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Contact position microsensors with travel ranges between 50µm and 2mm

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Abstract

Thorough investigation of the research done in the field of commercially available precise linear position sensors has revealed a certain gap in the travel range of 10µm to 2mm. In order to expand the scope of previous work on MEMS with sidewall embedded piezoresistors, this paper presents several contact mode position sensors within the same travel range.

One goal of the current paper is to demonstrate the applicability and advantages of MEMS with embedded flexures and sidewall piezoresistors for precise position monitoring. Another goal is to optimize the sensor signals providing a trade-off between various parameters such as: sensitivity, linearity, travel range, and resonance frequency/bandwidth of the devices. Since those sensors might have various applications, in this paper some experimental results from seven sensors having different travel ranges and dynamic characteristics are reported. Particularly, the experimentally measured sensitivities in the range between 50µV/µm and 5mV/µm @1VDC power supply are presented. Also, raw sensor signals with magnitudes of 10% to 28% of the power supply voltage have been observed.

Keywords: MEMS sensors, sidewall piezoresistors; monolithic flexures; position sensors.

1. Introduction

It is known from the practice that the position of any object is a dynamic value and depends simultaneously on multiple factors, thus challenging its accurate measurement. Especially, it is problematic to achieve accurate position monitoring in non-lab/industrial environment. In any case, the challenges strongly depend on the chosen method and the range of the measurement. Although, there is a growing demand for position data when vast variety of objects in rather diverse ranges and conditions, are monitored [1]. Between the available sensors, contact and non-contact ones should be mentioned, at least. Particularly, there is a need of position sensors with overlapping travel ranges to be developed. The devices studied in present paper are monolithic contact position sensors, made of

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single crystal silicon, that possess travel ranges between 50µm and 2mm. For the purpose, sensors with different layouts have been designed and the influence of various parameters have been considered and analyzed. Despite, it has been experimentally found, that due to the imperfections of the prototyping technology, some of the geometrical dimensions vary and thus, characteristics of the prototypes did not completely match with the predicted values.

Also, a critical reconsideration of previously reported data demonstrating that these devices could provide more that 100,000 measuring intervals [2], yielded the need to demonstrate applicability of the sensors in the above mentioned travel ranges at non-lab (industrial) conditions, incl. providing options for cross-range calibration. Another important aspect, arose at reconsideration and generalization of previously reported results with sub-nm resolution [3], and led to a confusing conclusion. As far as, position and displacement are vector values it is not realistic to assign the mentioned sub-nm resolution directly to the accuracy, if a single scalar value has been measured. Since the results of present study have been obtained by characterization of various in layout 1D sensors, they are related to the sensitivity and resolution of the sensors, but not to the accuracy. More generally, authors consider non-realistic to claim *accuracy* with more than 100,000 measuring intervals, if a single scalar value instead of genuine three, has been monitored.

2. In-plane moveable flexures with sidewall piezoresistors

Previously reported characterization data of MEMS sensors [2,3] with sidewall embedded piezoresistors have demonstrated the immunity to problems with loose move and backlash in the embedded flexures. Sensors are monolithic devices comprising two rigid parts – an anchored and a moveable one, and both parts are connected by means of supports and flexures, made of a 15µm membrane. At monitoring first, one of the above mentioned rigid parts is fixed to an anchored body and the other part is firmly fixed to the object to be monitored. Then the connecting supports are detached, thus the relative movement of the both parts is transduced to detecting cantilevers, provided with sidewall piezoresistors. As a result, the output sensor signal is correlated with the move stimulus. By a modification of the layouts of the embedded flexures, different transducing characteristics are attained. Respectively, the performance of the sensors can be optimized to the specific application by a modification of the flexure's layout. Consequently, the results achieved in present study of MEMS sensors with sidewall piezoresistors provide the opportunity to enlarge the targeted applications [2-4]. It should be highlighted that, despite the sensor signal is generated due to the strain in the sidewall piezoresistors, the considered sensors directly measure the position or displacement of the attached objects, due to the availability of the above mentioned embedded flexures.

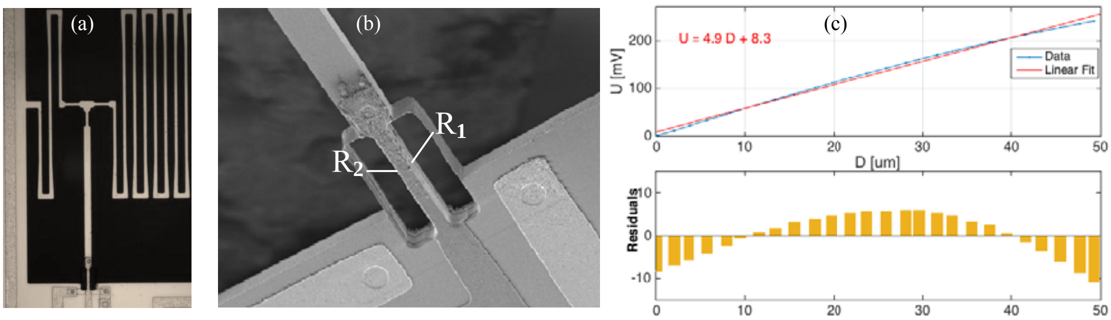


Fig. 1: (a) - Photo of an in-plane moveable cantilever with sidewall piezoresistors and a part of the flexure; (b) - SEM micrographs of the area of two sidewall piezoresistors and Al terminals; (c) – Sensor characteristic of the sensor having 50 µm travel range

All different in layout MEMS sensors comprise flexures, consisting of two in-plane movable cantilevers used for displacement detection, as the one shown in Fig. 1(a). Each in-plane moveable cantilever further comprises two piezoresistors R_1 and R_2, as illustrated in Fig. 1(b). Both piezoresistors are serially connected in a voltage divider and both voltage dividers are connected in a full bridge configuration. Thus, four sidewall piezoresistors contribute to the generated sensor signal, being proportional also to the supply voltage. As a result, sensor signals having magnitude of more that 20% of the supplied voltage have been recorded. This feature in combination with low noise level [5] provides the observed high resolution and sensitivity of the position sensors.

As an example, sensor characteristic of the 50µm travel range device is shown in Fig. 1(c). The experimental data are linearly fit and the residuals are also plotted in order to present the deviation from the linear model of the particular sensor. As a global measure for the sensors' nonlinearity the normalized norm of the residuals is chosen. It is defined by the ratio of the average residuals norm and the voltage at maximum displacement of the sensor. This device is characterized with high mechanical stiffness, resonance frequency of above 15 kHz and highest sensitivity of 4.9mV/µm @1VDC power supply. Raw output sensor signal of above 24% of the supply voltage value has been recorded. The device has no additional flexure elements and it suffers of relatively high non-linearity of the signal.

The single crystal silicon flexures are flexible but brittle – despite they are robust and don't reveal any fatigue at moves below the threshold, once the threshold displacement is reached, flexures are ruptured. Additionally, all experimental results have been obtained in tensile displacement mode. Due to the buckling of the flexures, compression mode is not suggested for present devices.

3. Experimental results

3.1. Different design approaches

There are two main types of 1D position sensor studied in the present work – both types are distinguished by the orientation of the detecting cantilevers with respect to the movement direction. As it might be seen from the upcoming examples, the detecting cantilevers can be oriented either along the direction of movement or in the transversal direction. Both approaches have been exploited in the designed prototypes.

At design optimization, the criterion of achieving maximal output voltage of the raw signal @ 1VDC for each targeted travel range has been chosen. Thus, the displacement conditions at flexure's rupture terminate both targeted parameters – the travel range and the maximal value of the sensor signal.

3.2. Sensitivity measurements

In the course of present study six other prototypes have been characterized and results are plotted in Fig. 2 (a)-(f) and reported in Table 1. Both above mentioned options for orientation of detecting cantilevers have been exploited.

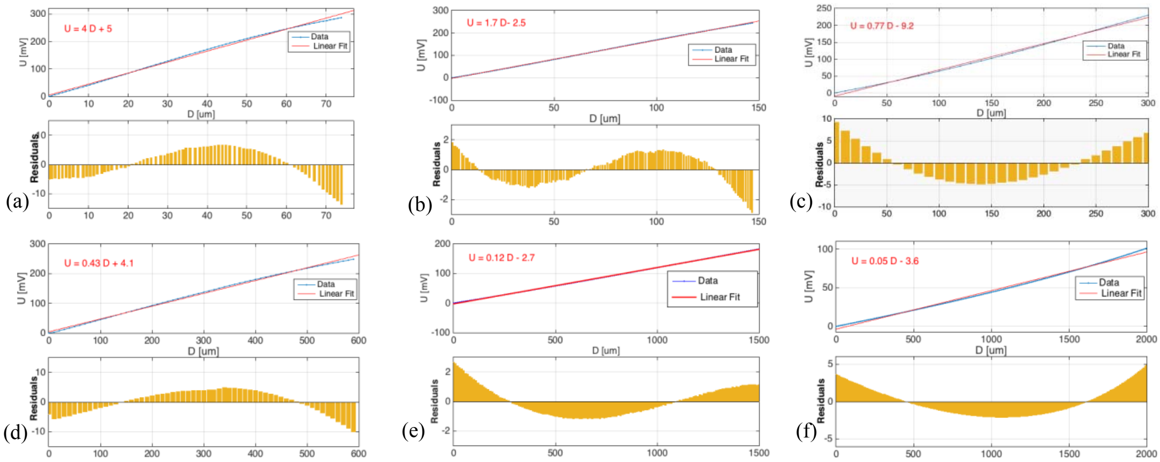
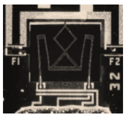
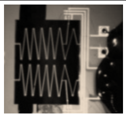
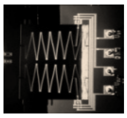
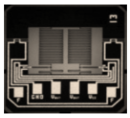


Fig. 2: Sensor characteristics of position sensors at travel ranges of: (a) - 75µm, (b) - 140µm, (c) - 300µm, (d) - 600µm, (e) - 1.5mm, (f) – 2 mm.

Particularly, for monitoring at travel range of less than 200µm, sensors comprising flexures with modified reed mechanisms are preferred. The both sensing cantilevers are oriented in the direction of the movement and they are bended in transversal direction. As an example, the sensor characteristic of a device with a modified flexure allowing travel range of 150 µm is shown in Fig. 2(b). A record high magnitude of the full range sensor signal, being a 28% of the supply voltage, has been observed. Another group of devices, exploiting two transversally oriented detecting cantilevers and differential springs, have been used for position monitoring in the range between

200μm and 2mm. The value of the sensor's output signal at full range varies between 10% and 25% of the supply voltage. As an example, the sensor characteristic of a device attained a maximal travel range of 2mm is illustrated in Fig. 2(f). This device has shown a lower sensitivity of 50μV/μm @1VDC. Rest of the devices has shown parameters' values between the above mentioned extremes and they suited various specific applications. For example, another device of the same group, having a travel range of 600μm and resonance frequency of about 4kHz has been successfully used [4] as close loop feedback in the 300Hz AFM scanner.

Table 1. Parameters of 1D position sensors' vs. layout of the transducing flexure

Sensors' parameter vs. layout							
Travel range, μm	50	70	150	300	600	1500	2000
Sensitivity@1VDC, μV/μm	4800	4000	1600	770	430	120	50
Max sensor signal @ 1VDC	240	280	245	240	250	180	100
Normalized norm of residuals, %	0.42	0.21	0.03	0.32	0.20	0.04	0.14

As a result, it has been demonstrated that parameters of the sensors for 1D position monitoring can be varied in very wide range – like the travel range from 50μm to 2mm, providing optimized performance in specific applications. Next research will be targeted on development of formalized design rules of the flexures that optimally fit a particular parameter to any specific application.

4. Conclusions

Contact linear position MEMS sensors having piezoresistors built-in into the sidewalls of flexures, have been prototyped and characterized. The experimentally measured parameters proved the concept to fit specifications for displacement monitoring between 50μm and 2mm, by tuning the flexure layout. Additionally, the presented results confirmed the viability of MEMS with sidewall piezoresistors, to attain variety of position monitoring applications.

Next serious challenge of the research was to distinguish the contributions of the sensors and measuring set-up to the observed characteristics. Most of the exploited set-ups revealed embedded non-linearity and hysteresis despite they have been calibrated by manufacturers in advance. This problem was not resolved during the present study and will be aimed in the future research. Despite that, the developed contact position MEMS sensors with sidewall piezoresistors are promising candidate for high precision tool for linear position monitoring.

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