SUB-0.05° PRECISION OPTOFLUIDIC DUAL-AXIS INCLINOMETER

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INTRODUCTION

We present a low-power bi-axial miniaturized inclinometer based on a mobile mass (spherical ball or fluidic droplet) positioned on a precision curved surface that is generated using a novel MEMS process. The detection of the mobile mass was implemented through an external optical system, using a quadrant photodetector. Nanotopography and chemical treatment of the curved surface have been implemented to increase accuracy when using a fluidic mobile mass, by tailoring wetting properties and minimizing contact angle hysteresis. We achieve a range of ±1° with a true linear bi-axial measurement of precision better than 0.05° .

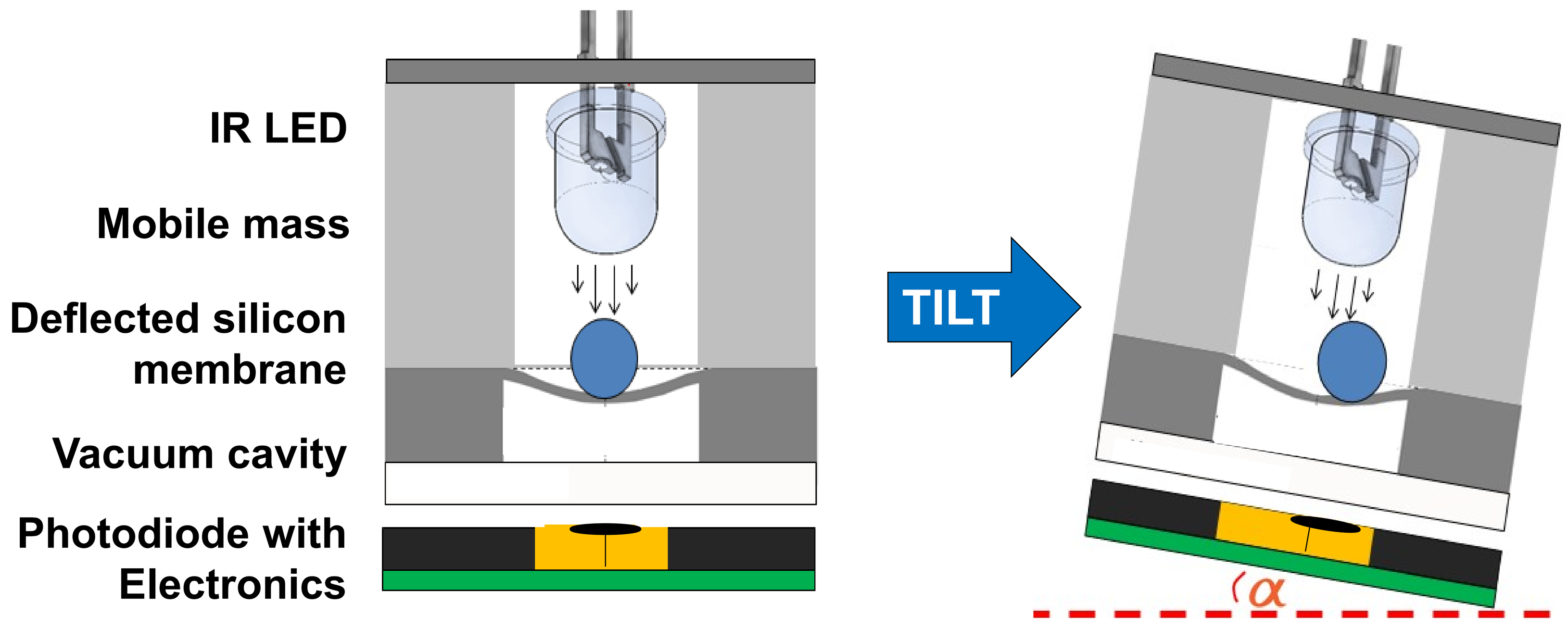

Figure 1: Schematic view of our inclinometer respectively in a non-tilted (left) and tilted state (right).

FABRICATION AND EXPERIMENTAL SETUP

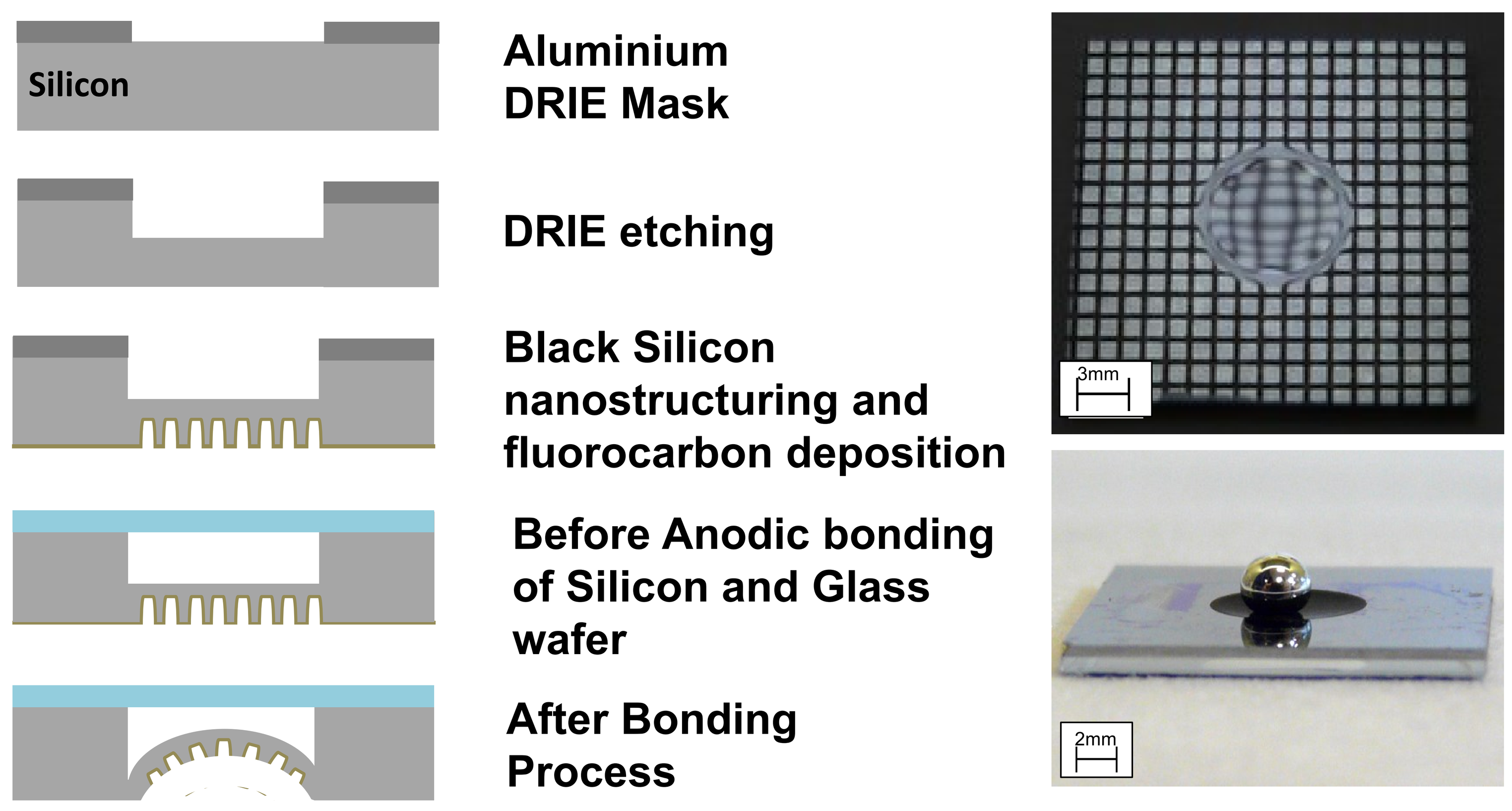

Figure 2: Left: Fabrication process of the nanostructured and chemically treated curved silicon membrane. Top Inset: Reflection of square grid seen in deflected unstructured membrane. Bottom Inset: Mercury droplet on Black Silicon membrane with fluoropolymer thin film.

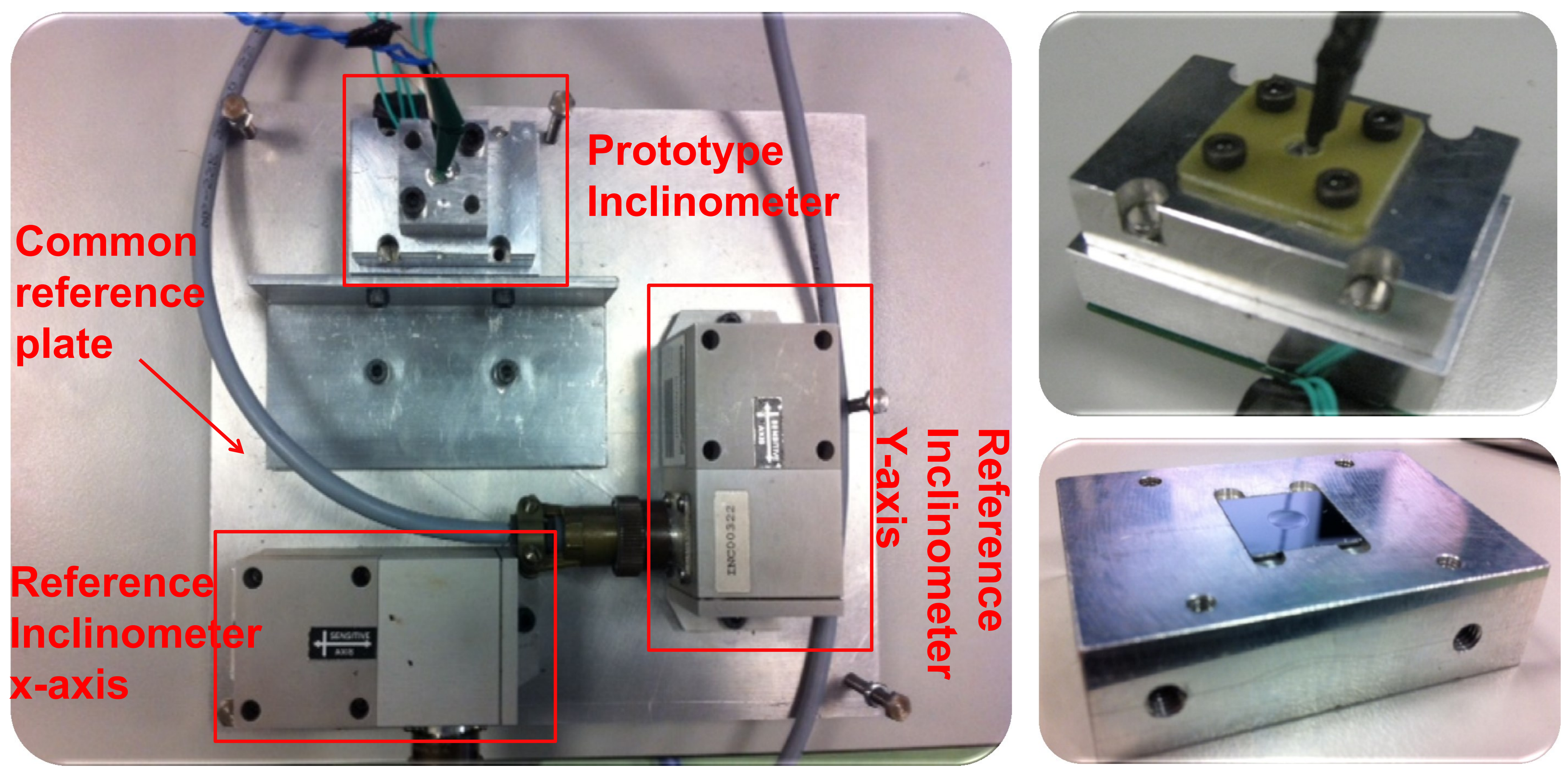

Figure 3: Left: Experimental set-up for inclinometer characterization. Top Inset: Picture of the complete prototype (5.5cm × 4cm × 3.5cm). Bottom Inset: Membrane holder.

RESULTS

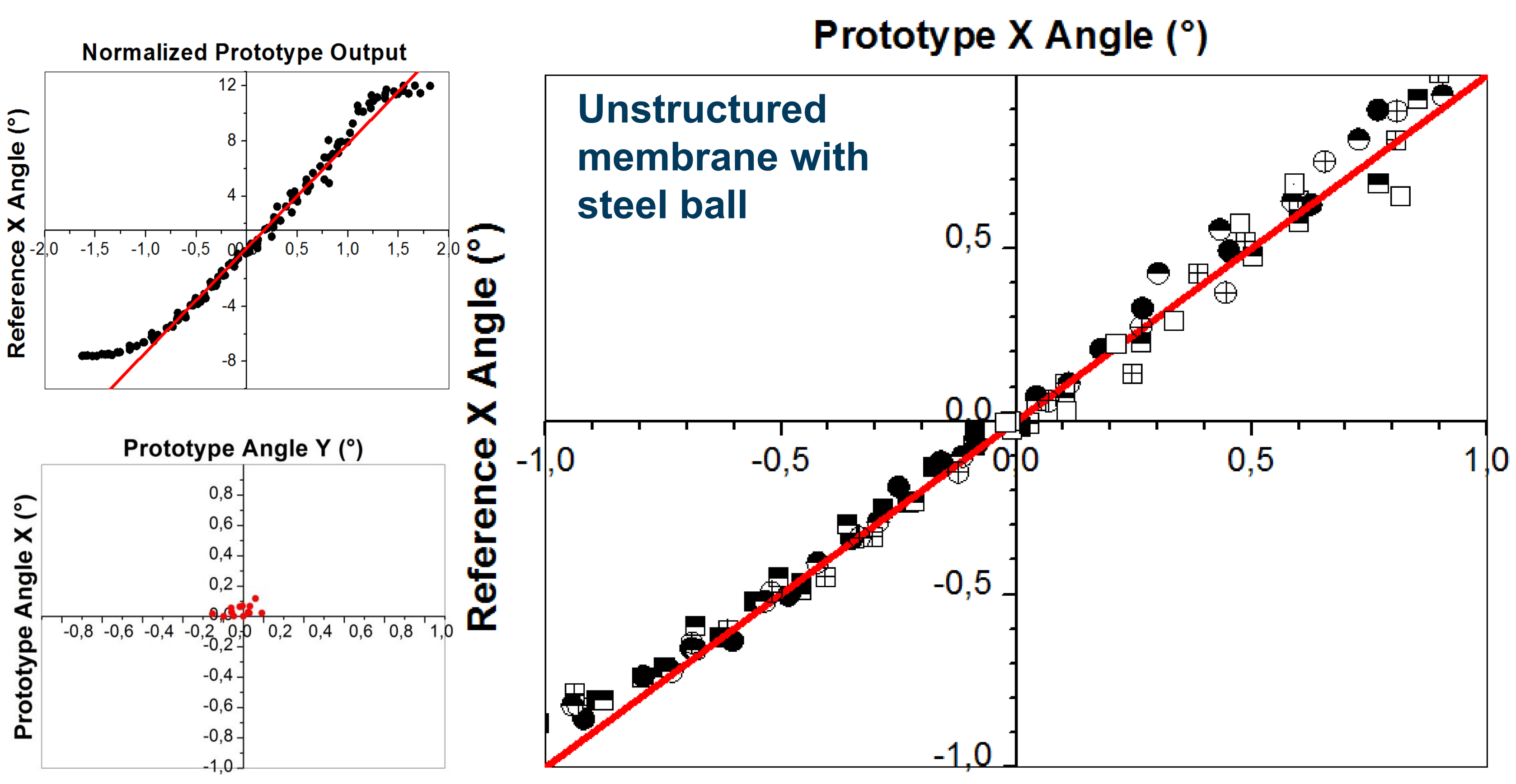

Figure 4: Experimental results of the unstructured membrane. Main graph: Plot showing good correlation between prototype and reference inclinometer measurements over the ±1° linear range. No sign of hysteresis (ascending sweeps with circles, descending with rectangles). Top left Inset: Normalized output of the prototype. Flattening outside the linear range is due to mobile mass shadow leaving center of quadrant detector. Linear fit to obtain calibration coefficient of 7,6/° . Bottom left Inset: Repeatability test following large angle tilt (>10°) showing standard deviation: y=0,033° , x=0,063°

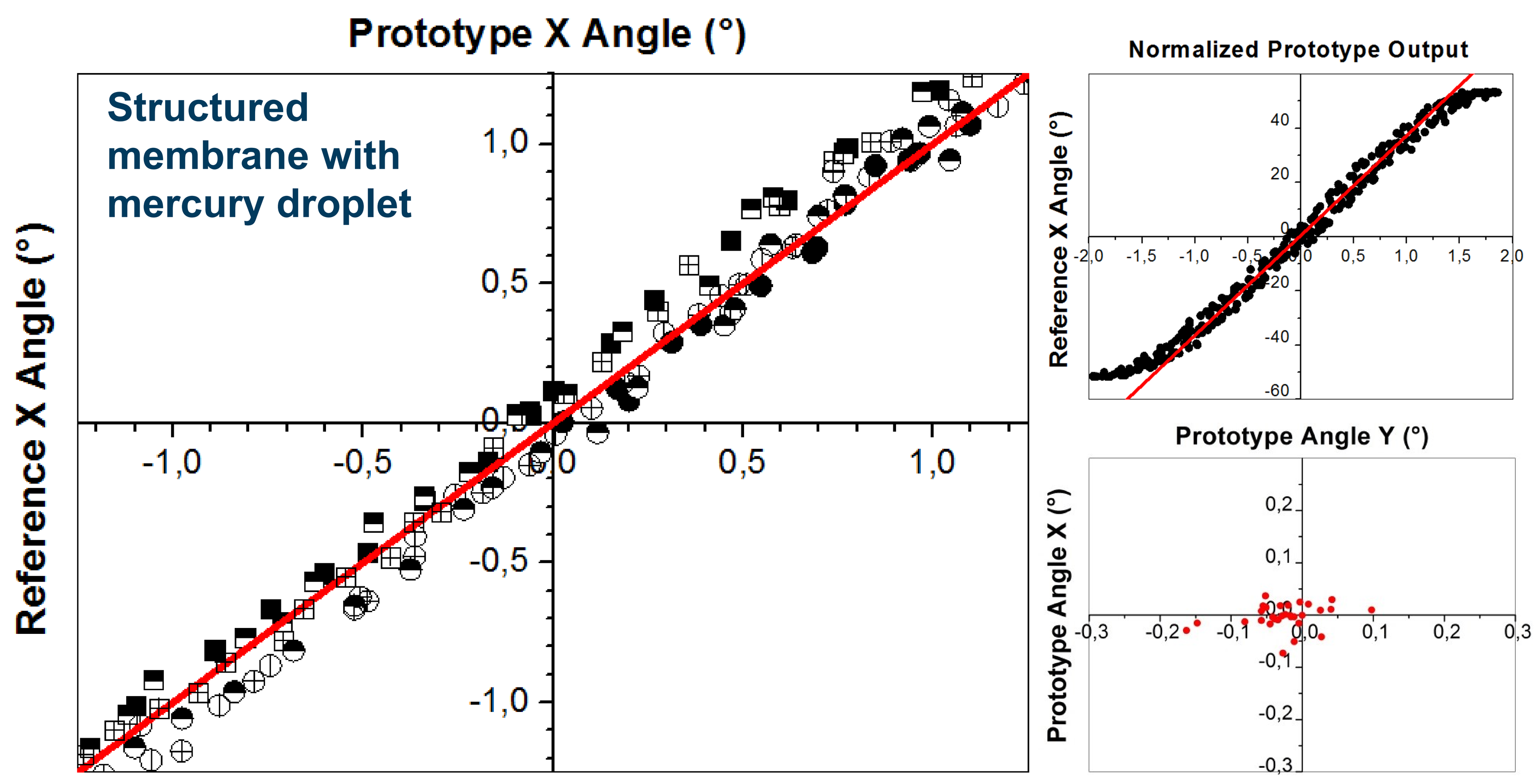

Figure 5: Experimental results of the structured membrane. Main graph: Plot showing significant hysteresis effects of prototype inclinometer measurements over the ±1° linear range (ascending sweeps with circles, descending with rectangles). Top right Inset: Full range normalized prototype output in x-direction. Linear fit to obtain calibration coefficient of 36,8/° . Bottom right Inset: Repeatability test following large angle tilt (>10°) showing standard deviation: y=0,024° , x =0,051°

CONCLUSION

- Low-power bi-axial miniaturized inclinometer displaying linear behavior over a large part of the measurement range, which can be tuned by adapting the membrane diameter and thickness (by controlling etch time, or using a high-precision SOI substrate).
- The use of high precision balls showed sub-0.05° precision levels, the errors being due to mobile mass surface roughness and sphericity errors.
- Using a fluidic droplet as mobile mass resulted in even better precision, but introduced hysteresis in the system.
- Since the membrane deflection is influenced by pressure an external pressure sensor is needed for accurate operation.
- Future work will aim at developing (1) an optical sensor combining both high precision and low hysteresis and (2) a sensor with electrical detection system.