Design and optimization of a 3-DOF planar MEMS Stage with integrated thermal position sensors

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Abstract

This work presents the design and optimization of a large stroke planar positioning stage in a single-mask MEMS fabrication process. Electrostatic comb-drive actuators were used to control the position and rotation of the 3-DOF stage. Thermal displacement sensors are integrated to provide feedback. Simulations show that we are able to reach a +/-120µm range of motion and +/-30 degrees of rotation. Preliminary measurements were performed which validated our models.

1 Introduction

MEMS positioning stages can be used in a variety of applications, such as micro-mirror manipulation, scanning probe microscopy and probe based data storage. Existing multi-DOF (Degree-Of-Freedom) stages often lack integrated position sensing [1], use complicated fabrication schemes and assembly [2, 3], or offer relatively small stroke [4]. The latter uses thermal actuators which is unfavourable for fast and accurate positioning. In this work we describe the design, optimization, and fabrication of a large stroke planar positioning stage with integrated displacement sensors for feedback control in a simple, single-mask fabrication process.

2 System design

The system consists of a 3-DOF stage that is connected with three single-DOF shuttles using leaf springs. An overview of one of the shuttles and the eccentric connection to the stage is given in Figure 1 and Figure 3. The single-DOF shuttles are actuated by electrostatic comb-drive actuators [5]. The electrostatic field of the comb-drive actuators give rise to a negative lateral stiffness, which can lead to instability (pull-in) if the lateral mechanical stiffness of the flexure mechanism is not sufficient.

The flexible multibody analysis software SPACAR [6] was used to numerically analyse the mechanical stiffness of the shuttles in actuation and lateral direction as a function of the displacement. The data from SPACAR is used to calculate if pull-in occurs for any stage position and rotation. In this way the work space of the 3-DOF stage is determined.

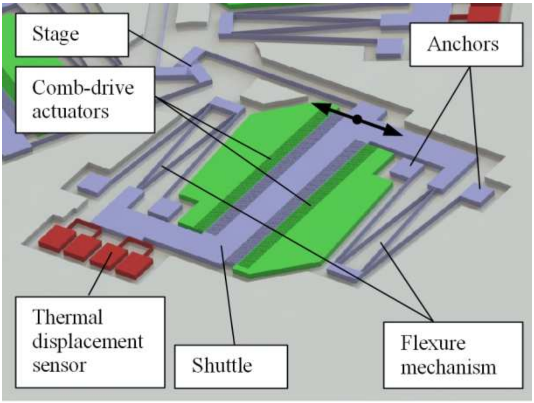

Figure 1: The figure gives an overview of one of the single-DOF shuttles together with the connection to the stage. The arrow indicates the DOF of the shuttle.

For feedback control of the stage, thermal displacement sensors are integrated in the design [7]. The temperature of the heaters changes due to a varying overlap with the 'cold' shuttle. The resulting change in electrical resistance was measured and results in a position resolution of 4nm at a bandwidth of 30Hz. To control the stage position using the displacement sensors on the shuttles, a geometric transfer function (mapping) between the shuttle positions and the stage position and orientation was developed. Simulations showed that with a double integrator control scheme (PII) we are able to control the position of the stage with an accuracy of 22nm and 0.17mrad.

3 Optimization

The work space of the 3-DOF stage is restricted by pull-in of the single-DOF shuttles in push as well as pull direction. This results in a hexagonal work space, which is given for several rotations in Figure 2 (left). The size of the stage (eccentricity), the length of the leaf springs towards the stage, and the point of attachment of the leaf springs to the stage and shuttles are varied to optimize the range of motion of the stage (the largest circle in the hexagonal work space). A stage eccentricity of 110µm leads to a maximum range of motion at zero rotation of +/-120µm, as can be seen in Figure 2 (right). For a rotation of 10° the range of motion decreases to +/-75µm.

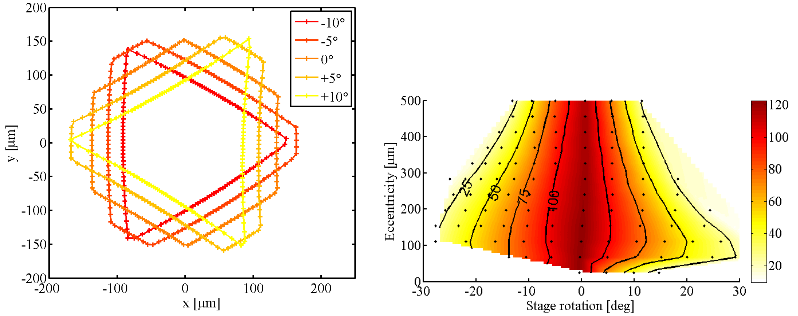

Figure 2: The work space of the 3-DOF stage is restricted by pull-in of the single-DOF shuttles in push as well as pull direction. This results in a hexagonal work space (left). The range of motion in micrometers is a function of the stage eccentricity and has an optimum of +/-120µm at zero rotation (right).

3 Fabrication and results

The complete system was designed to be integrated in a standard fabrication process based on a silicon-on-insulator wafer. Deep Reactive-Ion Etching (DRIE) is used to anisotropically etch high aspect ratio trenches. Thin structures are released from the handle wafer by isotropic VHF etching of the buried oxide layer, while wide structures stay anchored.

In spite of stiction in most of the fabricated devices, a number of measurements could be performed to validate our models. The voltage that leads to pull-in was measured for several stage designs and indicated that our model is correct within 10% with respect to the simulated pull-in voltages.

4 Conclusion

A 3-DOF planar MEMS positioning stage with integrated position sensors was designed and fabricated in a single-mask fabrication process (Figure 3). The stage is able to reach a +/-120µm range of motion and +/-30 degrees of rotation.

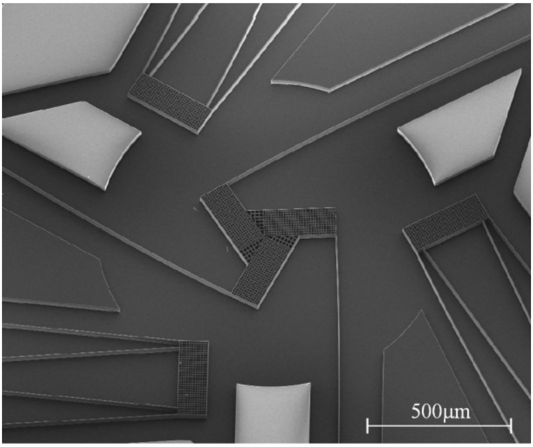

Figure 3: The figure shows a scanning electron microscope image of a fabricated 3-DOF stage together with the eccentric connection towards the three shuttles. Parts of the flexure mechanisms of the single-DOF shuttles are also visible.

References

[1] D. Mukhopadhyay, et al. A SOI-MEMS-based 3-DOF planar parallel-kinematics nanopositioning stage. *Sensors and Actuators A*, 174(1):340–351, 2008.

[2] L. Sun, et al. A silicon integrated micro nano-positioning XY-stage for nano-manipulation. *J. of Micromechanics and Microengineering*, 18(12):125004, 2008.

[3] E. Eleftheriou, et al. Millipede—A MEMS-Based Scanning-Probe Data-Storage System. *IEEE Transactions on Magnetics*, 39(2):938-945, 2003.

[4] L.L. Chu and Y.B. Gianchandani. A micromachined 2D positioner with electrothermal actuation and sub-nanometer capacitive sensing. *J. of Micromechanics and Microengineering*, 13(2):279-285, 2003

[5] R. Legtenberg, et al. Comb-drive actuators for large displacements. *J. of Micromechanics and Microengineering*, 6(3):320-329, 1996.

[6] J.B. Jonker and J.P. Meijaard. SPACAR - Computer Program for Dynamic Analysis of Flexible Spatial Mechanisms and Manipulators. In W. Schiehlen, editor, *Multibody Systems Handbook*, pages 123–143. Springer, 1990.

[7] B. Krijnen, et al. A single-mask thermal displacement sensor in mems. *J. of Micromechanics and Microengineering*, 21(7):074007, 2011.