A Novel Microactuator Based on the Working Principle of a Step-by-Step Switchgear

B. Schröter[1], J. Mehner[2], K. Hiller[1], T. Geßner[1,2], W. Dötzel[1]
[1] Chemnitz University of Technology
[2] Fraunhofer IZM

1 Introduction

Switchgears are to be found in many classical applications, e.g. mechanical clockworks, film projectors or typewriters. They are able to start up predefined positions and hold them subsequently [1,2]. A microstructure has been developed that works alike.

There is plenty of examples where scaling down established operational principles has led to successful micromechanical applications [3]. Various sensors like accelerometers [4], pressure gauges [5], gyroscopes [6] or vibration sensors [7] have been realised. Actuation principles are subject to miniaturisation, as well. Micromirrors for laser scanning devices [8] or mirror arrays for highly sophisticated optical applications [9, 10] have been previously demonstrated.

The micromechanical switchgear described in this paper makes use of single-crystal silicon, the most important material in semiconductor technology, as structural material. Due to the development of microelectronics, hyperpure silicon of crystalline perfection is available and can in many ways be structured by etching techniques. In addition to its excellent electrical properties, this material has very good mechanical properties [11]. Single-crystal silicon has a comparatively high strength. In a wide range it exhibits linearly elastic behaviour and does hardly exhibit hysteresis and fatigue effects, which enables the manufacture of springs with very well reproducible force-displacement characteristics. The elastic constants exhibit a relatively low temperature dependence. Compared to other materials, silicon has a low thermal expansion, is corrosion-resistant and can also be used at high temperatures. No ageing of any kind is observed.

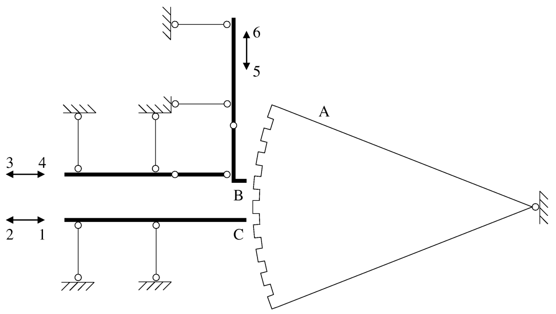

Fig. 1: Working principle, A: Toothed segment, B, C: shift dogs, 1...6 stops

2 Working principle

Figure 1 is a schematic drawing of the microstructure presented in this work. A toothed segment (A) performs a pivoting motion within the wafer plane. For this purpose the lower shift dog (C) can be engaged with the teeth by means of a straight-line infeed movement. In addition to this, the upper shift dog (B) can be deflected upwards and downwards by half a cycle size, i.e. 5µm. Advancing to the next position by one tooth is effected in six individual steps, at least one of the shift dogs having to be engaged in each case in order to keep the current position. Stops limit the travels. That way, no position control is needed. The activation takes place by means of a logical circuit, which drives the individual electrodes via driver transistors.

3 Design

The radius of the toothed segment of approximately 1.9 mm, results from the designing guidelines that a make-and-break cycle has to correspond to a length of arc of 10µm and an angle of 0.3 degrees. Thus an overall-angle of 15deg. can be passed through in fifty cycles. The electrostatic drives have been dimensioned for an operating voltage of 50 V. The thickness of the upper wafer (see fig. 4) and thus freely movable structures amounts to 50µm. The individual electrodes are insulated from each other by separation trenches and thermal oxide situated below them.

All hinges, drawn as circles in fig. 1, are local compliances. They have been designed to a length of 25µm and a width of 3µm. Flexible hinges have been chosen, because rigid bodies in solid pairing (sliding or rolling pairing with friction and wear) are restricted in their use in micromechanics [12]. That way, the entire structure becomes monolithic and no assembly is required. This avoids handling problems and there are no adjustment errors or manufacturing tolerances that keep the device from functioning correctly.

The drives make use of the electrostatic force. Fig. 2 shows this with respect to the displacement of shift dog B in direction 5 (or 6, symmetry, see fig. 1). The restoring force produced by the hinges implemented as leaf springs is a linear function of the displacement and tends to pull back to neutral position. Both forces sum up to the resulting force that causes the toothed segment to move on by one step.

Fig. 3 is a light micrograph of the microstructure which has been made. The pivotally mounted toothed segment and parts of the electrostatic drives are to be seen. The individual trapeziform teeth are shown in Fig. 4, which is a SEM micrograph.

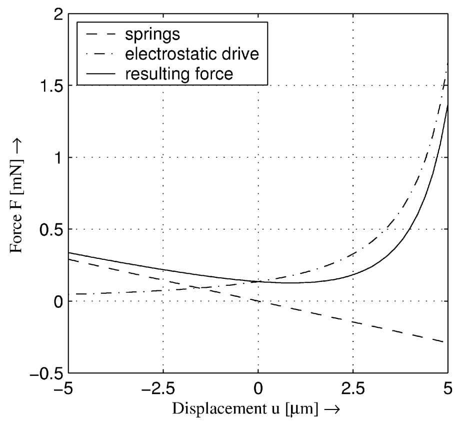

Fig. 2: Force vs. Displacement plot

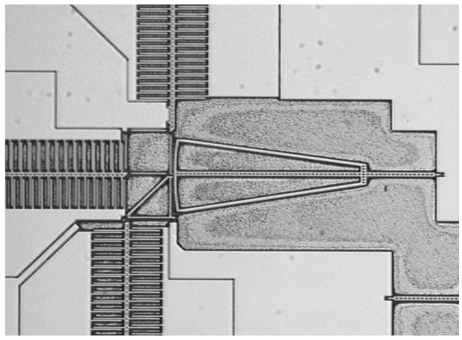

Fig. 3: *Light micrograph of the microactuator, the toothed segment is 1.9mm long*

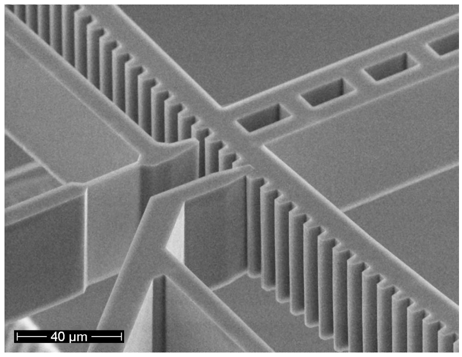

Fig. 4: *Close-up SEM micrograph of the teeth and shift dogs, the lower shift dog is engaged*

4 Measurements

For dynamic measurements a setup according to figure 6 is used. The specimen is sitting under a microscope (1) which is coupled via an optical fibre (3) to a laser-doppler interferometer (4). Its output signal is observed on a digital sampling oscilloscope (5) or a spectrum analyzer, respectively, depending on the desired information. If necessary, the data is transferred to a computer (6) for further calculations. A beam splitter (2) passes the picture through to a CCD camera (7) so the experiments can be observed on a video monitor (8).

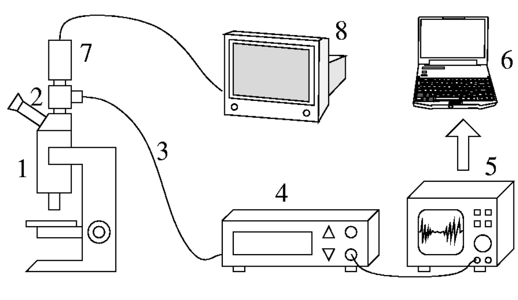

Fig. 6: Setup for dynamic characterization

5 Results

The geometrical measurements revealed, that the structures are on the top side about 0.4µm wider than on the bottom. The DRIE process had been adjusted to yield to such a profile rather than the trenches close with increasing depth. Thus, the vertical walls are slightly undercut with an angle of 0.2 degrees. This assures that no clamping between shift dogs and teeth occurs.

Fig. 7 shows the displacement vs. time characteristics of a forward step obtained with the setup drawn in fig. 6. Shift dog B is engaged with the toothed segment A. Drive 6 is switched off as drive 5 is activated. After a short time of about 14µs drive 6 has been discharged and parts B and A start to move towards stop 5. After another 50µs the end position is reached. Due to the large holding force (see fig. 2), hardly any chattering occurs.

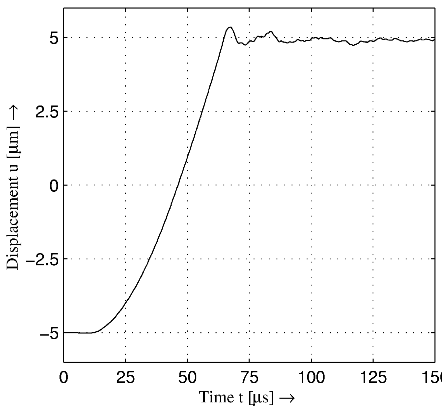

Fig. 7: *Displacement vs. Time plot*

Operating all drives according to table 1, switching frequencies of up to one Kilohertz have been reached.

6 Conclusion

We succeeded in scaling down the operating principle of a step-by-step switchgear as it is known from precision engineering to micromechanical dimensions, adapting it to micro techniques and proving its functionality. High working frequencies could be reached because of the small moving masses. The introduced microstructure represents a new class of microactuators.

7 References

[1] Richter, O.; von Voß, R.; Kozer, F.: Bauelemente der Feinmechanik. 8th Ed., VEB Verlag Technik, Berlin, 1958

[2] Ringhand H.; Wirth, Ch.: Feinwerkelemente. Carl Hanser Verlag, München, Wien, 1992

[3] G. Gerlach, W. Dötzel: Grundlagen der Mikrosystemtechnik, Carl Hanser Verlag, München, 1997

[4] Doscher, J.: ADXL105: A Lower Noise, Wider Bandwidth Accelerometer Rivals Performance of More Expensive Sensors, Analog Dialogue 33-6, 1999

[5] Sander C. S.; et al.: A Monolithic Capacitive Pressure Sensor With Pulse-Period Output. IEEE Transactions on Electron Devices, vol. ED-27, no. 5, may 1980, pp. 927-930

[6] Hiller, K.; Geßner, T.; et al.: A new bulk micromachined gyroscope with vibration enhancement by coupled resonators. in Micro System Technologies 98 by H. Reichl, E. Obermeier VDE-Verlag GmbH, Berlin, p.115-120

[7] Scheibner, D.; Mehner, J.; Reuter, D.; Gessner, T.; Dötzel, W.: Tunable Resonators with Electrostatic Self Test Functionality for Frequency Selective Vibration Measure-ments, Proceedings MEMS 2003, p.526-529, Kyoto, 2003, ISBN 0-7803-7744-3

[8] Gessner, T.; Kurth, S.; Kaufmann, C.; Markert. J.; Dötzel, W.: Micromirrors and micromirror arrays for scanning applications. Proc. SPIE 4178 pp. 338-347

[9] Hanf, M.; Kurth, S.; Billep, D.; Hahn, R.; Faust, W.; Heinz, S.; Dötzel, W.; Gessner, T.: Application of micro mirror arrays for Hadamard transform optics. 9^{th} Int. Symp. on Microwave and Optical Technology (ISMOT2003), Ostrava, Czech Republic 2003

[10] Hornbeck, L. J.: The DMD(TM) Projection Display Chip: A MEMS Based Technology. MRS Bulletin 4/2001, pp. 325-327

[11] K. Petersen: Silicon as a Mechanical Material, in Microsensors by R. S. Muller, IEEE Press, New York, 1990

[12] De Boer, M.P. and Mayer, T.M..: Tribology of MEMS. MRS Bulletin, April 2001