Novel Saw Tooth Gate for Stiction and Pull-in Voltage Controlled Ohmic Silicon NEMS Switch


'Nano Research Group, Electronics and Computer Science, University of Southampton, Southampton, SO17 1BJ, UK

b Atomic Electronics Group, National Institute for Materials Science, Japan

c School of Materials Science, Japan Advanced Institute of Science and Technology, Japan

e-mail: liam.boodhoo@soton.ac.uk

Keywords: NEMS, suspended, silicon, nanowire, CMOS compatible

Background

Nano-electro-mechanical systems (NEMS) are considered as potential candidates for low power switch integration due to the possibility for steep subthreshold slopes and near zero leakage currents [1]. However, irrecoverable stiction failure and high pull-in voltages have been shown to be significant issues for contact NEMS switches [2]. Existing NEMS switch device materials include graphene [3], carbon nanotubes [4], silicon carbide [5], silicon [6] and metal [7]. In this paper, a suspended ohmic silicon NEMS switch is presented with novel saw tooth electrostatic spiked gate design for stiction and pull-in voltage control.

Device I-V characteristics show abrupt pull-in (13.1 V) and pull-out (5 V).

Method

Doubly clamped NEMS devices are fabricated on 80 nm thick SOI using hydrogen silsesquioxane electron beam lithography for nano patterning. Sulphur hexafluoride (SF6) and oxygen (O2) gas chemistry reactive ion etching (RIE) is used to form the silicon devices. The doubly clamped beam is suspended using a vapour phase hydrofluoric acid (HF) under-etch of the 200 nm thick buried oxide (BOX) layer. The device layer is phosphorus doped to a concentration of $1 \times 10^{18}$ cm$^{-3}$. Resultant device parameters are as follows: 7.8 μm beam length, 102 nm beam width, 129 nm air gap, 85 nm electrostatic spike height. Fig. 1a and Fig. 1b depict scanning electron micrographs of the device after testing. Electrical characterisation is performed using an Agilent B1500A Semiconductor Device Parameter Analyser in an air environment at ambient temperature, pressure and humidity.

The saw tooth gate design leads to increased electric field during electromechanical actuation while ensuring minimal stiction after pull-in. Pull-in to top gate occurs at $V_{\text{GC}} = 13.1$ V and pull-out from top gate occurs near $V_{\text{GC}} = 5$ V. Fig. 2a displays gate current measured during a 15 V gate voltage sweep, the arrows indicate the hysteresis observed. Fig. 2b illustrates the I-V characteristics across the beam after electromechanical pull-in. A 10 mV voltage sweep is applied to the source electrode while ground is held at the opposite end of the beam and each gate electrode. The suspended nanowire carries a 37 nA current at $V_{\text{GS}} = 10$ mV and side gate isolation is maintained throughout.

Results

The novel saw tooth electrostatic spiked gate surface design introduces a decreased pull-in voltage by reducing the effective air gap distance. Pull-in voltage is reduced from 22.5 V simulated with a 214 nm gap, down to the experimentally observed pull-in voltage of 13.1 V Fig. 2a). The spike tip at the point of mechanical contact results in reduced stiction enabling electromechanical pull-out at around 5 V. Fig. 2b shows the I-V characteristics across the beam after pull-in and pull-out showing electrical isolation of the suspended beam after the pull-in tests.

Conclusions

Saw tooth gate design can be used to control stiction for ohmic contact NEMS switches as well as reduce the effective electrostatic actuating distance during electromechanical pull-in. This reduces the operating voltage for pull-in when compared with a device without the electrostatic spikes.

The research work described in this publication was conducted under financial support from the EPSRC-JST strategic Japan UK cooperative program N0VTOL project EP/P000469/1.


Fig. 1a: SEM images of doubly clamped suspended silicon NEMS device with saw toothed side gate to control pull-in voltage and reduce stiction. Saw tooth gate design leads to increased electric field during electromechanical actuation while ensuring minimal stiction after pull-in.

Fig. 1b: Close-up of stiction controller region with 129 nm air gap between 102 nm wide beam and gate electrode.

Fig. 2a: Electromechanical pull-in and pull-out to gate across a 129 nm gap. Source electrode is held at ground. Graph shows pull-in at 13.1 V and pull-out at 5 V. Current is limited to 100 nA.

Fig. 2b: 0 mV to 10 mV source voltage sweep. Opposite side of beam is held at ground. Graph shows current isolation from the gate electrode after pull-in and pull-out.