ROCHESTER INSTITUTE OF TECHNOLOGY
MICROELECTRONIC ENGINEERING

MEM Switches

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5-17-2012 Mem_App_Switches.ppt

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OUTLINE

Introduction
Applications
General Purpose Relays
RF Switches
- Electrostatic Actuation
- Magnetic Actuation

Patents

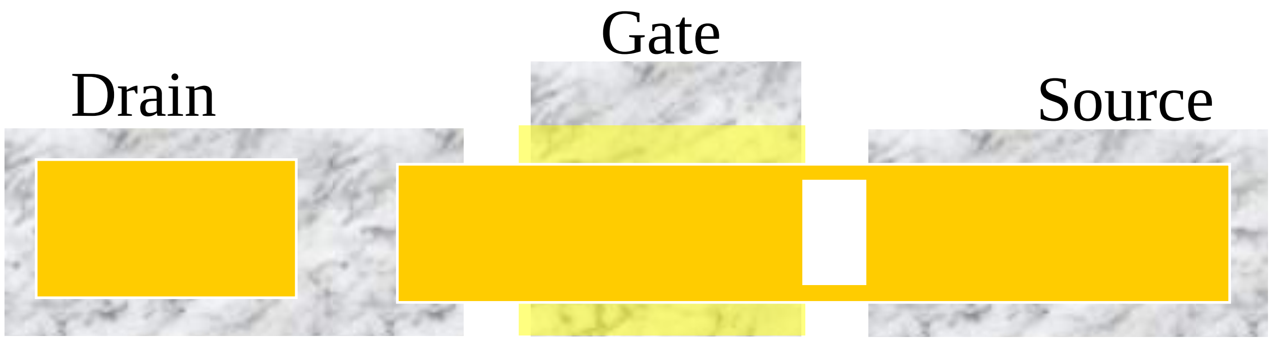
INTRODUCTION

Excellent Isolation >40dB@10Ghz
Low Loss <1dB@2Ghz
Low On Resistance <1 ohm
High Q >10,000
Low Power Consumption (almost zero)
High Currents ~1 Amp and 10 Amp Peak
Small Size
Low Actuation Voltage <6 Volts
Reliability >10E9 Cycles
Fast Operation 10-100 µsec
Small Packaging

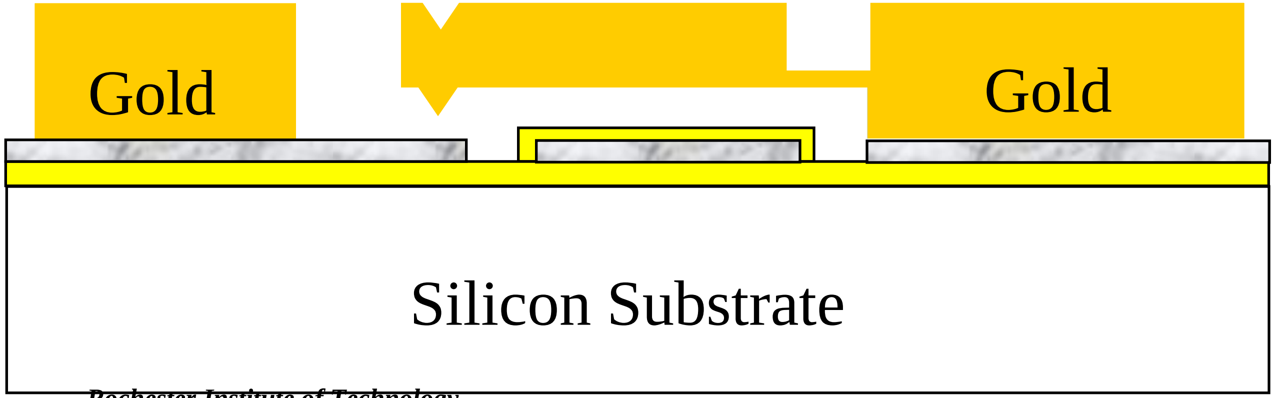
APPLICATIONS

Area	*System*	*Device*
Phased Array	Communication and Radar Systems	Switch (ground , space, airborne, missile)
Switching and Reconfigurable Networks	Wireless Communication (portable, base station) switches Satellite (Communication and Radar) Airborne (Communication and Radar)	Switch
Low power oscillators and amplifiers	Wireless	Varactors and inductors
	Satellite	
	Airborne	

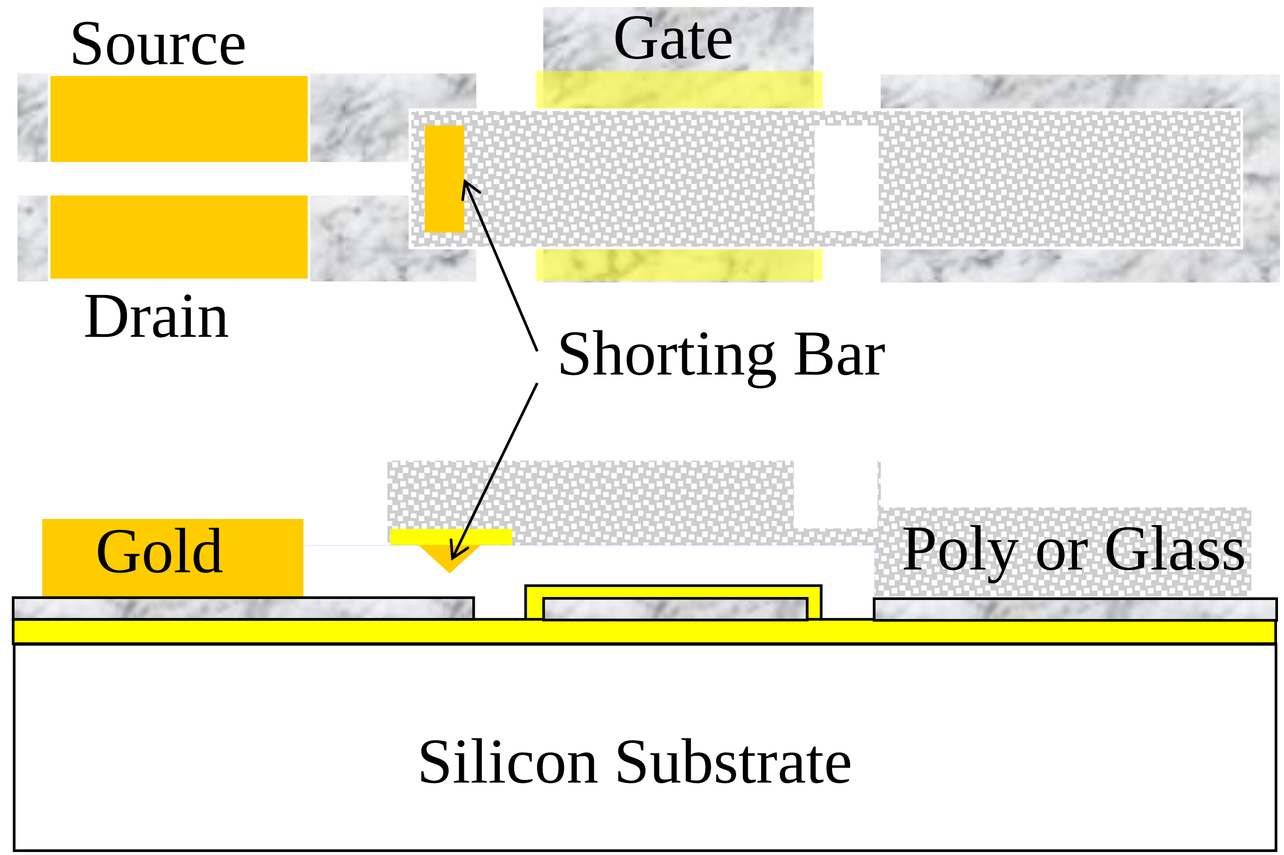
CANTILEVER TYPE SWITCH



$$F = \frac{\varepsilon_o \varepsilon_r A V^2}{2d^2}$$



CANTILEVER TYPE SWITCH – SHORTING BAR



$$F = \frac{\varepsilon_o \varepsilon_r A V^2}{2d^2}$$

ADI MEMS SWITCH

Size 100 µm x 100 µm

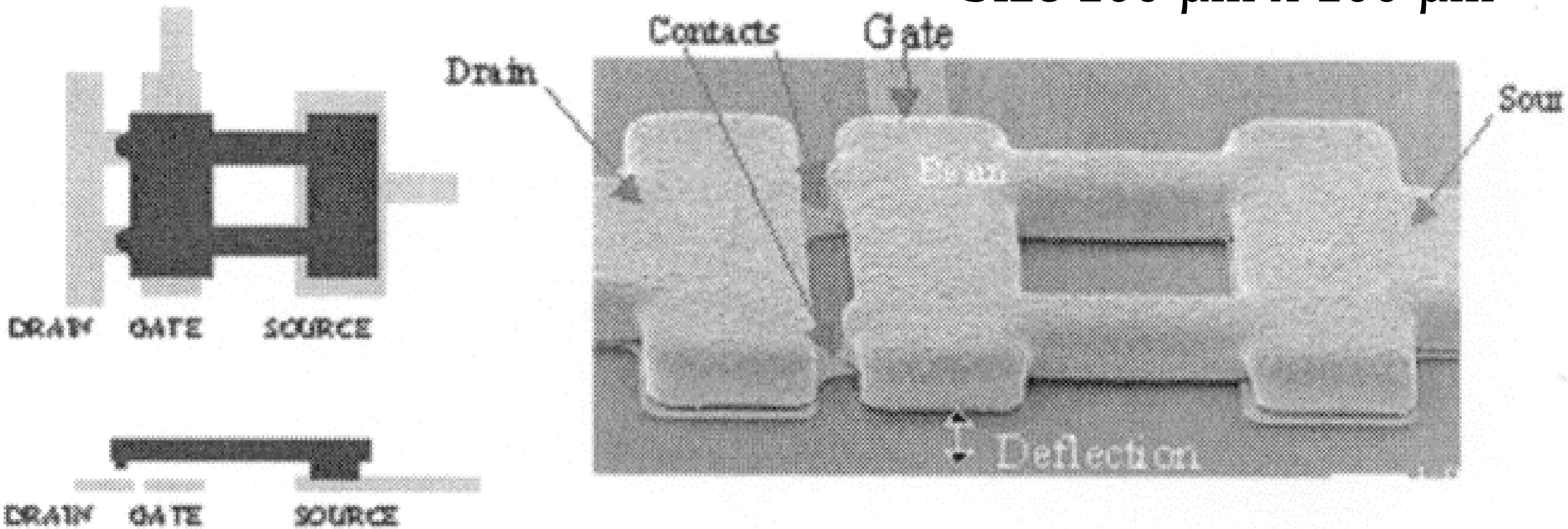


Figure 1. ADI MEMS Switch Configuration

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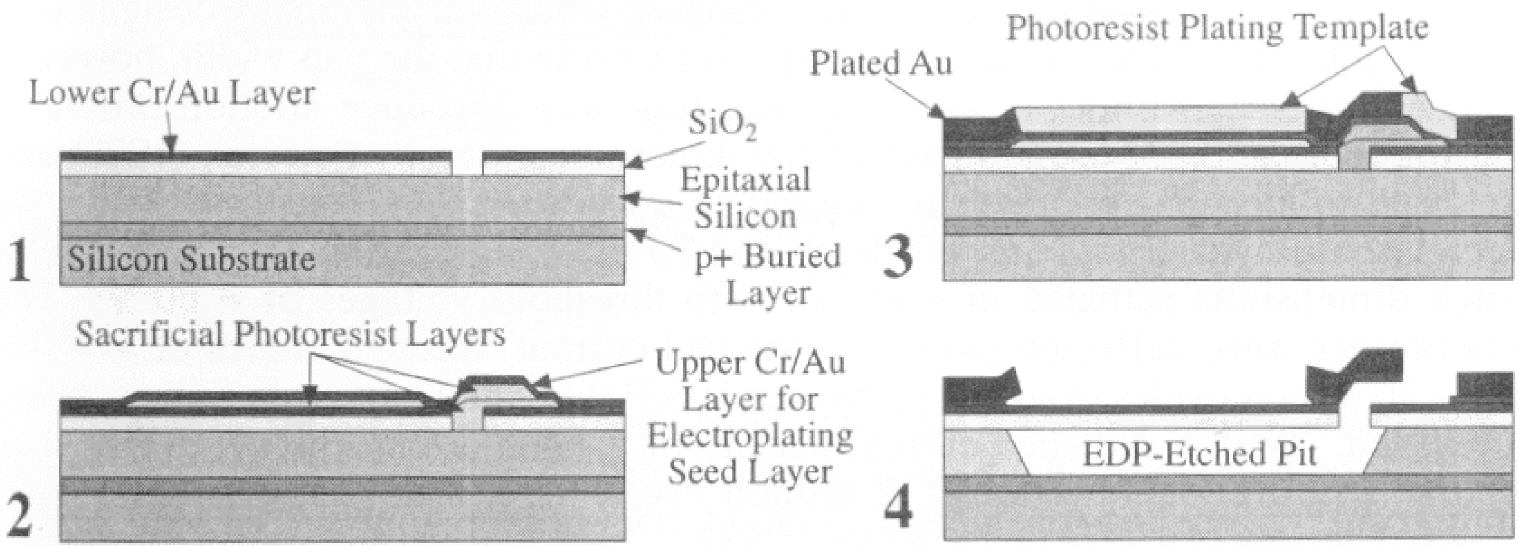
SINGLE CONTACT SWITCH



Cross-sectional diagrams of a single-contact micromechanical switch at various stages during the fabrication procedure. (1) After first metal etch and oxide etch. (2) After evaporation of Au-Cr plating base. (3) After selective Au plating through photoresist plating template. (4) Finished structure after photoresist stripping, removal of excess plating base, and EDP etch. After Petersen (1978a).

PACKAGED SWITCH

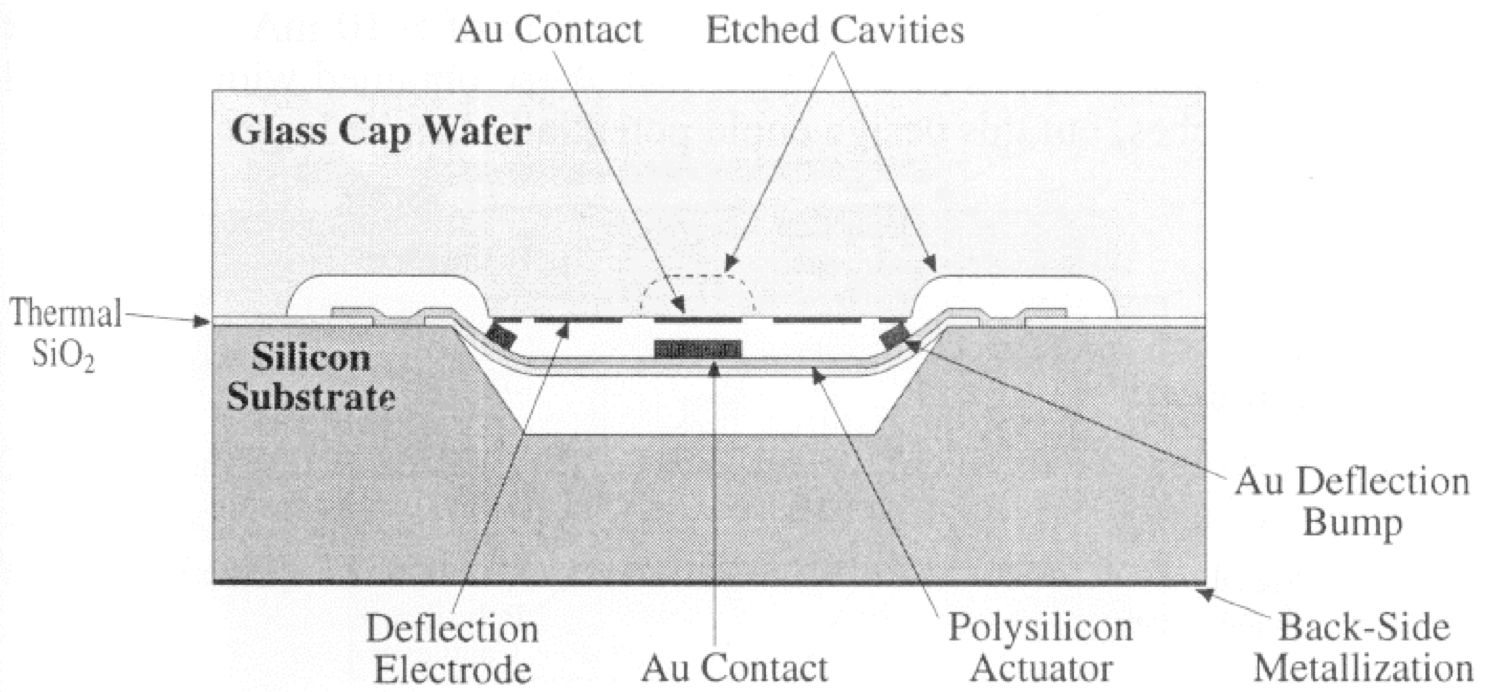


Illustration of a bulk micromachined, electrostatically actuated relay. Adapted from Drake, et al. (1995).

LATERAL MOVEMENT, Hg CONTACT SWITCH

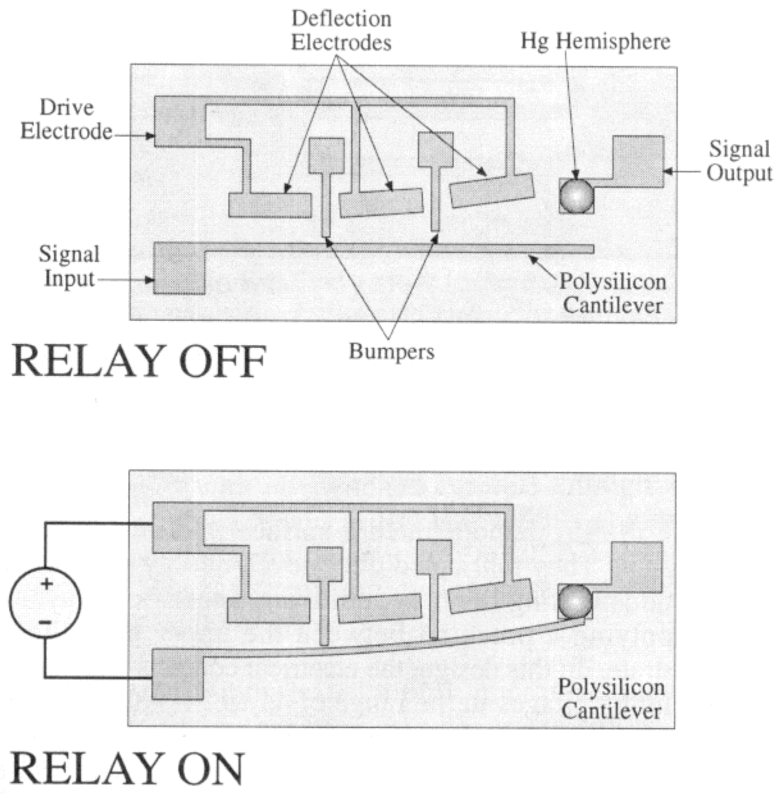
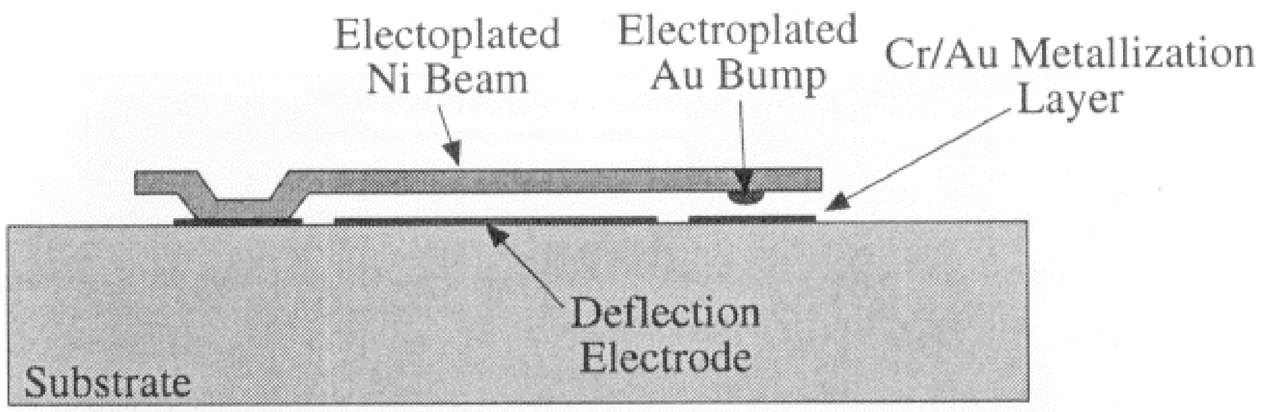


Illustration of a surface micromachined, mercury-contact electrostatic relay in the off state (top) and on state (bottom). Adapted from Saffer, et al. (1995).

ALL METAL SWITCH



Cross-sectional illustration of a surface micromachined, electrostatic relay, fabricated by electroplating Au bump contacts and Ni beams above a sacrificial copper layer (not shown). Adapted from Zavracky, et al. (1997).

MAGNETIC RELAY

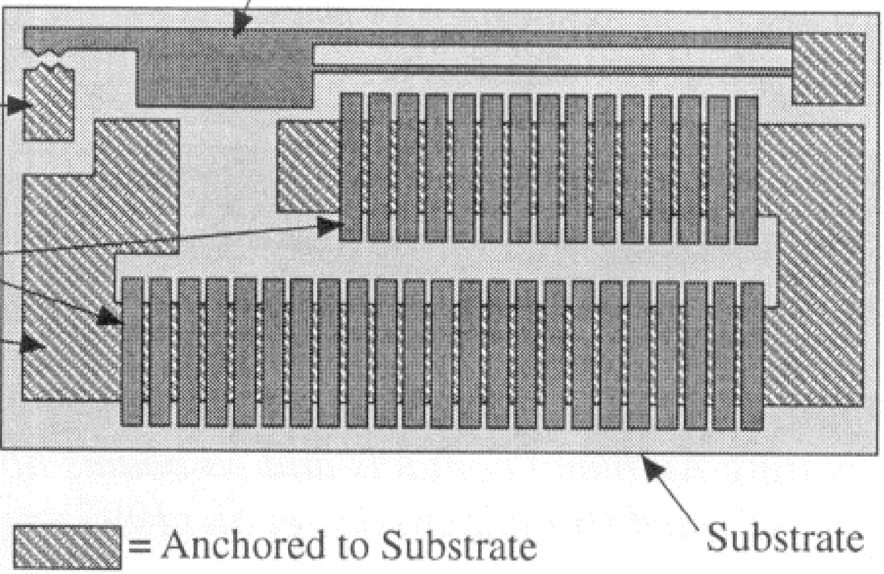


Illustration of monolithic, micromachined magnetic relay. Adapted from Rogge, et al. (1995).

MAGNETIC LATCHING RF SWITCH

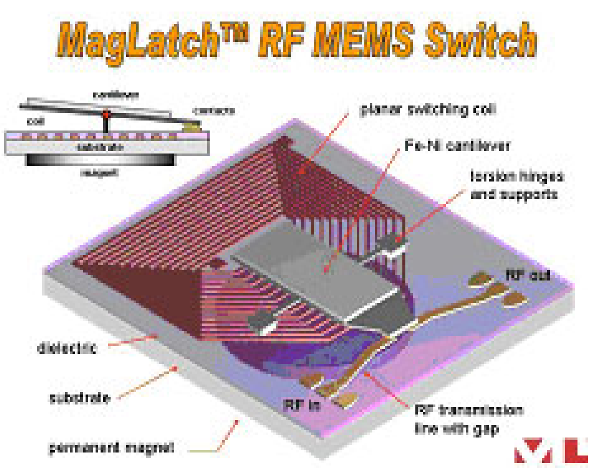
Operation Principle

www.magfusion.com

The principle behind the latching characteristics is the preferential magnetization of a cantilever made of soft magnetic material (e.g. permalloy). In a constant, nearly perpendicular magnetic field, a cantilever can have either a clockwise or a counter-clockwise torque depending on the angle between the cantilever and the field, which leads to the bistability. To change state of the switch, a second magnetic field (generated by a short current pulse through a coil in this case) realigns the magnetization of the cantilever and changes the direction of the magnetic torque, causing the cantilever to flip. The static external magnetic field instantly latches the switch in the closed or open position. The switch maintains this state until the next switching signal realigns the cantilever magnetization. The relay consumes no power to maintain the latched state.

MagLatch™ RF Switch

The superior performance figures demonstrated by the product prototypes have positioned Magfusion™ to introduce several high performance products in areas such as wireless communications, portable RF devices, consumer and industrial electronics, aerospace, automotive electronics, and automatic testing equipment. The switch operates with short (< 100 µs) current pulses and low control voltage (< 5 V).



MAGNETIC LATCHING RF SWITCH

Benefits

- Bi-stable, power supply is not required to hold the states, no power in quiescent states
- Operation voltage < 5 V, below 2 V demonstrated
- Switching energy < 50 mJ, switching current < 100 mA, switching time < 100 ms
- Provides low insertion loss, high isolation, high linearity
- High reliability (billions of cycles demonstrated)
- Operation in ambient environment (potentially lower packaging cost)
- Conventional microelectronic fabrication technology may be employed, reducing production costs
- Can be fabricated on a variety of substrates: Si, GaAs, glass, metal, ceramic, magnets, etc. Capable of post Si IC process and integration
- Small dimension (~ 1 mm x 2 mm per SPDT relay, much smaller dimension [0.1 mm x 0.1 mm] have been demonstrated)
- SPST, MPST, or MPDT capable. Non-latching type is available upon customer request.

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CAPACITIVELY COUPLED RF SWITCH

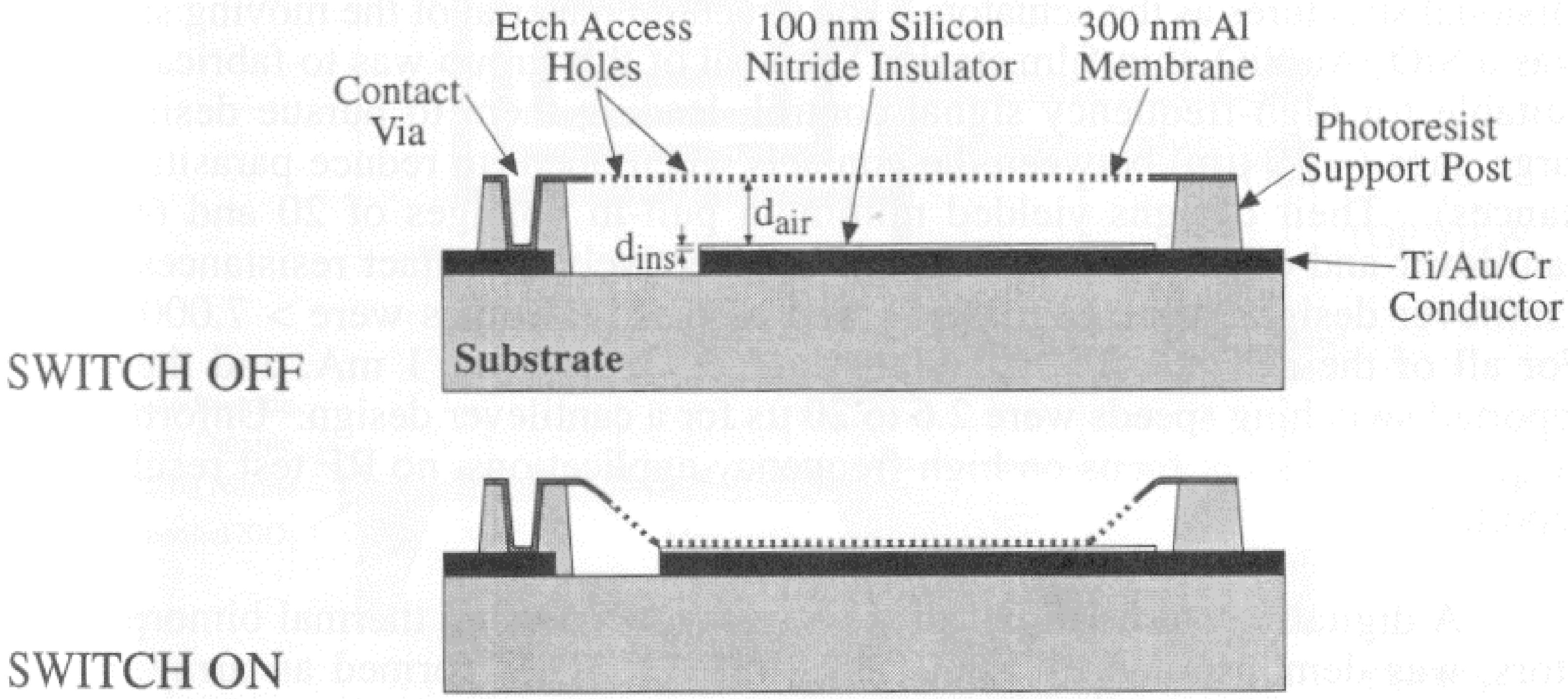

Illustration of a capacitively coupled, electrostatically actuated membrane-type RF switch. Adapted from Goldsmith, et al. (1996).

INDUCTOR ARRAY WITH THERMAL BIMORPH SWITCHES

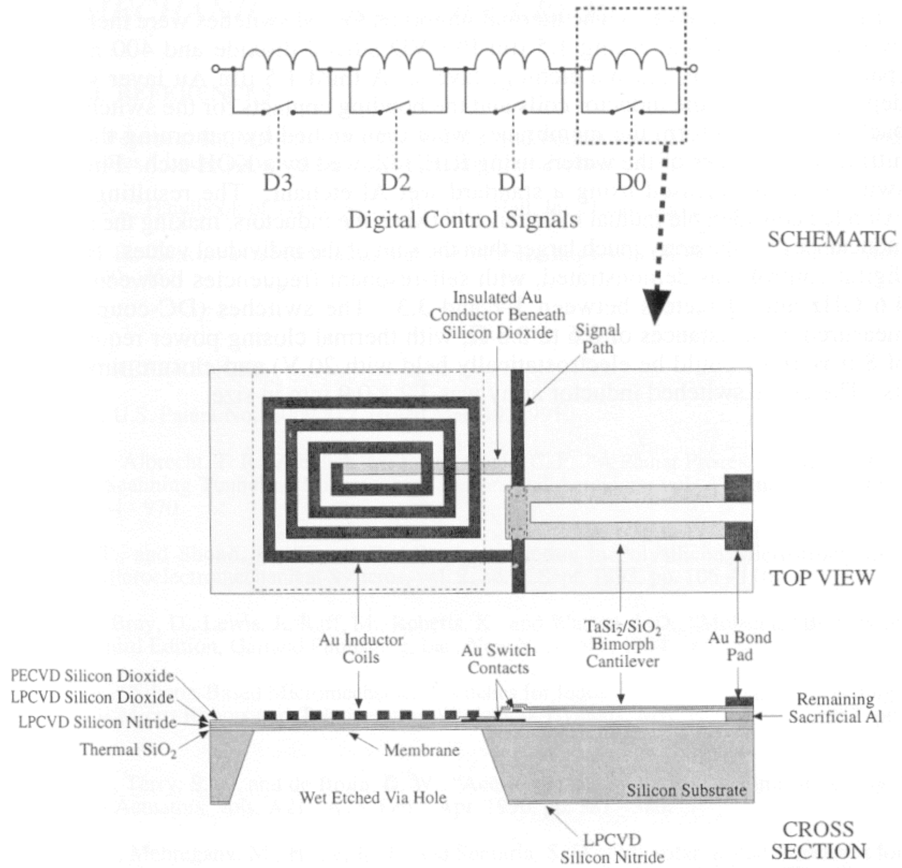

Illustration of a micromachined, digitally controlled inductor array, using thermal bimorph actuators for switching. Adapted from Zhou, et al. (1997). As seen in the schematic (top), one of the series inductor/switch combinations are shown in the top view (center) and cross section (bottom). When a particular switch is actuated, it bypasses the associated inductor.

PATENTS

US006069540A

United States Patent [19]

Berenz et al.

[11] **Patent Number: 6,069,540**

[45] **Date of Patent: May 30, 2000**

[54] MICRO-ELECTRO SYSTEM (MEMS) SWITCH

[75] Inventors: **John J. Berenz**, San Pedro; **George W. McIver**, Redondo Beach; **Alfred E. Lee**, Torrance, all of Calif.

[73] Assignee: **TRW Inc.**, Redondo Reach, Calif.

[21] Appl. No.: **09/418,341**

[22] Filed: **Oct. 14, 1999**

Related U.S. Application Data

[63] Continuation of application No. 08/897,075, Apr. 23, 1999, abandoned.

[51] **Int. Cl.**[7] **H01P 1/10**; H01H 57/00

[52] **U.S. Cl.** **333/101**; 200/181; 333/105

[58] **Field of Search** 333/101, 105–107, 333/262; 200/181, 339

[56] **References Cited**

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4,203,017	5/1980	Lee	200/339
5,638,946	6/1997	Zavracky	200/181

FOREIGN PATENT DOCUMENTS

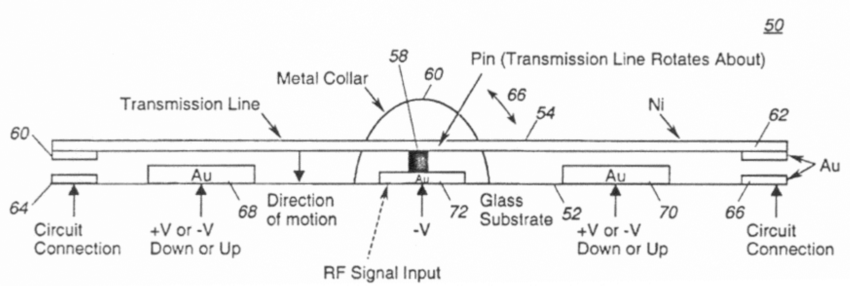
08235997	9/1996	Japan .

Primary Examiner—Paul Gensler
Attorney, Agent, or Firm—Michael S. Yatsko

[57] **ABSTRACT**

An RF switch formed as a micro electro-mechanical switch (MEMS) which can be configured in an array forming a micro electro-mechanical switch array (MEMSA). The MEMS is formed on a substrate. A pin, pivotally carried by the substrate defines a pivot point. A rigid beam or transmission line is generally centrally disposed on the pin forming a teeter-totter configuration. The use of a rigid beam and the configuration eliminates the torsional and bending forces of the beam which can reduce reliability. The switch is adapted to be monolithically integrated with other monolithic microwave integrated circuits (MMIC) for example from HBTs and HEMTs, by separating such MMICs from the switch by way of a suitable polymer layer, such as polyimide, enabling the switch to be monolithically integrated with other circuitry. In order to reduce insertion losses, the beam is formed from all metal, which improves the sensitivity of the switch and also allows the switch to be used in RF switching applications. By forming the beam from all metal, the switch will have lower insertion loss than other switches which use SiO2 or mix metal contacts.

22 Claims, 14 Drawing Sheets



US006046659A

United States Patent [19]

Loo et al.

[11] **Patent Number: 6,046,659**

[45] **Date of Patent: Apr. 4, 2000**

[54] DESIGN AND FABRICATION OF BROADBAND SURFACE-MICROMACHINED MICRO-ELECTRO-MECHANICAL SWITCHES FOR MICROWAVE AND MILLIMETER-WAVE APPLICATIONS

[75] Inventors: **Robert Y. Loo**, Agoura Hills; **Adele Schmitz**, Newbury; **Julia Brown**, Santa Monica; **Jonathan Lynch**, Oxnard; **Debabani Choudhury**, Woodland Hills; **James Foschaar**, Thousand Oaks, all of Calif.; **Daniel J. Hyman**, Cleveland Hts., Ohio; **Brett Warneke**, Berkeley, Calif.; **Juan Lam**, Agoura Hills, Calif.; **Tsung-Yuan Hsu**, Westlake Village, Calif.; **Jae Lee**, University Heights; **Mehran Mehregany**, Pepper Pike, both of Ohio

[73] Assignees: **Hughes Electronics Corporation**, El Segundo, Calif.; **Rosemont Aerospace, Inc.**, Burnsville, Minn.

[21] Appl. No.: **09/080,326**

[22] Filed: **May 15, 1998**

[51] **Int. Cl.**[7] **H01P 1/10**; H01H 57/00

[52] **U.S. Cl.** **333/262**; 200/181; 200/600

[58] **Field of Search** 333/262; 200/181, 200/600

[56] **References Cited**

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5,578,976	11/1996	Yao	333/262
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FOREIGN PATENT DOCUMENTS

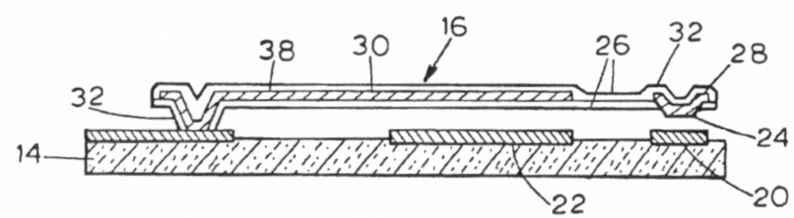
63-54801	3/1988	Japan	333/262

Primary Examiner—Justin P. Bettendorf
Attorney, Agent, or Firm—V. D. Duraiswamy; M. W. Sales

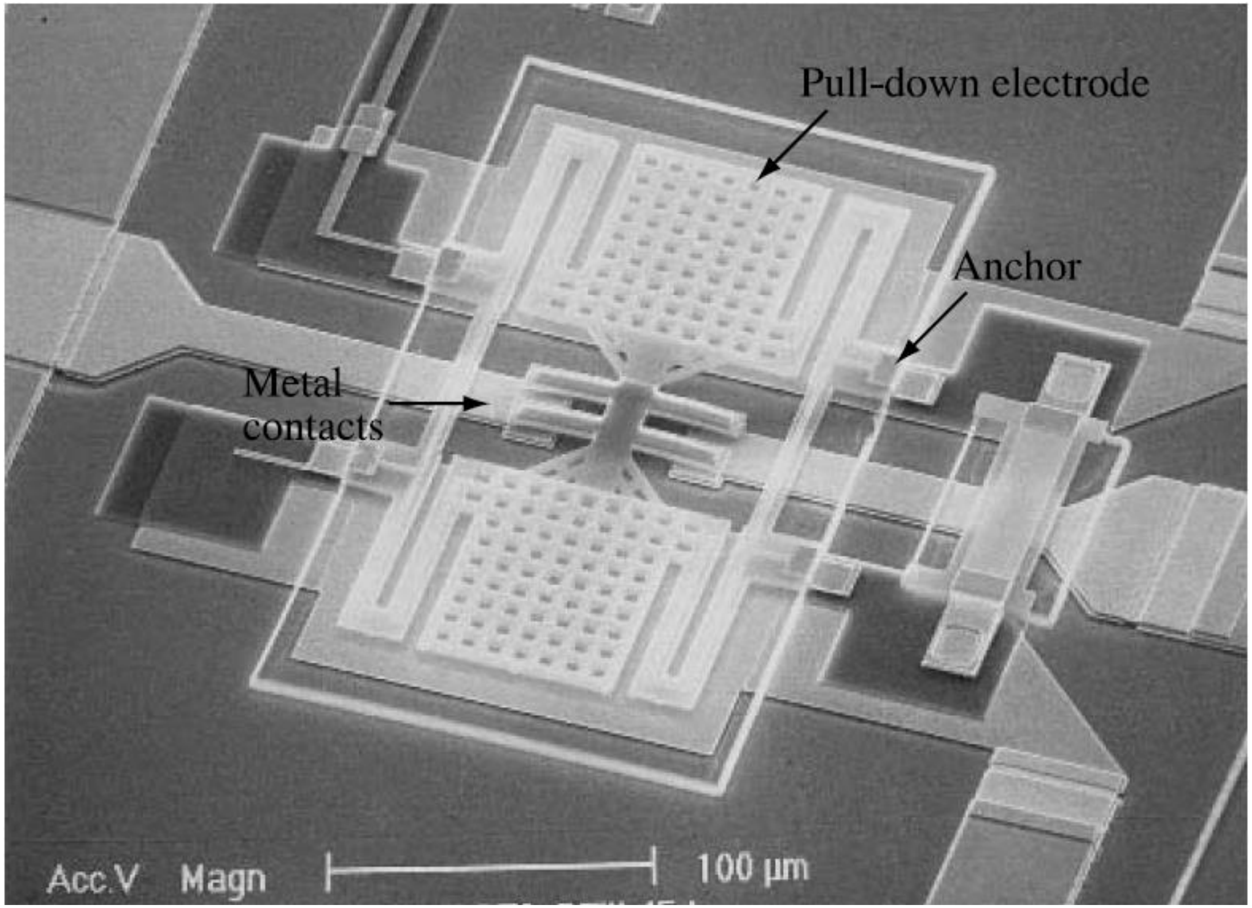
[57] **ABSTRACT**

Methods for the design and fabrication of micro-electro-mechanical switches are disclosed. Two different switch designs with three different switch fabrication techniques are presented for a total of six switch structures. Each switch has a multiple-layer armature with a suspended biasing electrode and a conducting transmission line affixed to the structural layer of the armature. A conducting dimple is connected to the conducting line to provide a reliable region of contact for the switch. The switch is fabricated using silicon nitride as the armature structural layer and silicon dioxide as the sacrificial layer supporting the armature during fabrication. Hydrofluoric acid is used to remove the silicon dioxide layer with post-processing in a critical point dryer to increase yield.

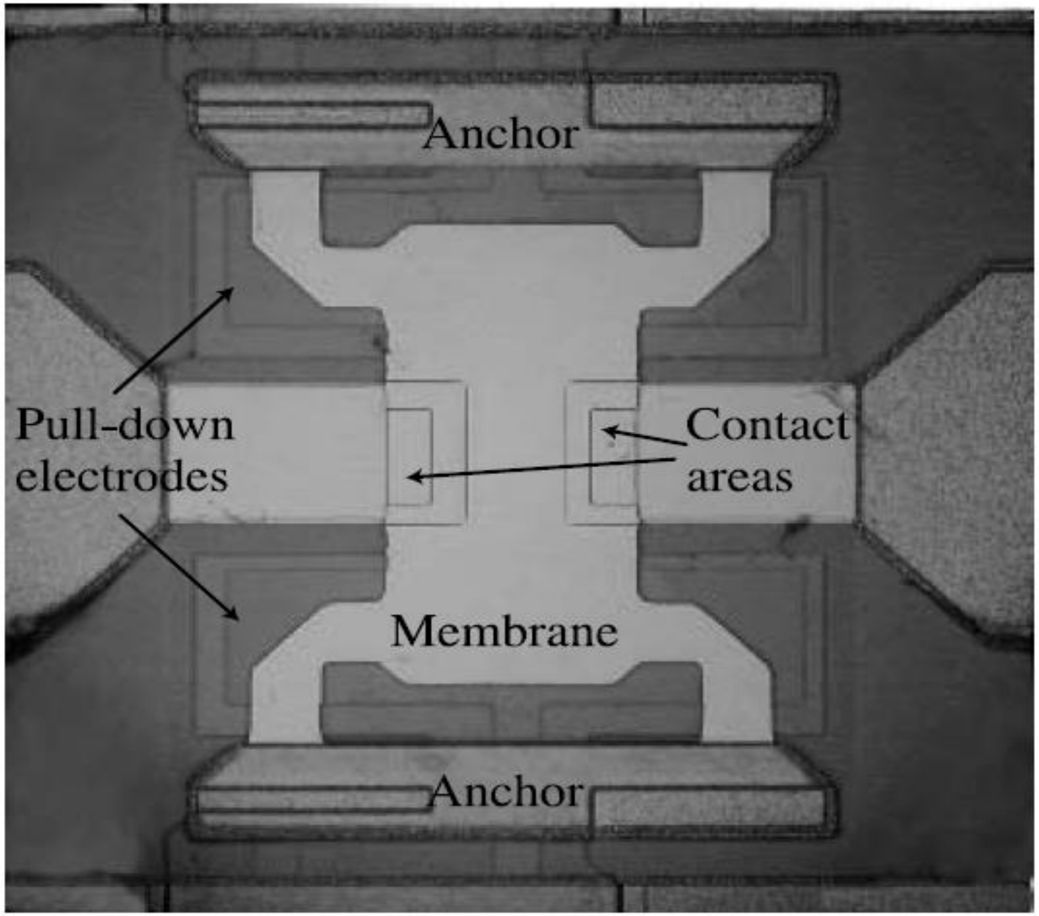
20 Claims, 5 Drawing Sheets



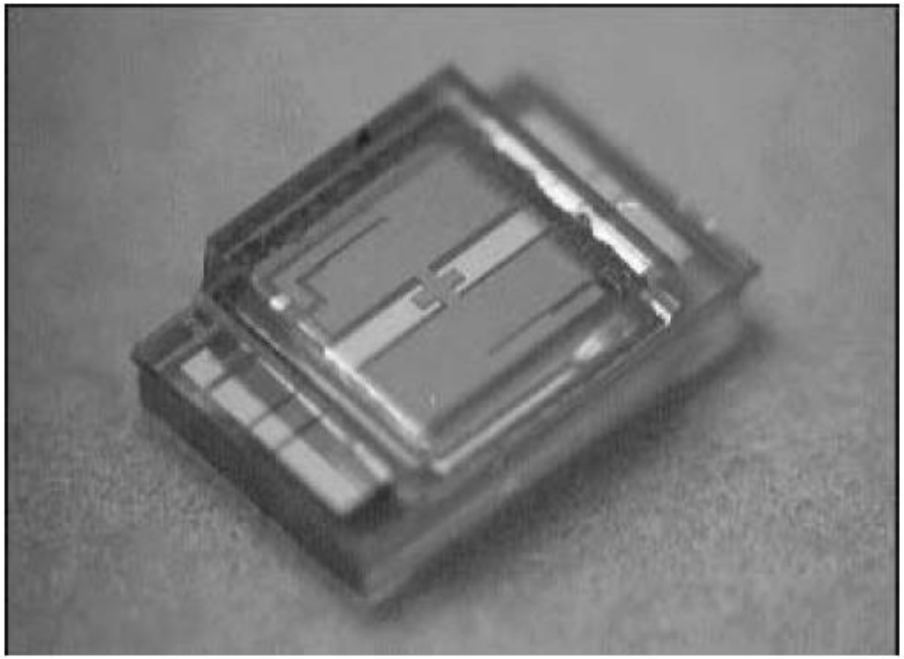
ROCKWELL SCIENCE CENTER MEMS DC SWITCH

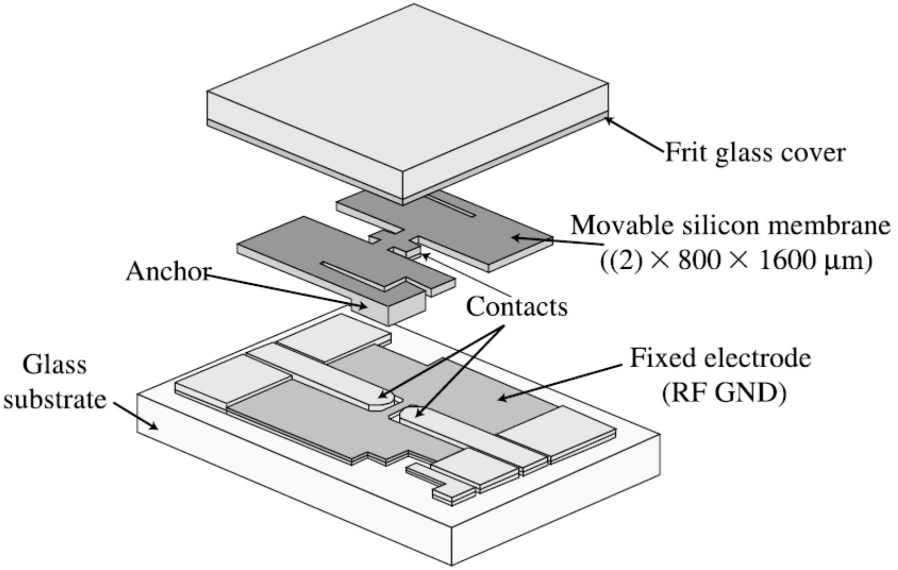


UNIVERSITY OF MICHIGAN ALL METAL DC SWITCH



OMRON DC CONTACT MEMS SWITCH





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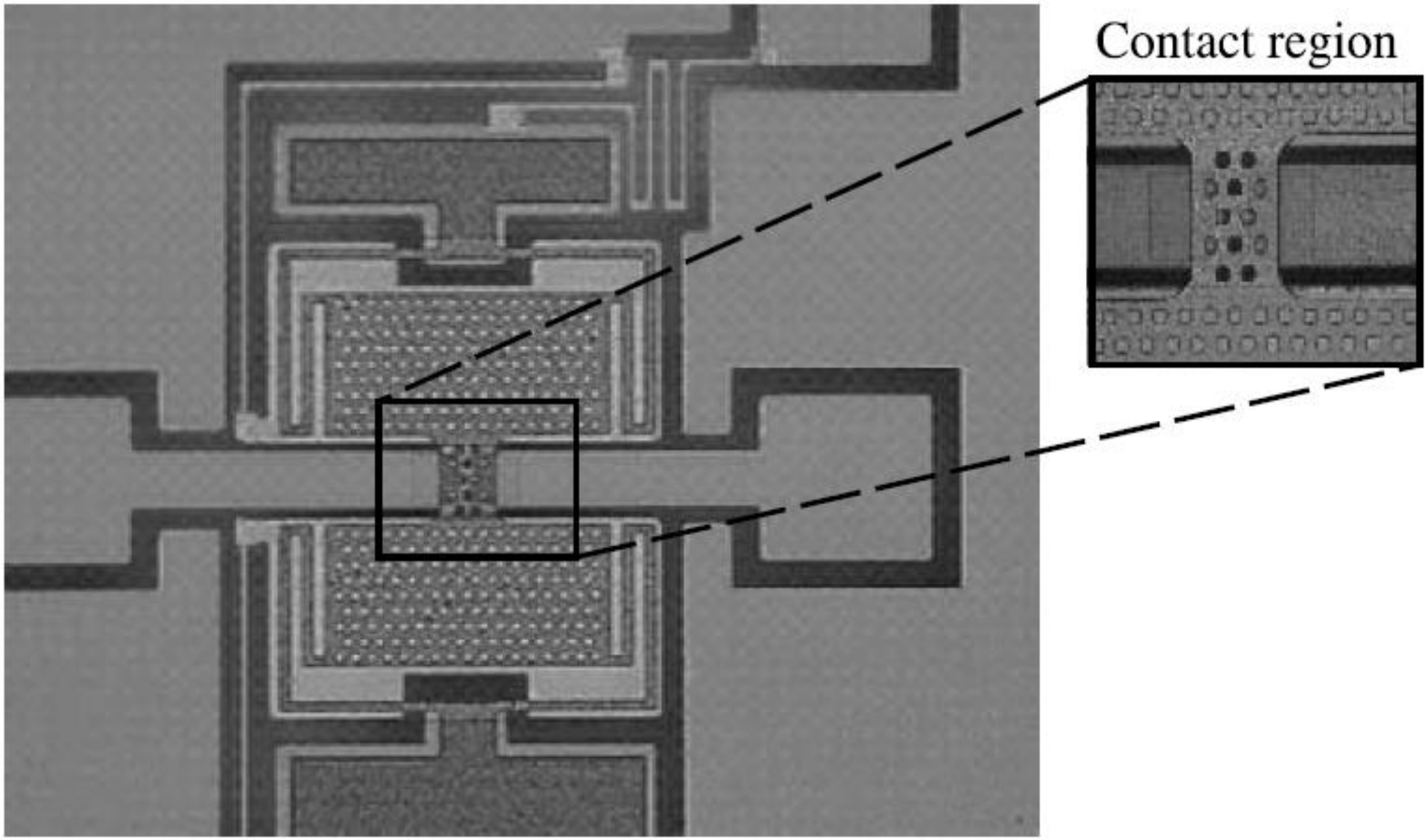
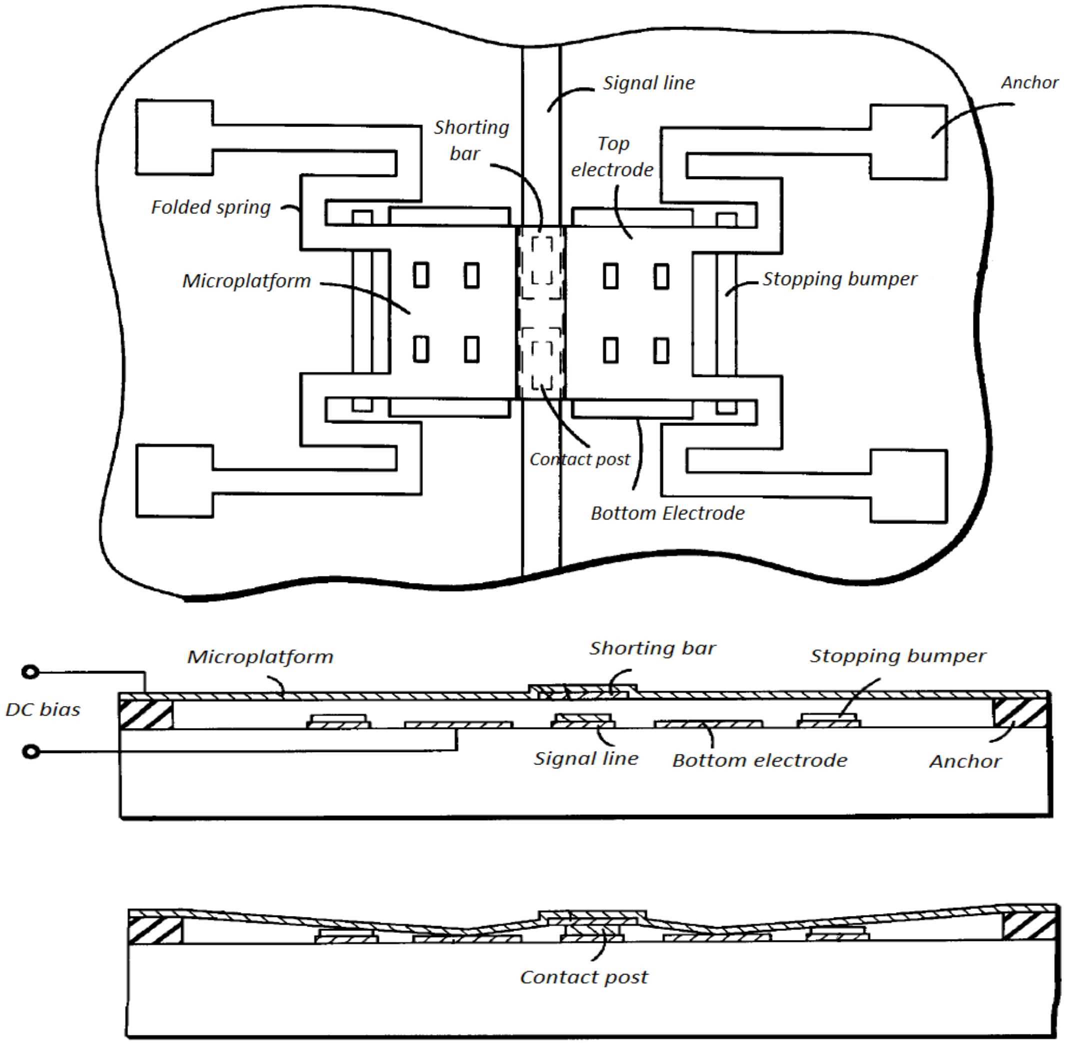
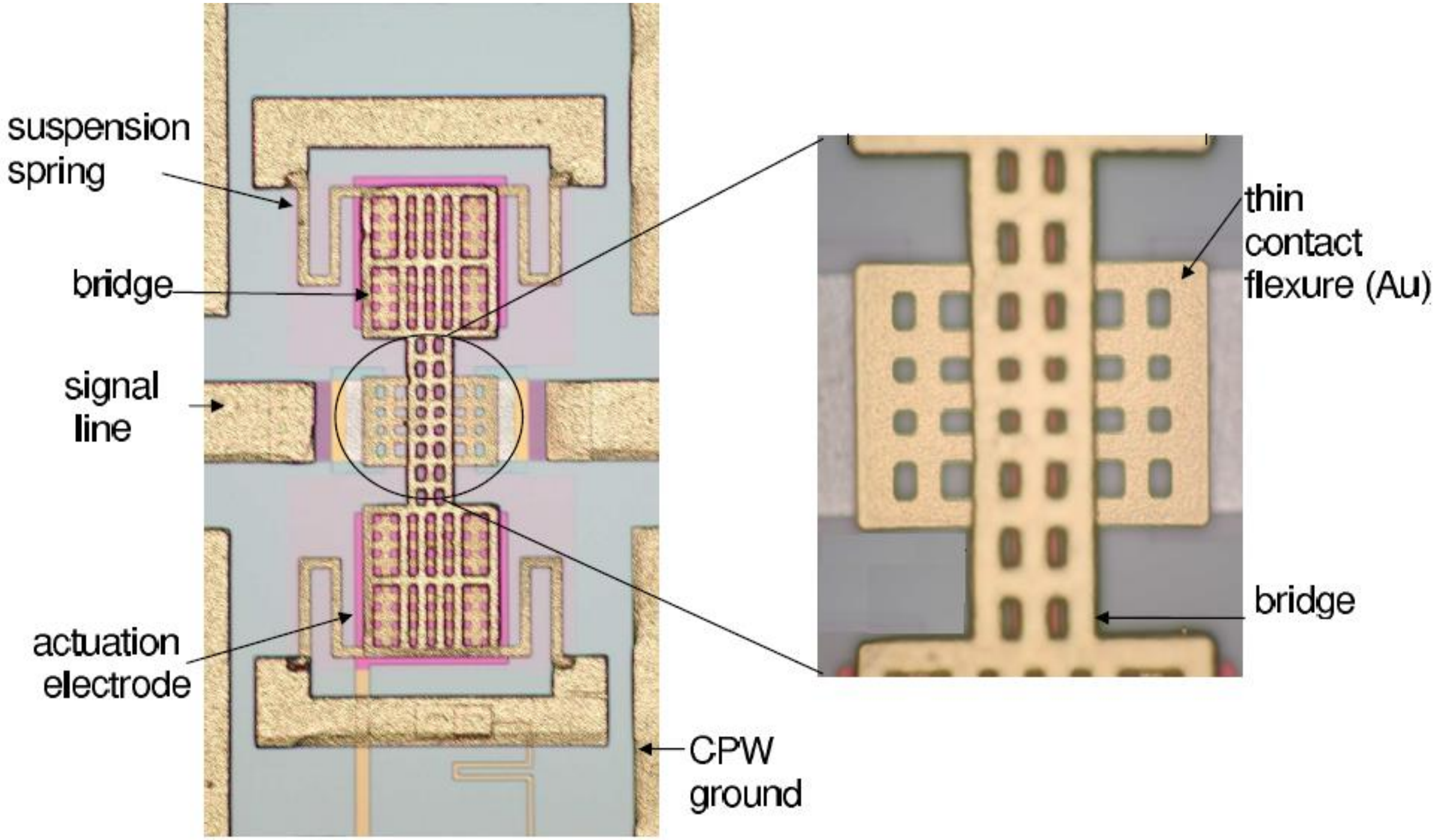
SAMSUNG DC CONTACT SWITCH



MOTOROLA FOLDED SPRING DC CONTACT SWITCH



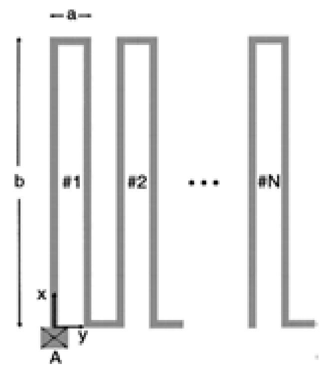
UNIVERSITY OF TRENTO LOW ACTIVATION SWITCH

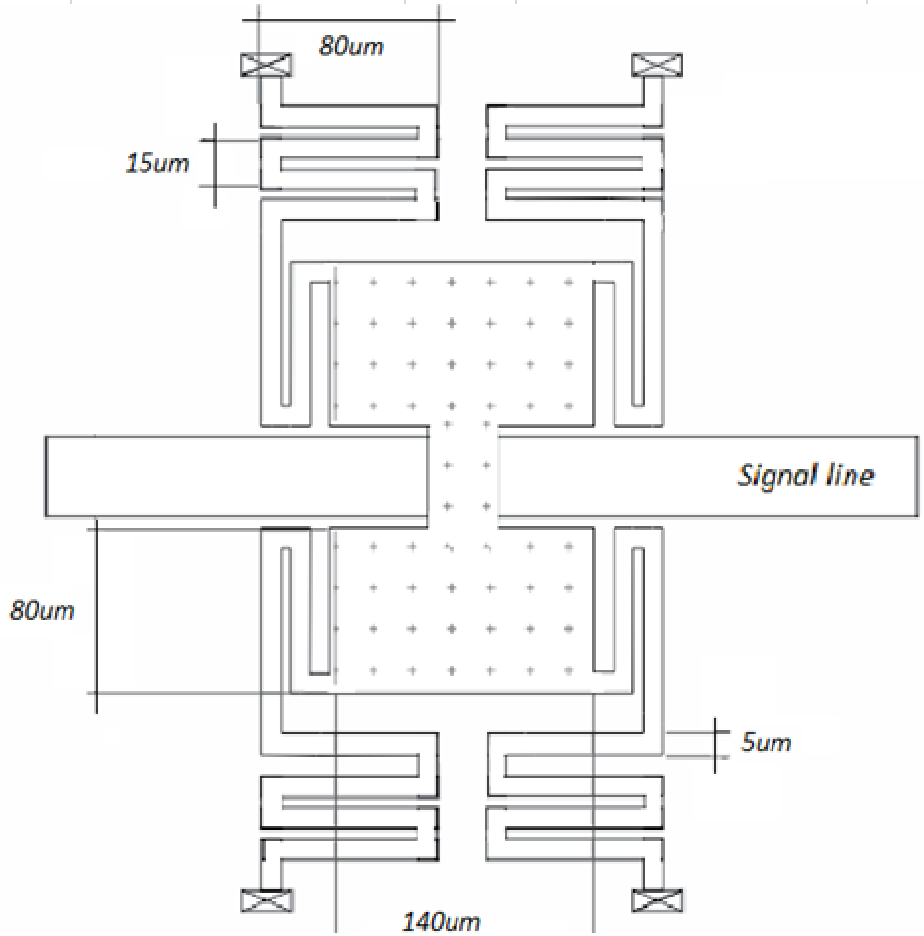


ARTUR NIGMATULIN DESIGN

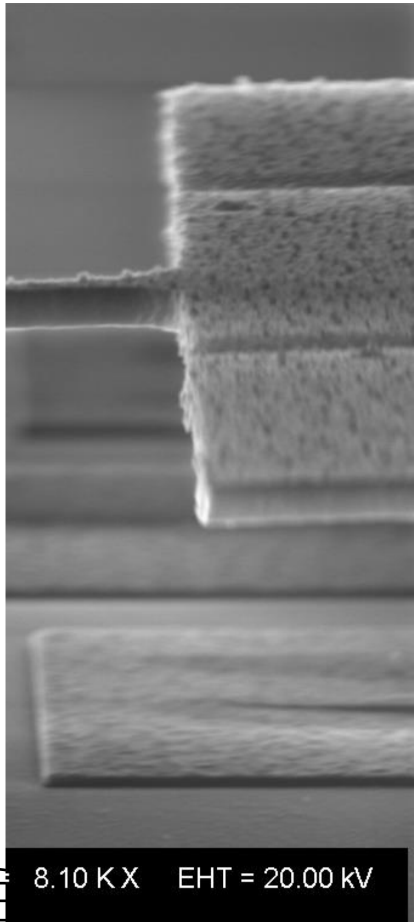
Number of turns in meander	3
Primary length (a)	1.50E-05
Secondary length (b)	1.00E-04
Thickness (t)	2.00E-06
Beam width (w)	5.00E-06
Poly (Youngs Modulus) (E)	1.60E+11
Poly (Poissons Ratio) (v)	0.22
Shear Modulus (G)	6.56E+10
X-axis moment of inertia (Ix)	3.33E-24
Z-axis moment of inertia (Iz)	2.08E-23
Polar moment of inertia (Ip)	2.42E-23
Torsion Constant J	9.98E-24
Initial gap (g0)	2.00E-06
Area	1.12E-08
Number of meanders	4
Spring constant of 1 meander	0.498796
Actuation Electrodes length	1.40E-04
Actuation Electrodes width	8.00E-05

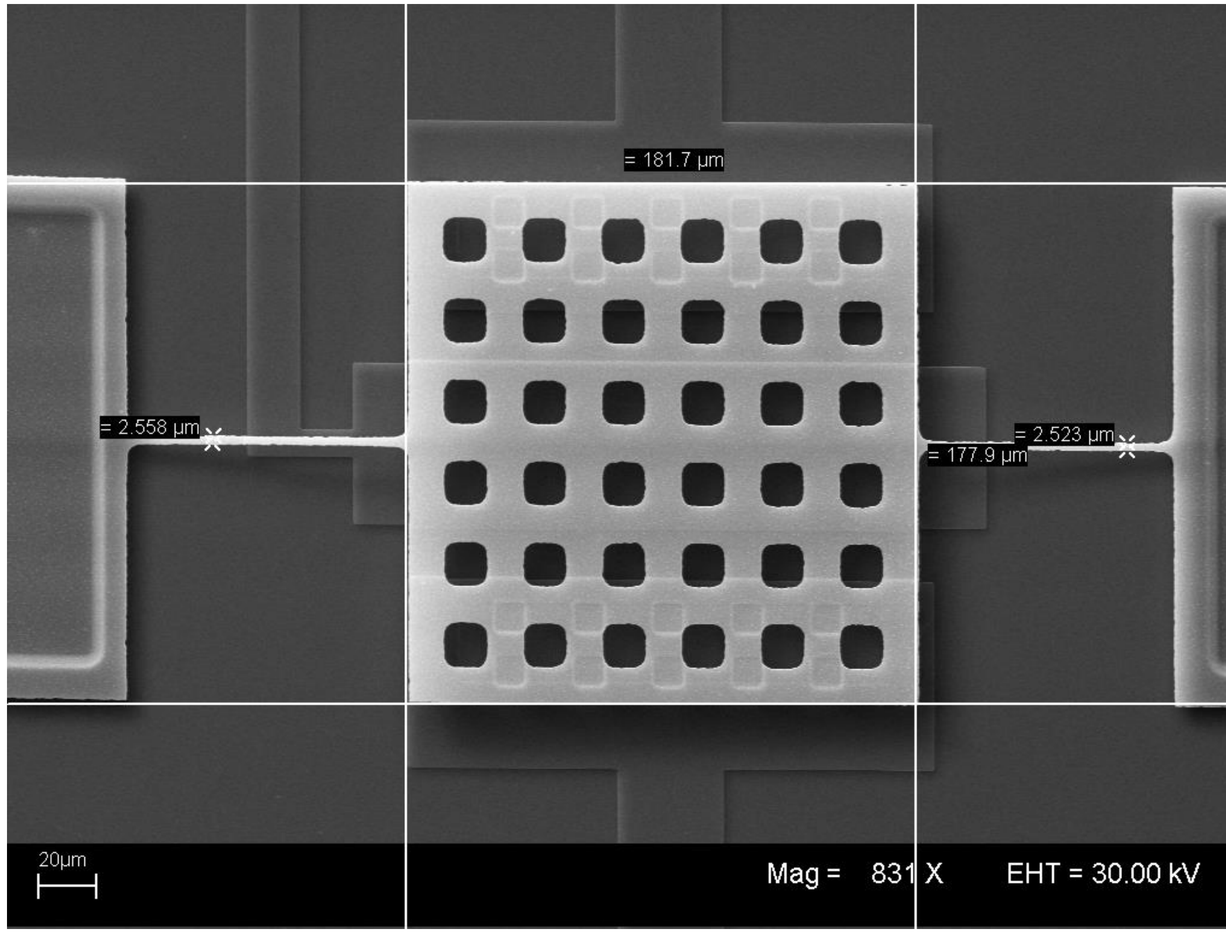
Total spring constant	**K**	**1.995183044**
Pull down voltage	**Vp**	**6.919204614**





RIT SWITCHES BY ANDREW ESTROFF





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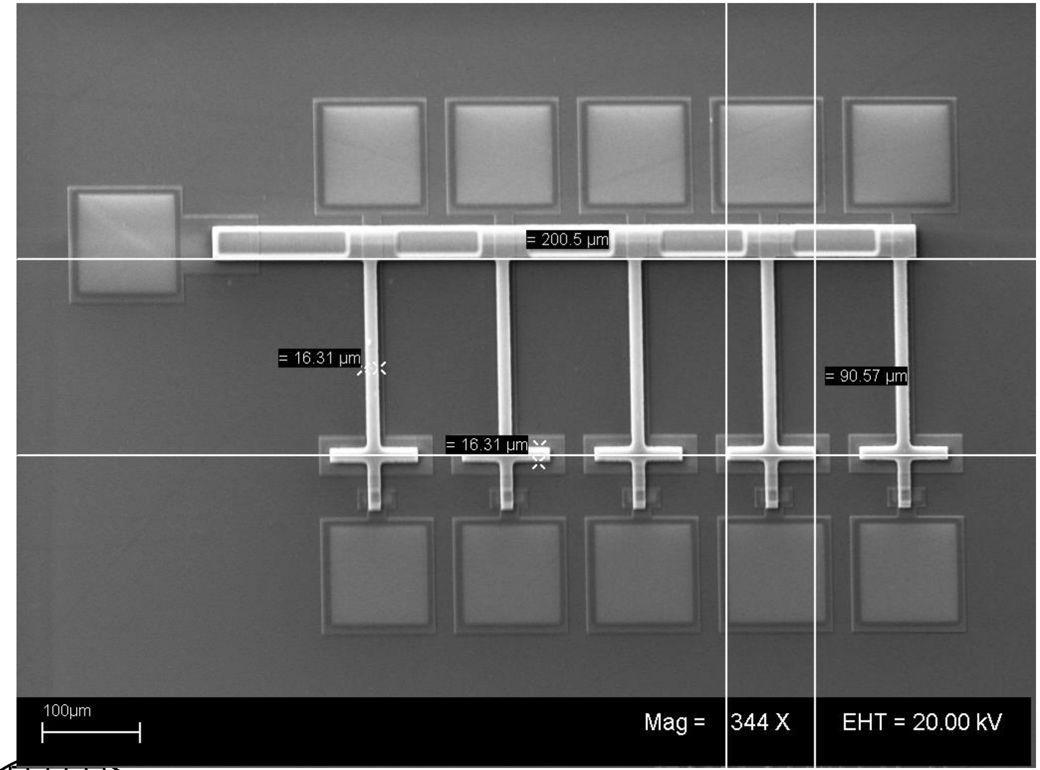
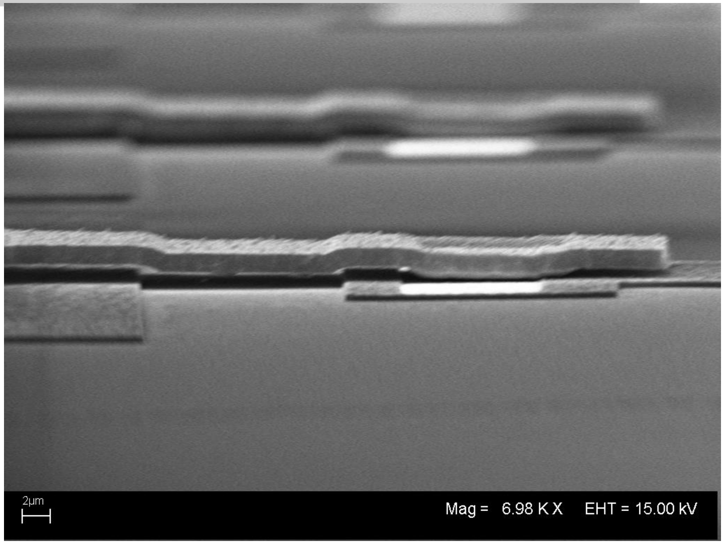
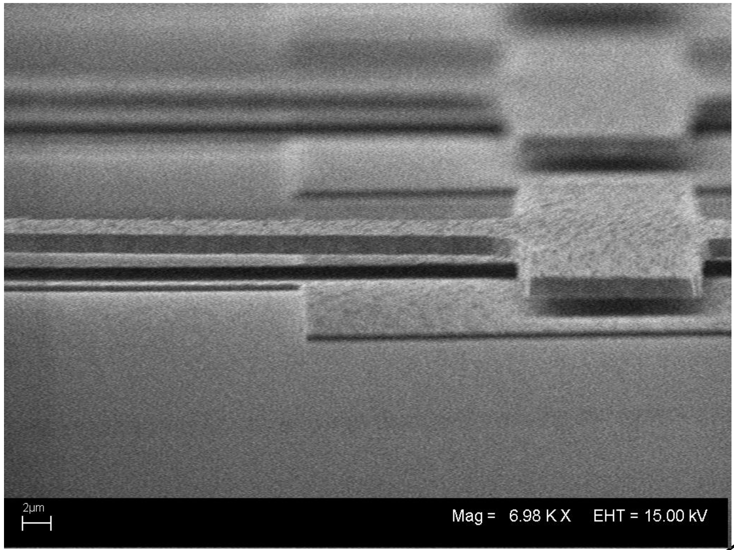
Full Paper

RIT MULTIPLEXER BY ANDREW ESTROFF







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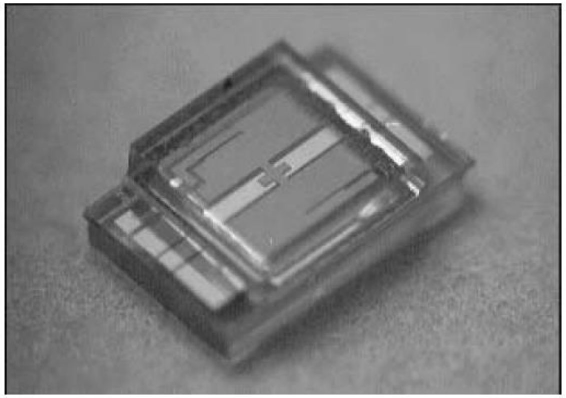
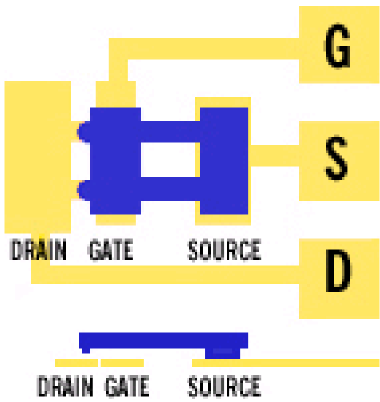
COMMERCIAL MEMS SWITCHES

Omron Co.
2SMES-01



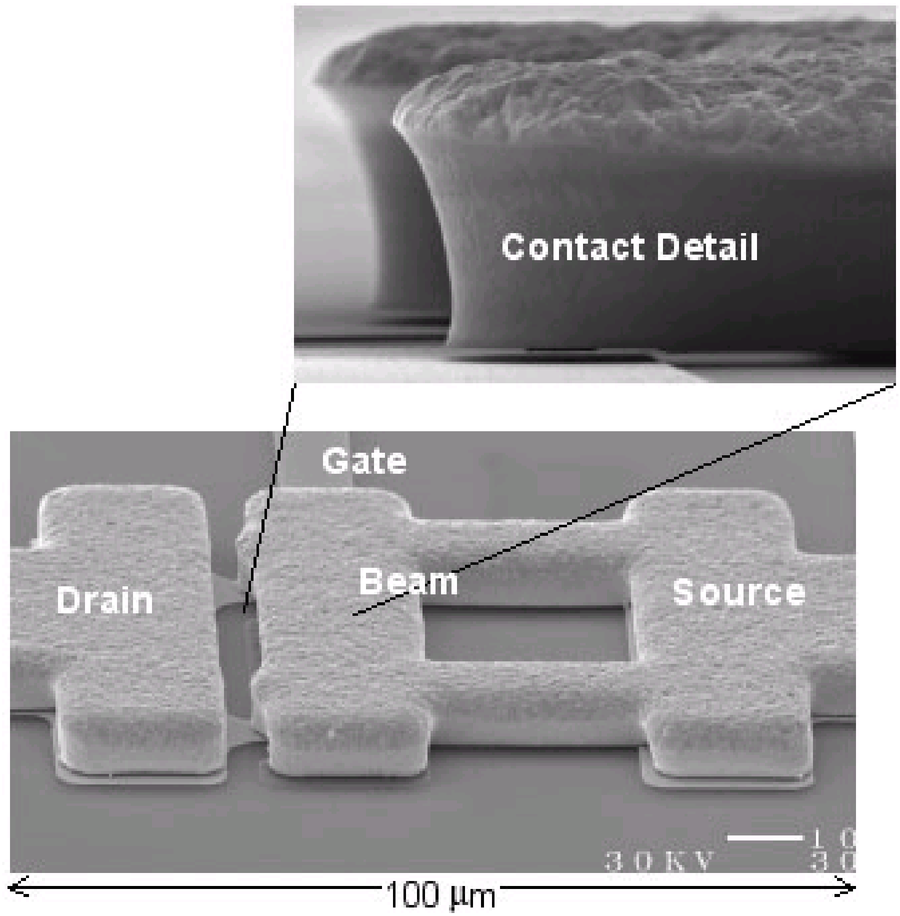
COMMERCIAL MEMS SWITCHES



Radant MEMS Switch *(continued)*

Operation

Under the cap, the beam is deflected by applying a voltage between the gate and source electrodes. The free end of the beam contacts the drain and completes an electrical path between the drain and the source.



RADANT MEMS RMSW200 SWITCH

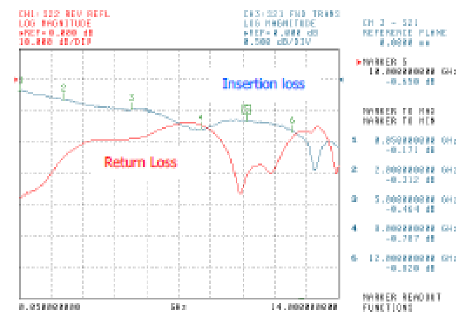
RMSW200-EV12
Evaluation Test Board
DC to 12 GHz for
RMSW200™

General Description

The evaluation test board has one RMSW200™ SPST RF switch connected to two SMA RF connectors, as well as a calibration line. The board requires an external supply to provide the gate actuation voltage.

Switch Insertion Loss
(Test Board minus Calibration Line Loss)

Switch Isolation



Test Board Insertion Loss

Gate-Gnd Voltage	Signal Path State
+/- 90 V	ON
0 V	OFF

RADANT MEMS INC.

- Phone: 978-562-3866
- Fax: 978-562-6277
- Email: sales@radantmems.com

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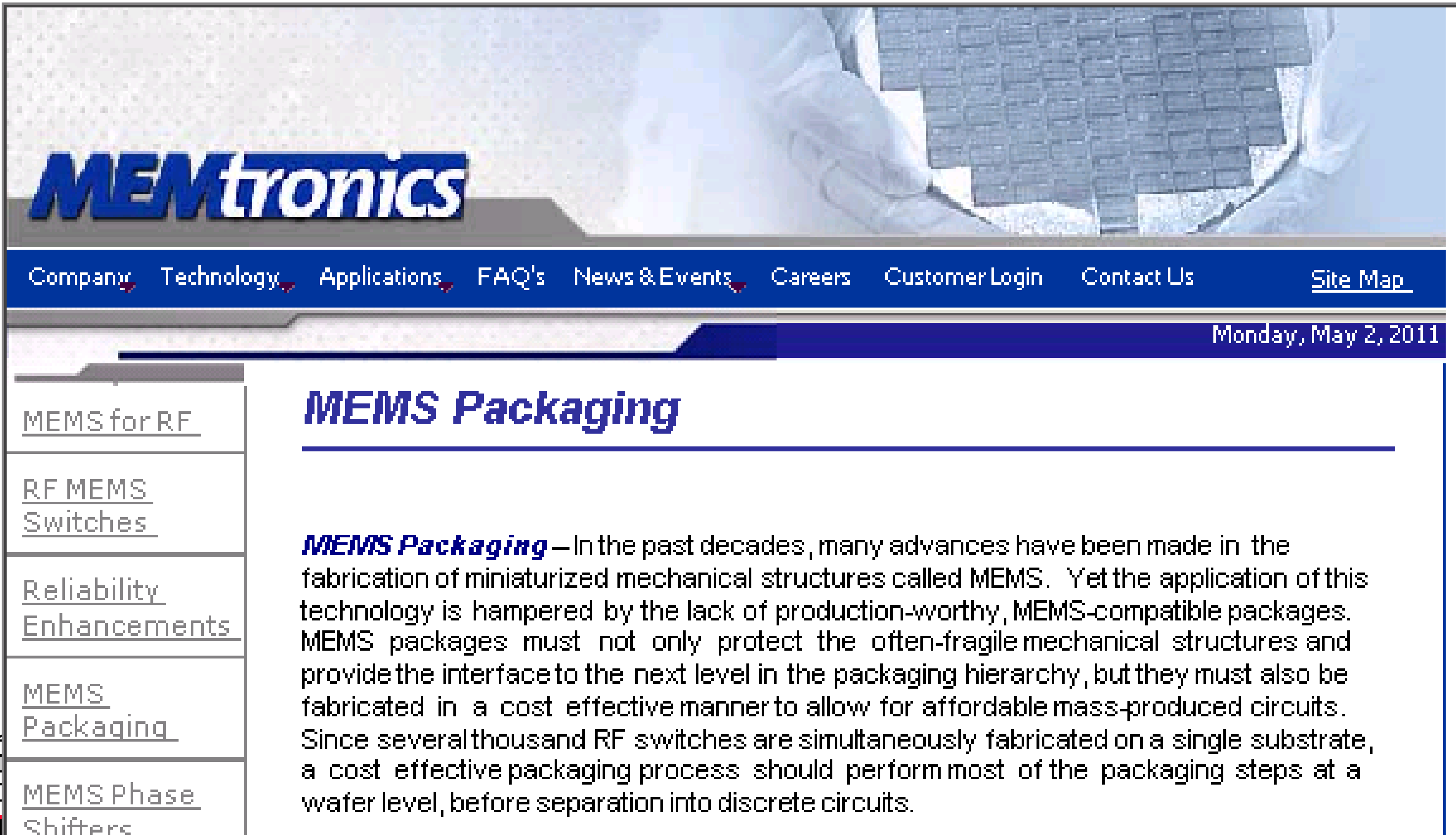
COMMERCIAL MEMS SWITCHES



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Monday, May 2, 2011

MEMS for RF

RF MEMS Switches

Reliability Enhancements

MEMS Packaging

MEMS Phase Shifters

MEMS Packaging

MEMS Packaging – In the past decades, many advances have been made in the fabrication of miniaturized mechanical structures called MEMS. Yet the application of this technology is hampered by the lack of production-worthy, MEMS-compatible packages. MEMS packages must not only protect the often-fragile mechanical structures and provide the interface to the next level in the packaging hierarchy, but they must also be fabricated in a cost effective manner to allow for affordable mass-produced circuits. Since several thousand RF switches are simultaneously fabricated on a single substrate, a cost effective packaging process should perform most of the packaging steps at a wafer level, before separation into discrete circuits.

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HOMEWORK – MEMS SWITCHES

1. Design a process to make a MEMS switch at RIT.

Or

2. Find out who sells mems switches and get some information on their products including price.

Or

3. Find a recent technical paper on MEMs switches. Summarize it on one page and attach a copy of the full paper.