Table 2– Simulated and measured stiffnesses together with the corresponding deflection in z-direction leading to fracture for single SP with a membrane thickness of 26 µm and different membrane lengths

Membrane length L_{mem} in mm	**0.45**	**0.35**	**0.25**
Simulated S_z in $mN.\mu m^{-1}$	0.61	0.73	0.94
Measured S_z in $mN.\mu m^{-1}$	0.26 ± 0.01	0.31 ± 0.01	0.38 ± 0.01
Fracture deflection in µm	713 ± 65	548 ± 65	488 ± 100

The sensing characteristics for longitudinal and transversal piezo-resistor arrangements at z-direction deflection are given in Figure 7b. The obtained sensitivities are sufficient to enable sub-micron precision measurements. The difference between both can be explained by the distribution of the strains in the membrane. Indeed the longitudinal arrangement profits from bigger strains values, which are located on the border of the membrane (towards the outside of the SP). To optimize the sensitivities, the resistors have to be placed accordingly.

Table 2 gives also the operation ranges for SP (maximum deflection before fracture) for different membrane length with a thickness of 26 µm. For this experiment, eight probes were deflected until fracture and the mean values and the interval of confidence by 99.9% were determined. The use of these SP for a 3D microprobe would improve the measurement range (more than 3 times) against actual silicon microprobes.

Finally, the mechanical characterization of a 3D micro probing system (Figure 6a.) happened with and without stylus. In Table 3, the measured stiffnesses in x-, y- and z-directions are presented. Without the stylus the constructed system is perfectly isotropic. The influence of the stylus (mounted in z-direction) can be seen on x- and y-directions, it's bending directions. However, in both cases the maximal anisotropy was 1.2, which is lower than every microprobe of today.

Table 3 – Measured stiffness in x-, y- and z-direction for a 3D micro probing system without and with stylus constructed from three SP with a membrane thickness of 26 µm and a membrane length of 0.35 mm

	without stylus	**with stylus**
S_x in $mN.\mu m^{-1}$	0.300	0.300
S_y in $mN.\mu m^{-1}$	0.290	0.270
S_z in $mN.\mu m^{-1}$	0.280	0.250
max. anisotropy	1.06	1.20

SUMMARY AND OUTLOOK

A new tactile sensor design composed of single silicon parallelograms was presented which presents numerous advantages for it use in conventional CMM and for many others application in 1D or 3D setups.

The simulations confirmed an isotropic behavior of this new design. It was also possible to optimize the geometrical parameters based on a parametric study. The developed on wafer-level fabrication enabled a low-cost realization of single SP. The mechanical and sensor response characterizations showed that over a wide deflection range ± 400 µm, a precise deflection measurement at a low stiffness was possible. The first characterization of a 3D micro probing system (without sensors) confirmed that an isotropic mechanical behavior can be achieved.

The described results prove that a new 3D microprobe with many advantages (isotropy, low stiffness and wide range) can be successfully realized. The fabrication of SP and the 3D assembly of SPs for complete measuring systems will further be optimized in near future. Concepts for getting all SPs electrically connected without mechanical interference will be tested soon.

ACKNOWLEDGEMENTS

We thank M. David for assistance during the development, fabrication and measurements.

This research was supported by the Deutsche Forschungsgemeinschaft, DFG, project number DI 1934/5-1.

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https://doi.org/10.24355/dbbs.084-201806291110-0