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4-Terminal Lateral MEMS Silicon Relay with Nanocrystalline Graphite Contact and Polymer Insulating/Mechanical Coupler

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Abstract

The first demonstration of a single contact lateral 4-terminal MEMS relay developed using silicon as the mechanical actuator, nanocrystalline graphite coating on the contact to improve ambient environment measurements and a photoresist polymer for an insulating mechanical coupler is reported. The relays demonstrate decoupling of the control and data signals across the two beams. Control of the pull-in voltage is measured through the use of body beam biasing.

1. Introduction

Micro-electro-mechanical (MEM) switching relays provide benefits in logic devices over CMOS for low power and harsh environment applications. Further, MEMS/NEMS relays can be used in conjunction with CMOS to reduce power consumption and improve performance efficiency in a FPGA [1]. To realize efficient FPGAs 4-terminal (4T) relays are essential. One of the main benefits a 4T relay provides over a 3-terminal (3T) relay is a greater reduction in the operating voltages of the relay, at much higher beam bias voltages. This is achieved by isolating the device source/drain signal from the gate/body signal. Thus, the body can be biased to provide a constant electric field across the gate and body terminals, reducing the field required to be applied via gate drive, thus reducing the pull-in voltage.

2. Device Fabrication

The MEMS relay is designed to be 200 µm long and 5 µm wide dual beam silicon beam fabricated using a 2 µm thick silicon-on-insulator with a 2 µm thick buried oxide. The gate to body beam gap is 2 um and the drain to source gap is 1 um. The device is designed to use a single contact for a relay that actuates in a lateral direction. The data signal travels through the source beam and drain contact in figure 1, while the control signal is applied between the gate and body beam.

The initial photolithographic patterning of the silicon etch and nanocrystalline graphite PECVD coating follows a similar process used to fabricate the 3-terminal relays seen in [2]. The silicon layer is etched then partially suspended to leave 1 µm of buried oxide on the substrate. This is so the NCG is isolated across the tip and drain due to the air gap between the silicon and buried oxide layer. After the partial release, 100 nm of NCG is deposited at 850 °C to uniformly coat the relays. The NCG is patterned and etched to remain only on the tip to avoid leakage via the conducting NCG film on the substrate surface. The reasoning for the NCG coating on the tip is to enable hot cycling measurement in air environment up to 2.8 million cycles with an on resistance of 17 kΩ, as seen in previous work [2], [3]. This provides a robust coating to fully evaluate the change in performance of the 4T lateral relay.

The 4T relay is formed by using a 6 µm thick AZ2070 (negative) photoresist to couple the two suspended beams. This enables a mechanical coupling between the two beams while also providing electrical insulation. After patterning the resist is hard-baked at 150 °C to ensure bonding between the silicon beams. Pad contacts are then formed by deposit 20 nm Cr and 200 nm Au using lift-off patterning before release. The relays are then etched using hydrofluoric vapour phase etching to release the relays.

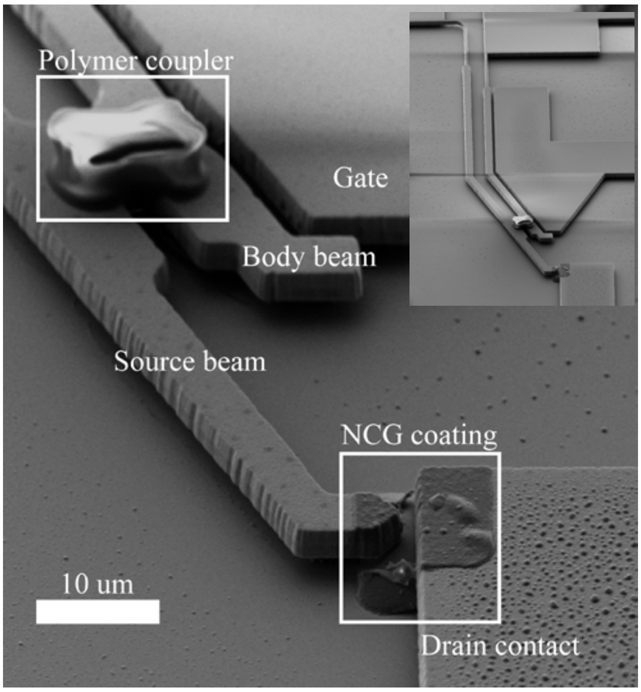

Fig. 1 Focused SEM image of the 4T lateral relay contact area. The two suspended silicon beams with a polymer coupling the two beams is visible at the top of image and is annotated to distinguish between the different parts of the relay. The NCG is visible on the tip contact of the source beam and drain contact. The inset shows the full device size with the gate electrode and hinges of the relay now visible.

3. Pull-in voltage modulation

Characterization of the 4T relay is performed by measuring the IV characteristics of the device with an Agilent B1500A. The gate voltage is swept from 0 to 50 V while different voltages are applied to the body beam, which range

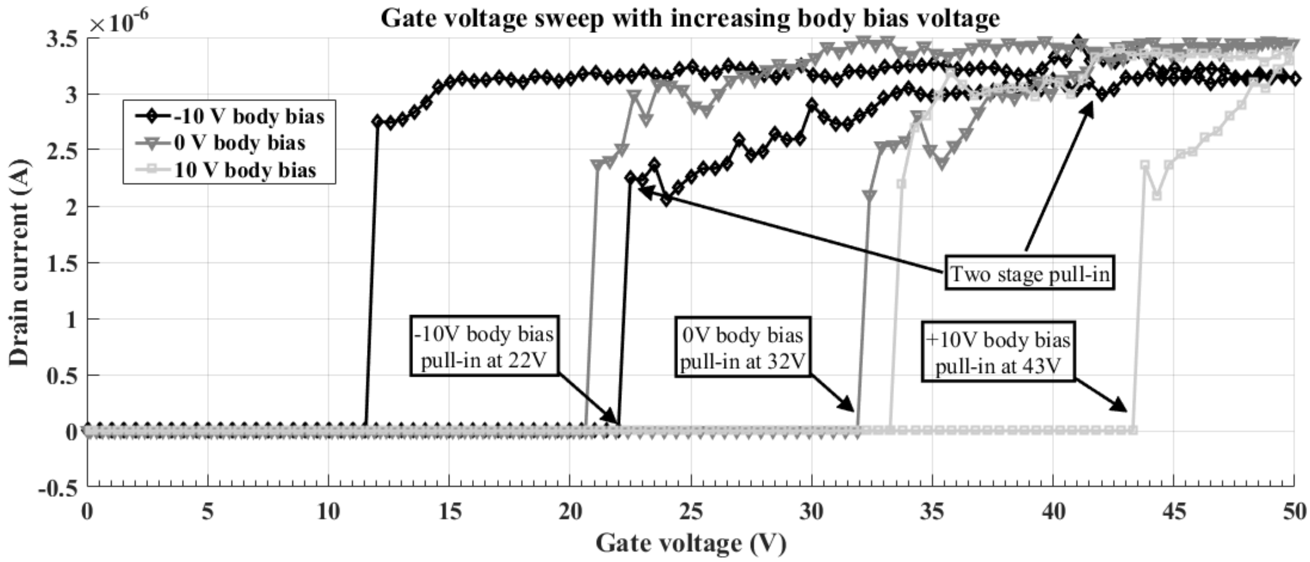

Fig. 2 IV characteristics of a 4T MEMS relay measuring the drain current of the relay and sweeping the gate voltage from 0 to 50 V. Different voltages are applied to the suspended body beam and are annotated in the figure. The pull-in/pull-out characteristics of the relay can be seen to shift left or right depending on the voltage applied to the body beam. The device switches consistently, with no change in the slope of the devices under different body bias voltages. A two stage pull-in is measured for the relay, this can be seen by the sharp increase in current from the initial mechanical pull-in followed by an increase in conduction due to the increasing contact force.

from – 10 to +10 V (figure 2). The drain contact is held at 3 V while the source beam is grounded.

The results of two devices are presented to show a consistency of the body biasing effect. Device A shows the IV characteristics in figure 2, whereas figure 3 is for device B and shows the relation between the body bias and pull-in voltage.

The relays demonstrate a two-stage pull-in, where there is a sharp pull-in on the initial contact reaching 70% of the on-current. The current then steadily increases to the final on-current of 3.1 µA. The two stages are caused by the initial mechanical pull-in and a slow increase in the contact force. Five hundred cycles have been conducted on the relays and show no sign of contact degradation indicating the NCG is capable of handling an increased contact force. No leakage is measured between the source beam and body beam or is there any decoupling of the beams in the cycle measurements. This result demonstrates the robustness of a polymer coupler for use in 4T lateral relays.

The change of the pull-in voltage against the applied body bias is plotted in figure 2. The relays demonstrate a linear relation between the applied bias and the change in pull-in. The linear relation between pull-in and body voltage is necessary to enable reduced operating voltages for MEMS devices, especially for logic functions. This proves the polymer coupler enables the 4T relay to perform as an ideal relay with no additional parasitic effects preventing the linear modulation of pull-in voltages.

5. Conclusion

This work is the first demonstration of a lateral single contact 4T relay utilizing a nanocrystalline graphite contact coating and a polymer mechanical coupler. The devices show characteristic body-biasing of the relay directly altering the pull-in voltage applied at the gate terminal. Future work intends to explore more detailed analysis of the 4T relays and logic configurations necessary for producing components in a MEMS FPGA.

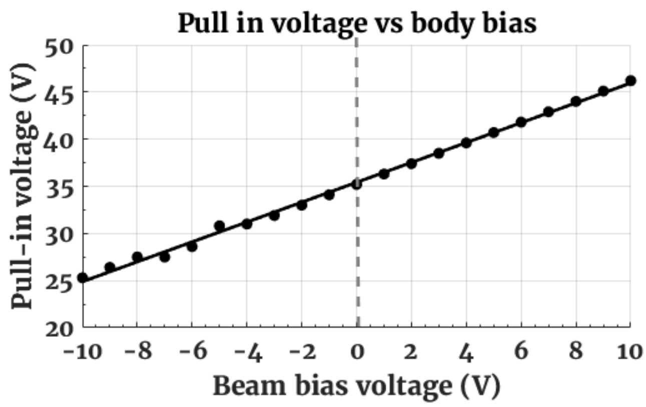

Fig. 3 Relation between the pull-in voltages in the gate voltage sweep against the applied voltage to the body beam. A straight line is fitted to the points to highlight the linear relation between the two.

References

[1] T.Qin, S.J.Bleiker, S.Rana, F.Niklaus, D.Pamunuwa, IEEE Access (2018), 6, 15997-16009.
[2] S.Rana, J.D.Reynolds, T.Y.Ling, M.S.Shamsudin, S.H.Pu, H.M.H.Chong, D.Pamunuwa, Carbon (2018), 133, 193-199
[3] M.Schmidt, C.Xu, M.Cooke, H.Mizuta, H.M.H.Chong, Materials Research Express (2014), 025031

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