PUBLICATION I

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In: Physica Scripta 2004. Vol. T114, pp. 193–194.
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Physica Scripta. Vol. T114, 193–194, 2004

Stability of Electrostatic Actuation of MEMS

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Received August 28, 2003; accepted October 2, 2003

PACS Ref: 85.85+

Abstract

The increased electrostatic stability of MEMS sensors enables new application areas for the sensors, and decreases the manufacturing costs of existing products. Especially in the applications where the MEMS component is operated under bias voltage close to the pull-in point, the undesired instability phenomenon becomes a major source of inaccuracy. We demonstrate that biasing the sensor to the pull-in point using AC voltage is significantly more stable than the conventionally used DC voltage biasing.

1. Introduction

Electrostatically actuated MEMS components find many applications today in areas such as inertial sensors, pressure sensors, relays, switches, etc. A serious limitation on the use of these devices lies in electrostatic stability. For example the instability results in increased tolerance in a varactor capacitor value and uncertainty of a sensor reading. Sensors with increased stability can be utilized with reduced test procedures hence decreasing the manufacturing costs of the final product. Also new application areas are enabled for sensors with increased performance values. For example improved inertial sensors could be used for short range navigation. Stable MEMS devices can also be utilized in precision applications like DC voltage reference and AC RMS converter as presented in [1].

The stability of capacitive transducers has been studied earlier [2, 3, 4]. The instability of capacitive MEMS components originates form electrostatic surface phenomena. Thin oxides are electrically leaky and therefore the electrical field between the surface of the oxide and the underlying bulk silicon tends to vanish due to surface charging. Another source of non-ideality is due to the surface potentials of MEMS electrodes. Surface potentials are not determined solely by the work functions of the electrode materials. Adsorption, e.g., can change surface potentials by several hundreds of millivolts.

2. Theory

The electrostatic force can be modeled as $F_{el} = (1/2)(\mathrm{d}C/\mathrm{d}x)(V - V_{offset})^2$ where V_{offset} is the component CV curve asymmetry, schematically illustrated in Fig. 2. V_{offset} depends on surface potentials and charges [1]. Typically $|V_{offset}| = 5\,\mathrm{mV} \ldots 500\,\mathrm{mV}$. If the MEMS structure is biased with a DC voltage $V = V_{DC}$, much larger than $V = V_{offset}$, the (relative) uncertainty in the electrostatic force is $\Delta F_{el}/F_{el} \approx -2\Delta V_{offset}/V_{DC}$. If the actuation is achieved by using an AC voltage $V = V_{AC}(t) = \sqrt{2}V_{AC}^{rms}\sin(\omega t)$, the uncertainty is lower, $\Delta F_{el}/F_{el} \approx 2\Delta V_{offset}V_{offset}/(V_{AC}^{rms})^2$. Here we have assumed that the frequency of the AC voltage is much higher than the mechanical resonance frequency of the MEMS structure to result only in a static displacement.

3. Measurement set-up

The measurement set-up, shown in Fig. 1, uses a HP Precision LCR Meter as an accurate capacitance bridge. The component used in the experiments was a bulk-micromachined silicon transducer [5]. The effective gap was 2.2 µm and electrode area 1.4 mm^2. The non-moving electrode on top of a glass layer was coated with 150 nm thick sputtered molybdenum and the moving electrode was coated with 200 nm thick evaporated molybdenum. The component was hermetically shielded in inert gas. The variation of the capacitance between the fixed electrode and the electrode attached to the bending beam as a function of the DC bias voltage, i.e. the component CV-curve, is shown in Fig. 2. The

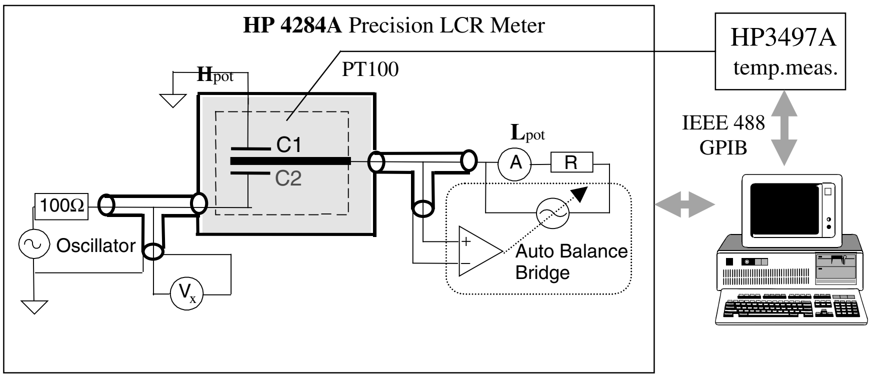

Fig. 1. Four terminal pair capacitance measurement set-up.

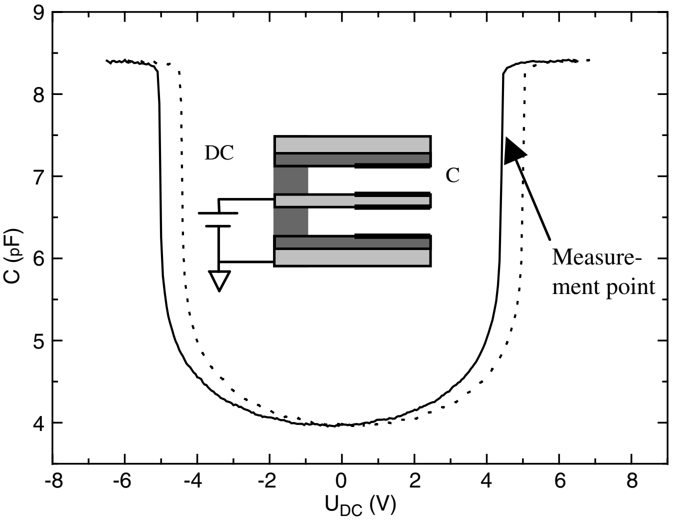

Fig. 2. Component capacitance as a function of the DC bias voltage. The offset voltage $V_{offset} = -0.29$ V. The dashed line schematically illustrates a large positive change in V_{offset} which decreased the capacitance under a constant DC bias voltage.

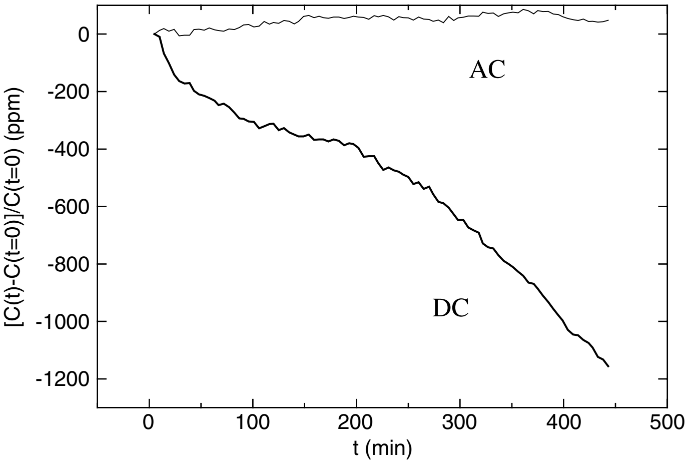

Fig. 3. Stability of the component capacitance near the pull-in voltage for DC bias voltage and AC bias voltage. The capacitance values have been normalized to the respective initials values.

component pull-in occurs at 4.3 V. The stability of the component was studied by measuring the capacitance and the capacitance derivative $\mathrm{d}C/\mathrm{d}V$ of the component as a function of time near the component pull-in point by varying the bias voltage. The pull-in voltage was generated in case (1) by a DC bias voltage, using $V = V_{DC} = 4.1$ V and $V_{AC}^{rms} = 180$ mV for the capacitance measurement, and in case (2) an AC voltage, $V_{AC}^{rms} = 4.1$ V and $V_{DC} = 0$ V. The measurement frequency was in both cases $f = 1$ MHz, i.e. well above the component mechanical resonance frequency, which was in the order of 10 kHz. The temperature of the component was maintained at $T = 23.2 \pm 2\,^{\circ}\mathrm{C}$.

4. Results

The measurement results are displayed in Fig. 3 and Fig. 4. The considerably larger drift of the capacitance when the bias voltage was generated using DC bias can be attributed to a change in the offset potential by $\Delta V_{offset} = 10$ mV. This can be concluded from the data correlating $C(t)$ and $\mathrm{d}C(t)/\mathrm{d}V$, shown in Fig. 4, which suggests that the biasing position moves away from the pull-in point due to the drift in V_{offset}, as schematically illustrated in the Fig. 2. The measured offset voltage V_{offset} change is $-[C(t = 450\,\mathrm{min}) - C(t = 0)]/[\mathrm{d}C(t)/\mathrm{d}V]_{\mathrm{ave}} = 10$ mV.

5. Conclusions

Stability of electrostatic actuation is important in several MEMS applications. Actuation using a DC voltage is prone to drifts due to surface charging and changes in surface potentials. We have show theoretically and experimentally that actuation using AC voltage is significantly more stable against electrode surface effects than actuation using DC voltage. These results have been confirmed by measurements of MEMS devices from completely different fabrication processes.

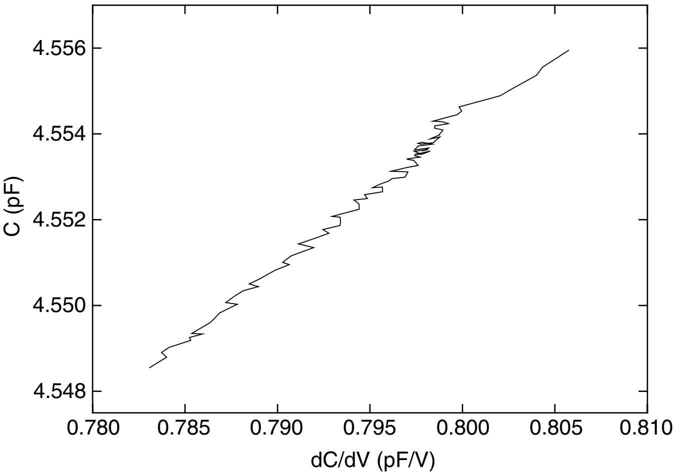

Fig. 4. Capacitance $C(t)$ as a function of $\mathrm{d}C(t)/\mathrm{d}V$, the voltage derivative of the capacitance.

Acknowledgements

This work has been carried out under EMMA project (IST-2000-28261) financed by EC and Finnish National Technology Agency Tekes.

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