose – Fabrication process of microfluidic channels for high-temperature applications

The main purpose of this research project was to develop a microsensor to measure the calorific value of natural gas by combustion. The high demand for cleaner and greener energy has led to an increase in focus on research projects for natural gas combustion, which is considered a cleaner process compared to burning fossil fuels.

The high energy density of hydrocarbon fuels creates a great opportunity to develop combustion based micro-power generation systems to meet increasing demands for portable power devices, micro-unmanned aerial vehicles, micro-satellite thrusters, and micro-chemical reactors and -sensors.

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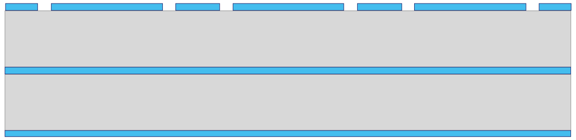
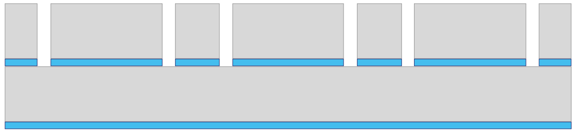
Process Steps

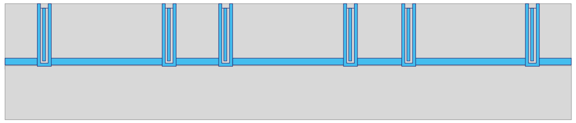
1. Firstly, the hard mask layer is patterned with 3 µm trenches, which are the outline of the microfluidic channels and silicon SHEs, using conventional broadband UV photo-lithography and reactive ion etching.



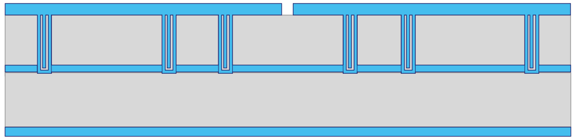
2. After that step, the trenches were etched 50 µm deep with high uniformity using a high aspect ratio Bosch-based recipe in an Oxford Instrument's **Plasma**Pro® **100** Estrelas DRIE system. The high-density plasma source and fast gas-switching capability of this Oxford Instruments DRIE system enables you to achieve profile verticality, smooth sidewalls and high etching rates with high selectivity to masking materials. After which the hard mask layer is stripped.



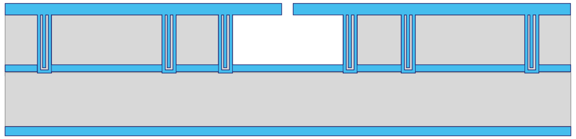
3. Then, the trenches are refilled again using a two-step approach consisting of a thermal wet oxidation and a low-pressure chemical vapour deposition of poly-crystalline silicon. The poly-crystalline silicon and thermal silicon dioxide at the top of the device layer are etched away using separate reactive ion etch approaches in an Oxford Instruments **Plasma**Pro® **100** Estrelas and another etching system, respectively.



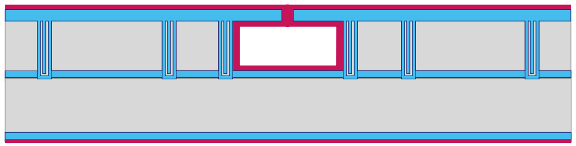
4. A new hard mask layer is deposited using a low-pressure chemical vapour deposition of SiO_2 using TEOS as precursor. Into this hard mask layer, a slit pattern is patterned using conventional broadband UV photo-lithography and reactive ion etching.



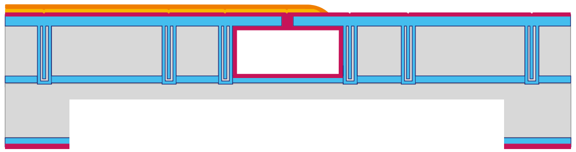
5. Subsequently, the microfluidic channels are etched using vapour-phase XeF_2, while using the SiO_2 of the buried oxide, the refilled trenches, and the TEOS-based hard mask as etch stop.



6. The microfluidic channel wall is formed by low-pressure chemical vapour deposition of low-stress silicon-rich silicon nitride (SiRN). This conformal technique ensures deposition of the channel wall through the slits before closure of the slits.

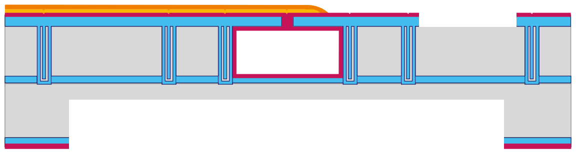


7. Metal contacts and temperature sensors are fabricated by depositing a tantalum adhesion layer and platinum electrode layer by magnetron sputtering, and a silicon nitride capping layer via plasma-enhanced chemical vapour deposition in an Oxford Instruments **Plasma**Lab **80** system, which produces excellent uniformity with control of film properties. These layers are patterned using conventional broad-band UV photo-lithography and ion beam etching in an Oxford Instruments **Ionfab.**

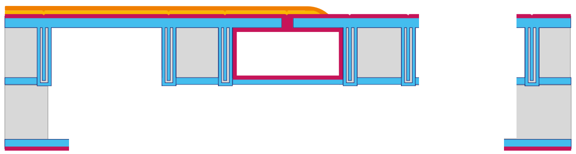


PlasmaPro® **100** Estrelas offers the ultimate flexibility with Bosch and Cryogenic processes.

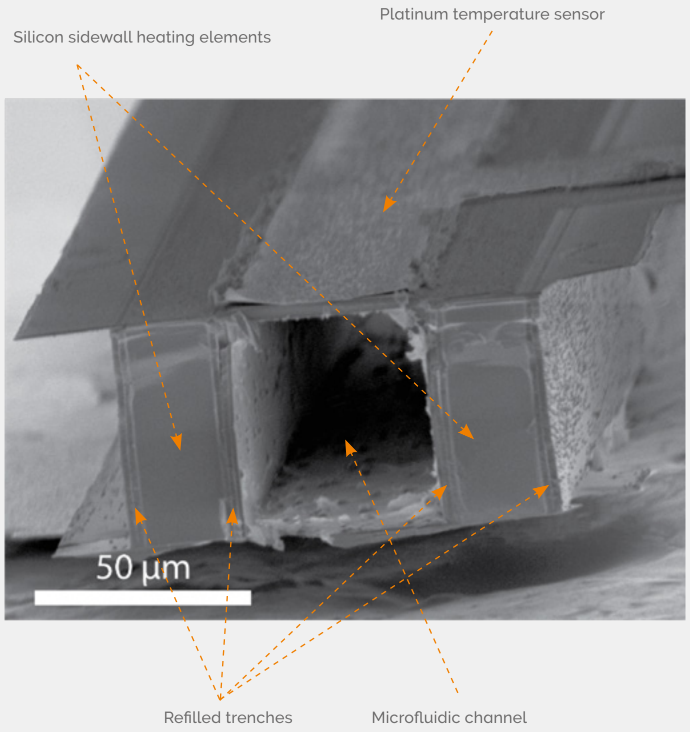
8. The microfluidic channels are suspended from the bulk of the wafer by first etching cavities into the handle layer using a Bosch-based approach. Then, on the device layer, release windows are etched into the TEOS-based SiO_2 and SiRN. The release is done by etching the silicon around the microfluidic channels with silicon sidewall heating elements using vapour-phase XeF_2.



9. Following the above fabrication process, the researchers achieved to produce a rectangular cross-section to both the channels and the silicon heaters, as the image below shows, "with large design freedom in shape, size, and heating power embedded in the sidewalls" [1], useful for many applications of microfluidics.



SEM of Cleaved Microfluidic Device



Conclusion

As high-aspect-ratio structures are a crucial part for the fabrication of MEMS devices, Henk-Willem currently continues to be involved in projects with high-aspect-ratio trench structures. In his current work, the research team try to optimize the trench entrance and sidewall profile angle "to prevent keyhole formation" [2], providing better mechanical strength and higher quality electrical and thermal insulations.

As a long-term partner with the University of Twente, Oxford Instruments Plasma Technology will continue to support their cutting-edge research and development projects into microelectromechanical systems and share our expertise to further develop their fabrication processes in semiconductor industries.

Henk-Willem Veltkamp
M.Sc., researcher and process technologist at the University of Twente

References

1. H.-W. Veltkamp, Y. Zhao, M.J. de Boer, R.G.P. Sanders, R.J. Wiegerink and J.C. Lötters, "High Power Si Sidewall Heaters for Fluidic Applications Fabricated by Trench-Assisted Surface Channel Technology," 2019 IEEE 32nd International Conference on Micro Electro Mechanical Systems (MEMS), 2019, pp. 648-651, doi: 10.1109/MEMSYS.2019.8870667.

2. H.-W. Veltkamp, Y.L. Janssens, M.J. de Boer, Y. Zhao, R.J. Wiegerink, N.R. Tas, J.C. Lötters, "Method for Keyhole-Free High-Aspect-Ratio Trench Refill by LPCVD," 2022, Micromachines, 13(11), 1908, doi: 10.3390/mi13111908.

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