

A Low-Power Printed Flexible Lorentz Force MEMS Switch with Electrostatic Hold-down

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Summary:

This work presents a flexible, printed MEMS switch based on Lorentz force actuation with electrostatic hold-down. The Lorentz force drives the pull-down motion, while a low electrostatic force maintains the closed state, reducing power consumption. The device consists of a printed silver conductive layer on a polyimide substrate and is released using a plasma etching process. Simulation results show that a current of 120 mA produces approximately 110 μm displacement, enabling contact closure. The switch has a resonant frequency of 33 Hz, and a spring constant of 0.018 N/m. Experimental results demonstrate switching operation and validate the proposed concept.

Keywords: Printed MEMS, Flexible electronics, Lorentz force actuation, Electrostatic hold-down, Low power switching

Introduction

Micro-electromechanical systems (MEMS) switches are promising alternatives to conventional electronic switches due to their small size, low power consumption, and comparable switching performance [1]. They are widely used in RF systems, reconfigurable electronics, and low-power communication circuits. With the advancement of additive manufacturing, printed and flexible electronic systems have attracted attention due to their low-cost and fast fabrication and compatibility with large-area substrates [2]. MEMS switches rely on mechanical motion to enable or interrupt electrical conduction, which is typically driven by electrostatic or electromagnetic mechanisms [3]. Electrostatic actuation offers low steady-state power consumption but normally requires relatively high voltage, while Lorentz-force actuation enables low-voltage operation but requires continuous current to maintain closure, increasing power consumption [4]. Recently, micro-printing technologies has shown potential for printed MEMS [5].

In this work, we present a printed and flexible MEMS switch that combines these mechanisms. The Lorentz force is used for pull-down actuation, while an electrostatic force maintains the closed state, eliminating the need for continuous current. The device uses a four-spring suspension design and is fabricated on a polyimide substrate. Simulation and experimental results demonstrate its performance and operation.

Working principle

Fig. 1 illustrates the structure of the switch and its operation. A permanent magnet is placed beneath the device to generate a static magnetic field. A direct current is applied through the fixed anchor pads (P2 and P4), creating an in-plane current. As a result, an out-of-plane Lorentz force is generated, which pulls the movable shuttle downward. When the shuttle reaches the contact pads, the switch is in the closed state. Once closed state, a voltage applied to the bottom electrode maintains the contact through electrostatic force. At this stage, the driving current can be turned off, reducing power consumption while keeping the switch closed. Fig.1 also shows the experimental setup used to monitor the switching behavior. A 5 V power supply is connected to the device through a 1 k Ω resistor, and an oscilloscope is used to measure the voltage at the contact pad. When the switch is open, the measured voltage is 5 V. When the shuttle is pulled down and contact is established, the voltage drops to 0 V, indicating the closed state.

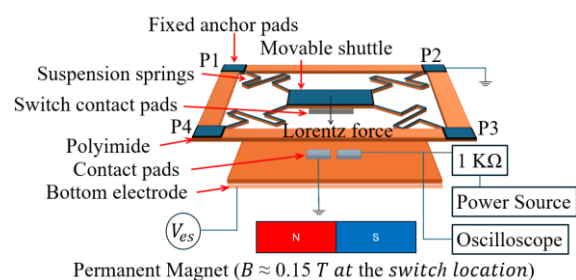


Fig. 1. Working principle of the MEMS switch.

Simulation and Experimental setup

A multiphysics finite element model was used in COMSOL Multiphysics to analyze the electromechanical response of the switch. The device is based on a printed silver layer (15 μm thickness, 100 μm line width, Voltera NOVA printer, ACI FS0142 silver ink) on a 25 μm thick polyimide substrate. The printed switch is released using oxygen plasma etching of surrounding polyimide. The switch closes when the vertical displacement reaches 110 μm , corresponding to contact with the bottom electrodes. Fig. 2 shows the simulated displacement distribution under Lorentz-force actuation. Its fundamental resonance frequency of approximately 33 Hz, and the effective spring constant is about 0.018 N/m.

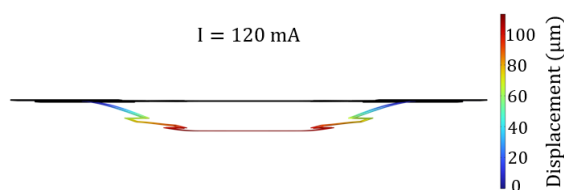


Fig. 2. Simulated displacement distribution.

Experiment Results

A fabricated switch is shown in Fig. 3. Experiments were conducted to measure the displacement versus current as shown in Fig. 4, along with simulation results. We can see that measurements follow the trend of simulation results. The dynamic response of the switch is shown in Fig. 5. In this test a square-wave excitation produces repeatable switching between open and closed states, with the contact voltage transitioning between 5 V (OFF state) and 0 V (ON state). Another test was conducted to explore the minimum voltage required to maintain the ON state. In this test the electrostatic voltage was swept down from 80 V to 0 with a step of 1 V, and at 28 V the switch released. Fig. 6 shows the results.

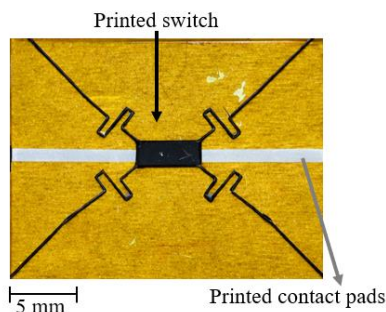


Fig. 3. Fabricated switch.

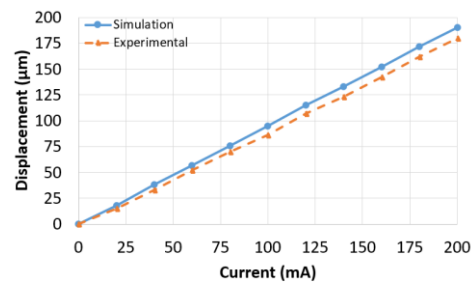


Fig. 4. Lorentz force displacement.

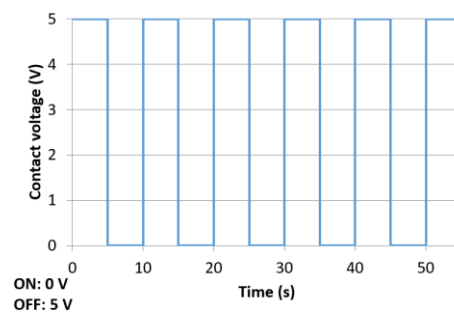


Fig. 5. Dynamic response of the switch.

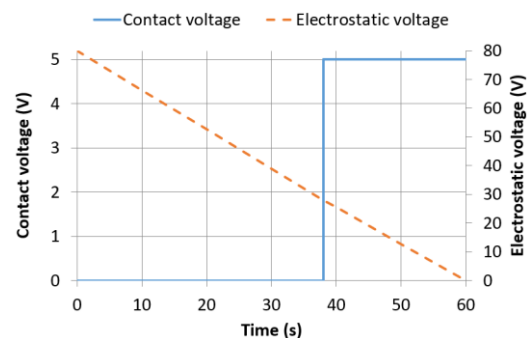


Fig. 6. Release voltage measurement.

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