# MECHANO-OPTICAL MICRO PILLAR SENSOR FOR BIOFLUIDMECHANIC WALL SHEAR STRESS MEASUREMENTS


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## Introduction

Wall shear stress (WSS) caused by viscosity induced shear forces in vicinity of walls, plays a huge role in biofluid mechanics. Due to its responsibility for near-wall fluid particle deceleration and pressure loss, this factor represents an indicator for blood coagulation and arterial stenosis. [1] For WSS measurements, a Micro Pillar Sensor (MPS) was developed. The sensor consists of a fluorescent, high aspect ratio microcylinder array (height: 120µm, diameter: 20µm) in vicinity of the wall, deflecting due to appearing boundary layer flow (Fig 1-left). The drag induced tip displacement, detected by Micro particle velocimetry (*µPIV*), represents the optical signal.

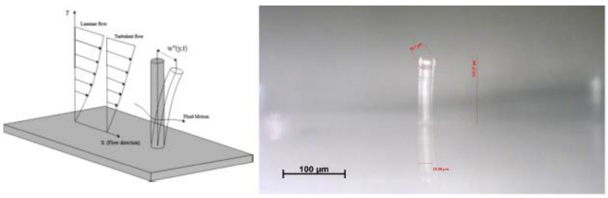


**Figure 1** WSS measurement principle using the MPS (left) and manufactured Micro Pillars with fluorescent tips (right)

## Methods

For sensor manufacture, a sacrificial molding technique was developed using PDMS (Polydimethylsiloxane) *Solaris®* and photolithography. The mold consists of multiple photoresist layers (*AZ 125nXT*) on a silicon wafer with high aspect ratio microholes. After PDMS curing, the Micro Pillars are released by dissolving the micromold. For optical detection, fluorescent silicate particles (diameter: 20µm) are mounted to the tips with a micromanipulation setup (Fig 1 - right).

The sensor calibration includes an experimental setup involving a noise-reduced, transparent laminar channel (2mm x 2mm) and *Fluorescence µPIV* for flow and MPS deflection measurement. For the Pillar measurement section, the microsensors are mounted to the channel bottom. The acquired optical signal and conventional WSS data via differential pressure measurements deliver the MPS calibration.

Fundamental drag behavior of the MPS is commonly described by the *Oseen-Approximation*, which is legit for the low Reynolds-number flow in vicinity of the wall. [2,3] In addition, the Micro Pillars can be described by the *Euler-Bernoulli* theorem for cantilever deformation. Further insight in the fluidmechanical conditions during WSS measurement is given by the usage of a numerical fluid-structure interaction (*ANSYS 19.2 ®*), providing drag (Fig 2 - left) and deflection (Fig 2 - right) during calibration. For the simulation, material data of the used *Solaris®* is obtained by cyclic Young's Modulus measurements (*Physica MCR 301*).

## Results

Micro Pillars with high aspect ratios were successfully manufactured with the presented sacrificial molding technique, which did not harm the sensitive microstructures during mold release (Fig 1 - right). Additionally, the arrays were highly detectable during *µPIV* measurement due to their fluorescent properties.
Numerical data showed great compatibility with the theoretical descriptions. The simulation also proved that the sensors (aspect ratio, material properties) are capable of measuring WSS as significant Micro Pillar tip deflections were present in the fluid-structure interaction. From a fluidmechanical perspective, simulation shows negligible influence on the boundary layer flow by the geometrical sensor presence.

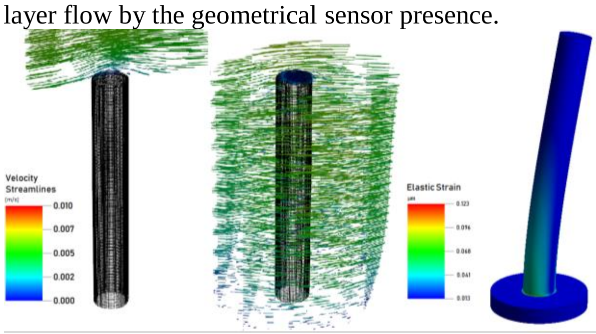


**Figure 1** Fluid-structure interaction results of the MPS: Numerical velocity streamlines (left) and sensor strain (right)

## Discussion

The presented sacrificial molding technique with usage of photolithography is a rather new method in Micro Pillar manufacture. It provides high aspect ratio microstructures with highly reproducible geometries. Due to their cylindrical shapes, sensor behavior shows great agreement with the theoretical model. In addition, the simulation demonstrates that the MPS is applicable for laminar flow conditions in biofluid mechanics as it provides local and vectorial WSS data.

## References


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