Design And Analysis Of A Novel RF MEMS Switch As An Unit Cell

Dissertation – II

Submitted in partial fulfilment of the requirement for the award of the

Degree of

Master of Technology
in
VLSI Design

by

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Under the Guidance of

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School of Electrical and Electronics Engineering
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PB, India

April 2015

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DISSERTATION TOPIC APPROVAL PERFORMA

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Abstract

The presented work proposed a novel design of low loss RF MEMS capacitive shunt switch. The proposed design introduces a high performance, high isolation and low insertion loss for multi-band frequency application. The compact switch design on quartz substrate is proposed in this paper. The geometry consist of a beam of two symmetric cantlevers type membrane on either side of transmission line. The overall area of the switch is 0.009 mm^2. This paper also presents spring constant, pull-in voltage, R, L and C, passivity, group delay and quality factor of the switch. Halfnium dioxide is used as dielectric material having dielectric constant 25. In this proposed design, fixed central capacitor concept has been utilized to reduce the capacitance in the up-state of the RF MEMS device. The float metal switch shows a return loss below 30 dB, an insertion loss of $<$ 0.054 dB, up to 25 GHz. The proposed switch can be useful for sub-system level and device level for multi-band applications. The overall up-state capacitance can be determined from the area of overlapinng between the free ends of cantilevers and ground planes rather than central overlap area as in case of the conventional movable type bridge based structure approach. An improvement of around 3.5 times in the bandwidth has also been achieved. The performance and reliability of a low-voltage RF MEMS capacitive shunt switch is investigated. The failure mechanism is due to wear, dielectric charging and stiction problems have been avoided through careful designing conditions. The RF MEMS switch is optimized by various factor like, bridge thickness, bridge height, dielectric thickness and dielectric material. The designed switch can be useful at device and sub-system level for the future multi-band .

Acknowledgements

I would like to offer my heartiest salutation to the Almighty God for unbroken health and courage bestowed upon me in all the adversities at every step and at every moment throughout the entire span of my studies and in every aspect of my life. It is matter of great pleasure for me to submit Dissertation-ll on Design And Analysis Of A Novel RF MEMS Switch As An Unit Cell, as a part of curriculum for award of Master of Technology (VLSI Design) degree of Lovely Professional University (Punjab). I am highly indebted to my thesis advisor Mr. Tejinder Singh for his constant encouragement and able guidance without which this work was not possible. It is my pleasure to be thankful to various people, who directly or indirectly contributed in various ways in preparing this Dissertation. Lastly, I would like to thank my parents for their moral support and my friends from whom I received lots of suggestions that improved my quality of work.

Certificate

This is to certify that the Dissertation-ll titled *"Design And Analysis Of A Novel RF MEMS Switch As An Unit Cell"* that is being submitted by "Amit Yadav" is in partial fulfillment of the requirements for the award of degree, *Master of Technology in Very Large Scale Integration*, is a record of bonafide work done under my/our guidance. The contents of this thesis, in full or in parts, have neither been taken from any other source nor have been submitted to any other institute or university unless otherwise cited for award of any degree or diploma and the same is certified.

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Objective of the dissertation [ ] Satisfactory / [ ] Unsatisfactory

Examiner I **Examiner II**

Certificate

This is to certify that Mr. Amit Yadav, bearing registration no. 11301750 has completed objective formulation of thesis titled, *"Design And Analysis Of A Novel RF MEMS Switch As An Unit Cell"* under my guidance and supervision. To the best of my knowledge, the present work is the result of his original investigation and study. No part of the thesis has ever been submitted for any other degree at any University.

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Declaration

I, Amit Yadav, student of *Master of Technology* under *"Department of Electronics and Communication Engineering* of Lovely Professional University, PB hereby declare that this thesis titled, "Design And Analysis Of A Novel RF MEMS Switch As An Unit Cell" and the work presented in it are my own. I confirm that:

- This work was done wholly while in candidature for a masters degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated/cited.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

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To my parents.

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Chapter 1

INTRODUCTION

Micro-electro-mechanical-systems (MEMS) has been revolutionized technologies for the 21st century and has revolutionize both industry and consumer products. RF MEMS switches are the most promising switches in the recent years in MEMS (micro-electro-mechanical-systems) technology[3]. RF MEMS technology have many advantages over the semiconductor devices like GaAs, FETs and PIN diodes because of its low loss and zero power consumption[32]. In MEMS the solution of dielectric problem can be reduced to minimizing the electric field across the dielectric and the atomic layer deposition. MEMS devices can think, sense, communicate and act. The interaction of electronics, light and mechanics together to form a micro-electro-mechanical-systems[4]. MEMS (micro-electro-mechanical-system) is a process technology used to create systems that combine mechanical and electrical component. RF MEMS switches are the specific switches which are designed to operate at micrometer to millimeter size[9]. MEMS is defined by a single fabrication process or it is limited only to a few materials. MEMS devices are fabricated using batch process technique. RF MEMS devices have ability to sense, actuate and control on the micro scale level and generate effects on the macro scale level[17]. MEMS can be found in systems like automotive, medical, electronic, communication, and defence application[52]. Micro-electronics integrated systems can be act as the brain of the systems and have decision making ability to allow microsystems to sense and control the environment[12]. The sensors gather the information from the environment through measuring thermal, chemical, mechanical, biological, optical, and magnetic phenomena[36]. The electronics process these kind of information derived by the sensors and through some decision making capability by microelectronics integrated systems to direct the actuators to respond by, positioning, regulating, moving and filtering, pumping, thereby, controlling the environment for some desired outcome[66]. RF MEMS devices are manufactured by using batch fabrication techniques, as the ICs are manufactured. Reliability, unprecedented levels of functionality and sophistication can be placed on a small silicon chip at a relatively low cost[70]. Examples of MEMS devices are the biomedical, data storage, micro-optics, robotics and fluid control, crash sensors of the airbag deployment system on modern automobiles and the pressure sensors in medical applications. The movement in MEMS switches are of two types: lateral and vertical[67]. In small size devices vertical movement is occurred and in large size devices lateral movement can be occurred. So, with the use of vertical design size can be made quit small[40]. Capacitive switch can be extended to 2 GHZ using high dielectrics. MEMS devices are of different types. These are as : pressure sensors, accelerometers, micro mirrors, gear trains, miniature robot, fluid pumps, micro droplet generators, optical scanners, probes (neural, surface), imagers and analyzers[49]. Micro-Electro-Mechanical-Systems is a device technology that integrates sensors, actuators, mechanical elements and electronics on a single silicon substrate through various micro-fabrication technology[28].

Micro : Small size, Micro-fabricated structures

Electro : Electrical signal / Control

Mechanical : Mechanical functionality

Systems : structures, Devices, Systems

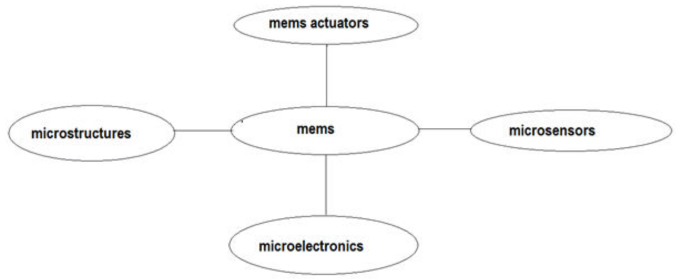

Figure 1.1: Classification of MEMS.

The uses of MEMS and those under study are[50]:

• MEMS used in global position systems and it can be used in courier parcel for constant tracking.

• MEMS sensors used in aeroplane wing. It sense and react to flow of air by changing the wing surface resistance.

1.0.1 Manufacturing Process Of MEMS

Micro-electro-mechanical-systems devices are fabricated using the same processes as like integrated circuits in semiconductors[16]. The most of the MEMS devices are made on silicon wafers or other semiconductor materials. The semiconductor material allows the use of integrated circuits and chemical etching processes used for semiconductor materials are well known and easily adapted to produce machines with microscopic detail.

Material

MEMS are made from a material called Polycrystalline Silicon (Poly-Si) which is a common material also used to make integrated circuits (IC). Poly-Si is doped with other materials like germanium or phosphate to enhance the materials properties[16]. Generally, copper or aluminum is plated onto the polycrystalline Silicon to allow electrical conduction between different parts of the MEMS device. The Material used for fabrication of MEMS, we will discuss the methods used for fabrication[72]. There are various methods to manufacture MEMS devices are enlisted below:

- Photolithography (Surface Micro machining)
- LIGA (Lithographie, Galvanoformung, Abformung)
- Bulk micromachining

Photolithography

Surface micro machining is the most frequently used manufacturing technique. Since no machining is actually done the term micromachining is little deceptive. Micro machining is applied to a broad array of techniques that utilizes photo chemical etching to produce parts. This process is also called the photolithography. This process is used to produce MEMS devices such as micro-valves and micro-motors. In this process ultraviolet (UV) light to "write" images onto the surface of a silicon wafer followed by plasma etching to create the MEMS devices[37].

Bulk micromachining

Bulk micromachining process is done within the bulk of a crystal wafer by selecting and removing the wafer material. It was developed in 1960. The principle is to remove selective amount of silicon from the substrate to form the membrane[25].

LIGA

LIGA is capable of creating finely defined microstructures of up to 1000 m. In the process a special kind of photolithography using X-rays is used to produce patterns in a very thick layers of photoresist[33]. The X-rays are shown through a special mask onto a very thick photoresist layer, which covers a conductive substrate. This resist is then developed.

- The pattern which is formed is then electroplated with metal.

- The metal structures which is produced can be the final product.
- To produce the finished product in that material the mould can then be filled with a suitable material, such as a plastic.

MEMS size have the order of the width of a human hair, because of these extremely small size ,these fabrication techniques takes place in very clean and controlled environment[15]. A piece of very small dandruff on the surface of a wafer is enough to ruin the device. For MEMS fabrication clean rooms having 100 to 1000 particles per cubic feet of air[45].

1.0.2 Classfication Of MEMS

MEMS devices are classified into three types. These are optics, mechanic and electronics. They together with MEMS and form the specialized technology using miniaturized combination of mechanics, electronics and optics. They uses batch Micro-opto-electro-mechanical systems (MOEMS) is also a subset of microsystems technology[30]. processing technology for their fabrication and design. The difference between the micro-systems technology (MST) and MEMS is that MEMS use semiconductor process to create a mechanical part[62].

1.0.3 MEMS configuration

MEMS have two basic circuit configuration used in RF to millimeter circuit design. Series switch and shunt switch are the two basic configuration. The series switch act as a open circuit when no bias is applied and act as a short circuit in the transmission line when a bias is applied. The ideal switch have zero insertion loss in the down state position and infinite isolation in the up state position. These switches are used extensively for 0.1 to 40 GHz. application[32]. The MEMS series are metal to metal contact type and operates with DC-50 GHZ and having low upstate capacitance and also 10-50 GHZ with capacitive contact and having low upstate capacitance.

The second type of switch is called shunt switch which is placed in shunt between the ground and transmission line. The shunt switch either connect it to the ground or leaves the transmission line depending upon the bias voltage[61]. When bias voltage is applied it act as an OFF state and when no bias is applied it act as an ON state. When no bias is applied the shunt switch have zero insertion loss and when bias is applied the shunt switch have infinite isolation. The MEMS shunt switch having DC- 60 GHZ with metal to metal contact type and having low inductance to the ground and 10-200 GHZ with capacitive contact type and having low inductance to the ground[69]. By changing the value of capacitance between the transmission and movable structures, the ON and OFF state can be achieved.

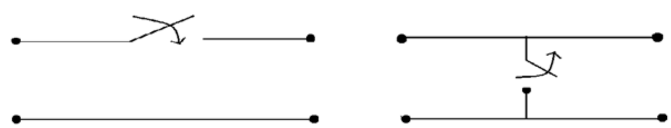

Figure 1.2: Series and shunt configuration of the MEMS switch.

1.0.4 Actuation Mechanism

MEMS switches uses four actuation mechanism. These mechanism are Electrostatic actuation, Electro-magnetic actuation, Electro-Dynamic actuation and Electro-thermal actuation, peizo-electric actuation. Most of the RF MEMS switches uses electrostatic actuation mechanism because it offers almost zero power consumption, easy and well known technology and specially allows upto 50V Vdc bias[71]. There are two main problems by using electrostatic actuation in RF MEMS switches : low mechanical stability and high actuation. The high actuation voltage induces malfunction by the charge trapping problem and degrade lifetime. To lower the actuation voltage meander spring type and push-pull concept have been utilized[39]. MEMS switching contact are of two types: capacitive and resistive[2]. Capacitive switches are more compatible with electrostatic actuation than resistive contact type. In capacitive contact type switching of DC signal is not required. It allows switch configuration. Capacitive contact type have more reliability than resistive type. capacitive contact type have basic technology available with Ta2O5. MEMS have two driven configuration: switch and relay. Switch have simple structure than relay and has robust nature and having pin compatibility with FETs and PIN diodes. Actuation voltage meander spring type and push-pull concept have been utilized. The meander spring type switch increase the switching speed and improve spring constant and also reduce the switching time[20]. Electro-magnetic actuation resolve the above problem[64]. It increase the mechanical stability and use low actuation mechanism. Electro-magnetic produce large force to allows radio frequency MEMS switches to have a mechanical robust structure. Because these switch can be implemented with membrane having high spring constant. Electro-magnetic actuation also independent of initial position of actuator[25]. Electromagnetic actuation provide constant current to be applied during a given switching period, so it requires relatively large power other than all mechanisms.

1.0.5 Why MEMS

• MEMS technology allow miniaturization of existing devices[63].

• MEMS offers the solutions which is not attained by macro-machined products. For e.g., Capacitive pressure sensor is capable of sensing the pressure of the order of 1 m Torr. This is not possible with macro-machined capacitive diaphragm[11].

• Because of micro-machined technology of MEMS devices they are very useful in biology-microelectronics and optics-electronics[6].

• MEMS using batch fabrication technology to manufacture the electro mechanical systems, to increasing the reliability and decreasing the cost.

• MEMS allows the integrated systems, Viz., sensors, actuators, etc. in a single package and offers the advantage of performance, reliability, ease of use, cost etc.

1.0.6 Performance comparison of RF MEMS, PIN and $FETs$

Table 1.1: Comparison between MEMS, PIN and FETs

Parameters	RF MEMS	$PINs$	$FETs$
Voltage	20-80	3-5	3-5
Currnet (mA)	0	3-20	0
Capacitance ratio	40-500	10	n/a
Cutoff frequency (THz)	20-80	1-4	0.5-2
Isolation (1-10 GHz)	Very high	High	medium
isolation (10-40 GHz)	Very high	high	low
isolation (60-100 GHz)	high	medium	none
Power handling (W)	< 1	< 10	< 10

RF MEMS switches have many advantages over PIN and GaAs switches in terms of almost zero power consumption, high isolation, low insertion, much lower intermodulation distortion, light weight, small footprints, high linearity and low cost. Due to these advantages RF MEMS are used in RF to millimeter wave design[44].

1.0.7 Difference Between ICs And MEMS

Most silicon based MEMS and integrated circuits are fabricated using same microfabrication technology. These two devices are different in many aspects[46]. These are enlisted as below:

Table 1.2: Comparison between ICs and MEMS

SR. NO.	MEMS	ICs
1	3D complex structure.	2D structure.
2	MEMS doesnt have any basic building block.	Basic building block of ICs are trans
3	May have moving parts.	No moving parts are in ICs.
4	Packaging is very complex.	Packaging techniques are well devel
5	May have interface with external media.	Totally isolated with media.
6	Functions include chemical, optical and biology.	ICs have only electrical function

1.0.8 Applications Of MEMS

• Automotive application: MEMS devices are used as sensors like internal navigation sensors, accelerometers, gyroscopes, air conditioning compressor sensor, Brake force sensors, suspension control accelerometers, airbag sensors, pressure sensors and intelligent types[31].

• Automotive radars.

• Satellite communication systems.

• Wireless communication systems.

• Silicon pressure sensors e.g. disposable blood pressure sensor and car tyre pressure sensors.

• Accelerometers in consumer electronics devices like personal media players, cell phones, game controllers and a number of digital cameras[10].

• MEMS devices are used in Inkjet printers, which use thermal bubbles ejection or piezo-electrics to deposit ink on papers.

• Instrumentation systems: These requires high performance switches, phase shifters, SPNT networks.

• Radar systems for defence applications: missile systems, phase shifters for satellite based radars and long range radars.

• Biochips for detection of biological agents and hazardous chemical.

• Microsystems for high throughput selection and drug screening.

• Micromachined scanning tunneling microscopes (STMs) and chemical applications.

• Electronics application: disk drive heads, projection screen televisions, inkjet printer heads, earthquakes sensors, mass data storage, avionics pressure sensors.

• Biomedical and biotechnology applications: muscle stimulator, drug delivery systems, blood pressure sensors, implanted pressure sensors, prosthetics, pacemakers, miniature analytical instruments.

• Communication systems: RF Relays, switches and filters, fibre-optic network components, voltage controlled oscillators (VCOs), tunable lasers, splitters and couplers[58].

• Defence applications: surveillance, munitions guidance, arming systems, data storage, embedded systems, aircraft control.

• Anti-theft devices.

• Home security devices.

• Computer screen scrolling and zooming devices.

• Image stablizers cameras and phones.

• Clinical laboratory testing.

1.0.9 Advantages of MEMS

• Extremely low power consumption: Electro-static actuation, leading to a very low power dissipation. This is very useful in large re-configurable antenna or phased array requiring thousands of elements[65].

• Very high isolation: RF MEMS switches are fabricated in air so they have very high isolation and having low off state capacitance resulting in very high isolation.

• Very low insertion loss: RF MEMS switch having very low insertion loss.

• Very high cut off frequency: MEMS switches have very high cutoff frequency (30-80 THz). While cutoff frequency of PIN diode is 1-2 THz and of FETs is 0.2-0.5 THz.

• Easy integration and low cost: RF MEMS switch are fabricated by surface micromachining technology.

• Intermodulation products: MEMS switches having low intermodulation products because these devices are mostly linear. MEMS devices performance is better than PIN and FETs switches around 30 db.

1.0.10 Disadvantages of MEMS

• Relatively low speed: The switching speed of most MEMS switches are around 3-50 μs.

• Reliability: The reliability of MEMS switches are lower than PIN diodes and FETs[23].

• Power handling: Most RF MEMS switches can not handle power more than 0-20 mw with very good reliability[56].

• Packaging: packaging environment should be inert atmospheres (argon, nitrogen, etc.) and in very low humidity. The packaging of MEMS switches also adversely effect the reliability of switches[49].

• Cost: MEMS switches having low cost but in comparison of semiconductor PIN diodes it is more because it is fabricated process require complex requirement[55].

Chapter 2

LITERATURE REVIEW

2.1 Viviana Mulloni (2013)

This paper proposed the optimization technique of long term reliability of RF MEMS switch. In this paper a carefull study of geometrical and mechanical characteristics of the clamped-clamped dielectric less MEMS switches in order to increase their reliability performance in terms of long term actuation and switch property control behavior. This all effect the switch membrane design. Which is made stopping pillar dimension and more robust. This strategy also reduceing charge injection and charge non-uniformity. This design is more resistance to high bias voltage and the membrane deformation during actuation. Also the optimization strategy aimed at charging non-uniformity and reducing charging can not be effective. This strategy is used to reduce the wear and modification during prolonged actuation.

2.2 Gabriel M. Rebeiz (2013)

In this paper geometry design is improved in a capacitive RF MEMS switch reliability. This is achieved by reducing the stress gradient and intrinsic biaxial stresses on the switch membrane. The intrinsic biaxial stress causes the stress stiffness and minimize the curling. By varying the curling constant we achieved stiffness of the switch. Stress gradient and biaxial stresses affect the actuated mirrors. Topology optimization can help to improve the stiffness of the switch.

2.3 H. Jaafar, K.S. Beh. (2014)

This paper presents the design constraints, key performances and fabrication technology of the RF MEMS switch devices. A detail study of actuation voltage, insertion loss, ease of cost, reliability and cost of fabrication and application are compared and all the parameters are discussed. Lot of optimization technique is used to reduce the actuation voltage using a high dielectric material. Hinge structure and CMOS process technique are explored. The advantage of this switch is high switching speed , low cost and commercial availability. The disadvantage of this switch is low isolation, high insertion and require large current to operate.

2.4 Ryan C. Tung, Adam Fruehling (2014)

Electrostatic actuated switches are suffered from discrete switch bounce during closure the switch that increases the wear and tear and effects the switching time and movement of switch. In this switch Doppler vibrometer to analysed the switch response. To understand this concept , we develop a multiple type eigenmode model of the cantilever switch with repulsive, adhesive contact forces, electrostatics and rarefied gas damping . And find that the high frequency bounces within a single bounce. This process evaluates the multiple time scale involved in bounce events. This paper also presents the study of dependence of the phenomenon on the contact stiffness and adhesion. It also shows the adhesion, actuation voltage in dc contact switches, landing pad stiffness can diminish or increase repeated impacts during actuation. This paper proposed a very compact model and numerical simulations is conducted to explain multiple time scale processes. Multiple time scale bouncing results the intermittent excitation of 2^{nd} eigen mode system during the contact events. So by this paper we use to understand the bouncing phenomenon and bounce related wear in radio frequency MEMS switches.

2.5 Mahesh Angira and Kamaljeet Rangra (2014)

This paper represents the capacitive shunt RF MEMS switch is presented. In this proposed design, a float metal concept is utilized. The structure of the switch is also asymmetric on either side of transmission line to implement the shunt switch. This paper presents the high isolation in C, X and Ku bands. Cantilever beam is used in this paper. Three isolation peaks has been observed at different frequencies. These isolation peaks are 42.63, 44.22, 47.75 dB when right, left or both the cantilevers are electro-statically actuated in down state position respectively. Insertion loss has been improved as compare to other switches. Also pull-in voltage reduced by 50

2.6 Kamaljit Rangra And Mahesh Angira (2014)

This paper present the capacitive shunt RF MEMS switch having low insertion loss . In this design float metal concept is utilized. By reducing the capacitance in the up-state position insertion loss is improved. Also isolation can be improved by changing the inductance in the down-state position. Switching time is also improved and bandwidth is also improved around 2.5 times other than conventional switch. This proposed switch is useful for many-band application.

2.7 Tejinder Singh (2014)

This paper present the novel design of combination of series and shunt membrane. By doing this high isolation is achieved. Both the membranes (series and shunt) are designed in this way to work on same actuation voltage. In this paper electrostatic actuation is used. The advantage of this is that the switch have low power consumption. By providing meanders in membranes low voltage operation is achieved. Overall size is very less and the switch is very compact. The switch shows high isolation and low insertion loss. In this paper various parameter like RF performance, Q-factor, eigenfrequencies are analyzed. The operating voltage is also very less as compared to high isolation operation of other switches.

2.8 Bansal (2014)

This paper disscussed the failure mode and mechanism. The failure phenomenon occured when the switch geometry failed to actuate. The major failure modes in RF MEMS switches are: creep, electromigration,pitting of contact surfaces, delamination, stiction,fracture, electrostatic discharge and wear. This paper presents an updated review on failure mechanism such as wear, creep, fatigue. Failure in RF MEMS can cause due to mechanical, electrical, biological, chemical and thermal.

2.9 Fedder (1999)

This paper describes the stiction, creep and wear degradation phenomenon. Stiction in RF MEMS has been a catastrophic failure mode in switches. surface roughness and environmental conditions can cause the stiction problem. The large surface to volume ratio of RF MEMS switches makes the interfacial friction, wear and stiction. The self-assembled monolayers (SAMs) and hydrophobic films are able to release stiction problem. A wear resistant anti-stiction coating is highly desirable for preventing the RF MEMS switches from stiction, wear and friction.

2.10 Arab Ali (2014)

one dimension of the geometry is reduced to nano range and the two other are remains large then the structure is called as a quantum well. By reduing the two dimension of the geometry to nano range and the other remain same, then the nano structure is called as a quantum wire. By reducing all the three dimension of the geometry to a nano range, then the structure is called quantum dot. This paper investigated and developed the techniques for assessing the reliability of 1-D nano-components. After then, he experimented to developed the techniques to assess a 2-D nano-components, e.e., nano-discs and nano-films.

As the feature size are reduced upto 10 nm, scaling goes up with serious restriction. The low switching speed restrict their use in the applications such as RF (radio frequency) where the high speed is not required. The voltage up-converter components are required due to their large actuation voltage requirement. By downscaling MEMS to NEMS, these restrictions (actuation voltage and switching speed) are eliminated. An evaluation and systematic analysis of (CNT) carbon nano-tube based NEMS devices are presented and discussed their advantages by.

2.11 Yang (2010)

Due to the scarcity of data, Bayesian approach is of more importance in reliability of the nano-scale structures. While some research has been investigated, still there is a room to apply this tool and philosophy in the reliability assessment of MEMS devices. This paper developed and experimented a full Bayesian analysis on change point, cost optimal burn in time and hazard rate for a nano-scale high dielectric constant gate dielectric film. Weibull exponential distribution is used to inference and plot the L-shaped hazards rate function. They observed this function for nano-electronic devices. The posterior and prior total expected costs can be minimized by optimizing and evaluating the burn-in time using the proposed model.

A flexible nonparametric Bayesian approach is presented by for modelling the L-shaped hazard rate functions. Its change point for the novel nano-electronic device called metal oxide semiconductor (MOS) capacitor with the fixed oxide high dielectric constant gate dielectric. This proposed method can be used to examine the reliability of novel nano-electronic devices. When the failure mechanism are not known, then the current parametric reliability design are not applicable, and the limited data are available.

An experimental and analytical study on reliability of the micro-mirror with the interdigitated cantilevers are able of symmetrical bidirectional rotation are presented by. They investigated that, the reliability of these devices can be improved by using the bending interdigitated cantilever instead of the conventional twisting hinge. The experiment shows that the von mises stress for cyclic rotation in the micro-mirror with twisting hinge structure is of two times greater than the stress in the micro-mirror with the interdigitated cantilever beam. This paper evaluate a series of two component and single component ionic liquids ultra thin films used in MEMS devices and study their surface properties and formation by using ellipsometric thickness measurement, X-ray photoelectron spectra and AFM. The nano-tribological behaviors and adhesive of the films were examined by a colloidal probe.Their study can help to design the ionic liquid films.

2.12 Geetha (2013)

This paper investigated the results on design optimization. The modification can only affect the membrane of the switch. For a fixed value of central conductor and all other parameters are varying, we can observed the performance of RF MEMS switch. In the ON state, the insertion loss is varied with capacitance. By decreasing the capacitance in the ON state, we can increase the insertion loss. By varying only the bridge width and all other parameters are kept fixed, the up-state capacitance is effectively varied and hence changes the insertion loss of the switch. The magnitude of S_{11} increases with the increase in bridge width.

In the OFF state both the capacitance and inductance determine the switch resoponse. If we vary the bridge width and all other parameter kept fixed then the variation of resonant frequency can be observed. Both the capacitance and inductance are varied, if the variation of bridge occured along the length. The bridge inductance is determined by that portion of the bridge which is over the CPW slot and is independent of that portion which is over the center conductor. The center conductor bridge area determines the capacitance. Hence the resonant frequency varied with the bridge width.The study observed that narrow bridge width and wider CPW slot results in large inductance value. The spring constant varies linearly with bridge width. So, pull in voltage is actually independent of bridge width. Changing the electrode area by varying the bridge width can tune the switch into different frequencies.

2.13 Philippine (2013)

We intend to accommodate a expositery conclusion on MEMS reliability by covering extant literature on design optimization, offers a starting point for researchers and pinpoint the ideas for future research. A systematic and comprehensive survey on the reliability research has been presented. Over the last decade MEMS have been vastly expanded, as reviewed in this survey. Although a research on reliability is still incomplete. A lot of research is required to understand the reliability issues in MEMS. There is still a lack of research on system level reliability. As reviewed in this survey, the methods for burn-in analysis and accelerated life testing is of great importance to facilitate the further commercialization of MEMS devices.

An electromagnetic modeling in RF MEMS is used to evaluate the RF performance in the down-state and up-state. As reviewed, the isolation bandwidth can be obtained by varying the inductive section with large dimension. Sam is an most effective measure to prevent sriction in MEMS devices and reduces the surface energy. There is an unlimited demand of reliable anti-stiction MEMS devices in today's market.

2.14 Dadgour (2011)

The reliability of cantilever beam using the dynamic Raman spectroscopy that enables the direct data collection of the Weibull fracture test on MEMS devices. The obtained measurement resolution and the primary results examines that Raman spectroscopy is a suitable approach to measure dynamic strains induced in MEMS geometry. This paper study the effects of plasma-enhanced CVD (chemical vapour deposition) on the dielectric charging of silicon nitride films ued in MEMS devices. A high correlation in the electrical properties of the silicon nitride films obtained from both the techniques was observed. This proposed method can be used to determine the dielectric layer which is more reliable for an electrostatic actuated MEMS devices. A technique based on mix-mode transient circuit simulation to examine the robustness of ESD protection in NEMS devices.

Due to the very broad range of loading rates and types, it is very important to develop the techniques for analyzing the dynamic failure of Au RF MEMS geometry.

This paper also analyzed the dynamic failure of MEMS devices over a broad range of loading types and rates. Three investigated method were developed for analyzing dynamic response of The MEMS devices. They used to determine the maximum threshold value of the dynamic loading rates where no loss can be observed. The proposed paper analyzed the effect of process variations on the device.

This paper investigated the techniques to model and analyze the reliability of the MEMS devices. They proposed the system level reliability based on surface methodology. They presented experiment and simulation based lifetime estimation method for component, material and system levels. The study investigated that thermo-mechanically reliable design for the micro-system can be achieved by combined computational and experimental approach.

Chapter 3

SCOPE OF STUDY

There is a good scope of research when it comes excellent result of switch parameters like isolation, insertion, return loss, stress analysis, pull-in voltage, Q-factor. A novel design of RF MEMS Capacitive shunt switch is reported with high isolation and low insertion loss in X, K and Ka band is proposed. The switch consists of the cantilever type membrane and both the membrane are operated with same actuation voltage. We need such a switch which have low actuation system, high isolation, high stiffness. The insertion loss can be reduced by reducing the capacitance in the up-state position. A float metal concept and fixed central capacitor is also observed for better insertion. We need to care about switch reliability and bounce phenomenon and also minimizing the curling effect.

Intense research has been made since last decade in the field of MEMS. Increasing the reliability of switch, Increasing the isolation, increasing the return loss, decreasing the insertion loss of the switch are the key parameters which are still under research. The voltage requirement is very less as compared to the other high isolation operation devices.

RF MEMS switches have many advantages over PIN and GaAs switches in terms of almost zero power consumption, high isolation, low insertion, much lower intermodulation distortion, light weight, small footprints, high linearity and low cost. Due to these advantages RF MEMS are used in RF to millimeter wave design. Micro-electro-mechanical-systems (MEMS) has been revolutionized technologies for the 21st century and has revolutionize both industry and consumer products. RF MEMS switches are the most promising switches in the recent years in MEMS (micro-electro-mechanical-systems) technology. RF MEMS technology have many advantages over the semiconductor devices like GaAs, FETs and PIN diodes because of its low loss and zero power consumption. In MEMS the solution of dielectric problem can be reduced to minimizing the electric field across the dielectric and the atomic layer deposition. This RF MEMS switch can be used in the application where the RF performance is the main concern over switching speed such as space systems and wireless communication.

Chapter 4

OBJECTIVE OF STUDY

- There is a good scope of research when it comes excellent result of switch parameters like isolation, insertion loss, return loss, stress analysis, pull-in voltage, Q-factor and pull-down voltage.
- Stress analysis is required to observe the maximum stress gradient and improve the areas which are prone to fatigue.
- To design a very compact and small size and low cost switch which have Excellent RF performance.
- To increase the reliability of the switch.
- Both the cantilever operates with same actuation voltage.
- To decrease the creep effect, stiction, wear degradation and dielectric charging problem.
- It is not an easy task to obtain values of all these parameters because these parameters are in trade off with each other. So there is need to optimize these parameters.
- Power handling is a major drawback of these switches which should be improved.

- To optimize the design for better RF performances.
- The switch should operated in multiband frequencies.

Chapter 5

Design tools and materials

For implementing the switch we use ANSYS, It is a commercial FEM solver for electromagnetic structure. Basically high performance structure simulator is the full wave electromagnetic simulator. ANSYS is used to calculate the parameter such as resonant frequency, S- parameters, and fields. It allows to solve any 3D geometry. Ansoft is the tool used for high frequency and high productivity, development and also in virtual pointing.

5.0.1 System requirement

It can operate in Windows XP(32/64), minimum 128 Ram, 8 MB video card minimum, Mouse or other pointing device, CD- ROM.

Comsol multiphyscis is used to calculate spring constant, vertical displacement, von mises stress. First we create a model in the model wizard. Select the space dimension for your component. Now add one or more physics interface. Select the study type that will used for computation. Model builder is the tool where u can define the model and its component. Parameter used in the model are user defined constant scalers. Specify the mesh element size. when we complete the design then we defined the material. After defining the material, we set the boundary condition.

Set the fixed constraints and boundary load. Select the total force as load type and the negative sign indicates the force applied in negative Z direction.

5.0.2 Material

The substrate is the base of the switch and it have uniform electrical properties and chemical resistance. Quartz substrate has high melting point. Halfnium dioxide is used as dielectric material. Hfo2 has high dielectric constant equals to 25 is more than silicon nitrate and silicon dioxide. The material node contains the material property. Mostly we use gold or aluminium for making the membrane. Quartz glass and silicon are used as substrate. Silicon nitrate, silicon dioxide and halfnium dioxide are used as dielectric material. The dielectric constant of halfnium dioxide is 25, silicon di-oxide is 4 and silicon nitrate is 7.

Chapter 6

Research methodology

By intensive literature review of various papers we come to know that MEMS technology is replacing all those conventional technologies which are bulky and having poor performance. Despite the fact MEMS switches are not much reliable as compared to those conventional switches but they are used in RF application due to their excellent RF performance and very wide band of operation. Theoretical work is the first step to calculate various parameters of switches. These parameters include actuation voltage, Spring constant of flexure, Capacitances related to the switches and switching time of switches. We shall calculate the isolation, insertion loss, actuation voltage, pull down voltage, spring constant, capacitance, quality factor, R, L and C parameter. We will compare these parameters with the older records. FEM (Finite element modeler) is used to design flexures. Graphs of parameters like force required to actuate the switch and spring constant are extracted using FEM simulators. Parameters like stress analysis at various corners and maximum stress at any flexture is analysed in FEM simulator. Pressure distribution at various parts of flexures is extracted from COMSOL. At last comparing simulated results and analytical results we conclude that simulated results shows good performance. The procedure to be followed in the research is:

- Problem definition.
- Detailed background literature review (reading research papers, journals, etc.).
- Developing a theory to work on, or planning a solution to the given problem.
- Designing a model to work on.
- Coding and testing.
- Evaluation of results and gathering statistics.
- Generalization of results.
- Preparation of reports.

Chapter 7

Proposed work

The presented work proposed a novel design of low loss RF MEMS capacitive shunt switch. The proposed design introduces a high performance, high isolation and low insertion loss for multi-band frequency application. The compact switch design on quartz substrate is proposed in this paper. The geometry consist of a beam of two symmetric cantlevers type membrane on either side of transmission line. The overall area of the switch is 0.009 mm^2. This paper also presents spring constant, pull-in voltage, R, L and C, passivity, group delay and quality factor of the switch. Halfnium dioxide is used as dielectric material having dielectric constant 25. In this proposed design, float metal concept has been utilized to reduce the capacitance in the up-state of the RF MEMS device. The float metal switch shows a return loss below 30 dB, an insertion loss of < 0.054 dB, up to 25 GHz. The proposed switch can be useful for sub-system level and device level for multi-band applications.

In the presented paper, RF MEMS capacitive shunt switch based on fixed central capacitor concept has been suggested. The insertion loss of the switch has been improved by minimizing the capacitance in up-state. By changing the inductance in down-state position, isolation is tuned in different bands. The presented capacitive MEMS switch geometry is shown in Fig. 7.1.

7.1 Device principle and working

The presented RF MEMS capacitive shunt switch has a CPW line for signal transmission on a 100 μm thick quartz substrate and the dielectric layer of Hafnium Dioxide is used due to very high dielectric constant. The geometry consist of cantilever beam on the either side of the transmission line. When both the cantilever beam are in the up-state position, the switch is ON. Insertion loss is achieved in the ON state. By pulling down the right, left, and both cantilever beam in down state, the OFF state can be achieved through electrostatic actuation. Isolation characterstics is defined in OFF state. The electrode at the bottom provides actuation as well as hold down force to the memberane. The actuation voltage is provided to capacitive shunt switch to OFF the switch. The output and input RF ports are physically connected to each other and therefor normally switch is ON. The RF MEMS switch is based on a 50 CPW signal line of 70/60/70 μm. The cantilever structure based switch results in high reliability and very high temperature stability in comparison of fixed-fixed beam. Optimized RF MEMS switch having cantilever beam has lower high stiffness, actuation voltage and excellent performance. The dimensions used in designing the capacitive shunt switch have been given in Table 8.4. To realize the multi-band functionality of the switch, the inductance value has been put different on the either side of cantilevers structures. Figure 7.2 shows the top view of designed switch.

7.2 Electrical modelling

MEMS capacitive shunt switch having two sections of t-line and a lumped CLR model with the capacitance having a down-state and an up-state value. The geometry of the switch is suspended at a gap height g_o above the dielectric layer on the signal line. The ratio of up-state capacitance to the down-state capacitance defines the RF response of the MEMS capacitive shunt switch. The CPW signal line are of length

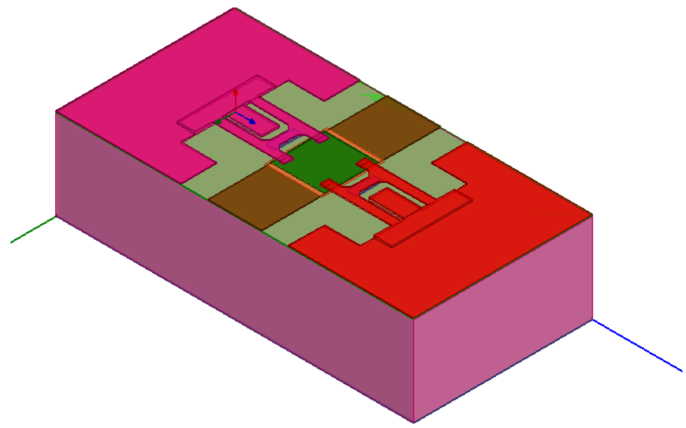

Figure 7.1: 3D view of compact capacitive shunt switch

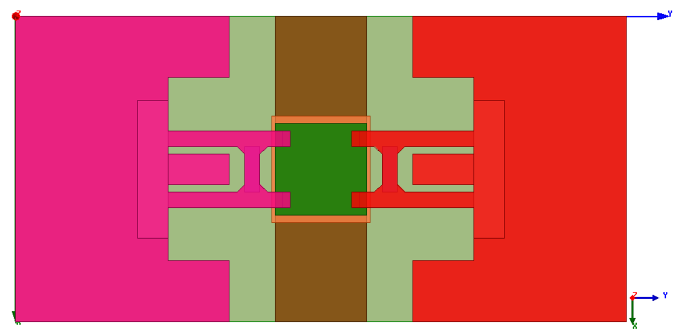

Figure 7.2: Top view of designed switch

$(\frac{W}{2}+l)$, Where l is the distance form edge of the MEMS bridge to the reference plane. The switch shunt impedance is - The switch shunt impedance is

$$Z_s = R_s + j\omega L + \frac{1}{j\omega C} \tag{7.1}$$

with $C = C_u$ or C_d the value of C depends upon the position of the switch either the switch is in up-state or in down-state. The LC resonant frequency of the switch is-

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

The RF MEMS switch impedance can be calculated by-

Table 7.1: Dimensions of the designed RF MEMS switch

S. No.	Dimensions	Value (μm)
1	Length of bridge	100
2	Width of bridge	90
3	Length of bridge flexures	80
4	Width of bridge flexures	10
5	Thickness of all exures	1
6	Electrostatic Gap (go)	2
7	Float metal thickness	0.5
8	signal line dielectric thickness (t_{ox})	0.15
9	Substrate dielectric thickness	0.5
10	Electrodes Area $\times$ 2	30 $\times$ 10
11	Substrate Area	400 $\times$ 200

$$Z_s = \begin{cases} \frac{1}{j\omega C} & \text{for} f << f_0; \\ j\omega L & \text{for} f >> f_0; \\ R_s & \text{for} f = 0. \end{cases}$$

The lumped CLR model of the bridge behaves as the capacitor below the resonant frequency. At the resonant frequency, the model behaves as the bridge resistance R_s and behave as an inductor L above the resonant frequency. This MEMS bridge inductance is dominated by the portion of the bridge over the signal line gaps. The portions of the RF MEMS bridge over the CPW conductor and the ground plane provides the insufficient bridge inductance because current is carried on the edges of the ground plane and the CPW central conductor. The RF MEMS capacitive switch electrical performance has been characterized by the S-parameter in the up-state and the down-state of the MEMS bridge.

The reflection coefficient of RF MEMS switch in the up-state is given by

$$S_{11} = \frac{-j\omega C_u Z_0}{2 + j\omega C_u Z_0}$$

and if $|S_{11}| \leq -10dB$ or $\omega C_u Z_0 << 2$ then,

$$|S_{11}|^2 = \frac{\omega^2 C_u^2 Z_0^2}{4}$$

Large series inductance can be easily achieved by the adding of a short high impedance section with width and length, between MEMS bridge and ground plane. The resonant frequency of the capacitive shunt switch can also be varied by choosing high impedance section dimensions.

The S-parameters S_{21} and S_{11} have been estimated in the up-state position represents the insertion loss and return loss respectively. In the down-state position S_{21} represent the isolation characterstics and S_{11} represent the return loss of the MEMS switch.The design parameters of the RF MEMS switch such as inductance, capacitance and resistance play very important role to calculate isolation, return loss and insertion loss in unactuated and actuated states.

The RF MEMS capacitive Shunt switch having parallel Plate capacitance in up-state is

$$C_{up} = \frac{\epsilon_0 w W}{g + t_d/\epsilon_r}$$

The down state capacitance of MEMScapaccitive shunt switch is

$$C_d = \frac{\epsilon_0 \epsilon_r w W}{t_d}$$

The ratio of capacitance in down state to up state is called figure of merit.

$$C_{ratio}(\frac{C_d}{C_{up}}) = \frac{\epsilon_r A_{down} g}{t_d A_{up}}$$

7.2.1 Electrostatic actuation and spring constant

When voltage is applied between the cantilever beam and the pull down electrode, an electrostatic force is induced on the cantilever beam. The electrostatic force applied to the cantilever beam is calculated by considering the power delivered to the time-dependent capacitance. This electrostatic force is induced in the beam is approximated as being distributed across the cantilever beam section above the electrode. The cantilever beam starts to move downward as the electrostatic force is applied, increasing the electrostatic pressure on cantilever beam and decreasing the gap g_o . The increased electrostatic force is greater than the increased restoring force at $(\frac{2}{3g_0})$, so that the membrane becomes unstable and collapsing of the beam to the downstate position occured. The pull down voltage is-

$$V_p = V(\frac{2g_0}{3}) = \sqrt{\frac{8K}{27\epsilon_o Ww} g_o^3}$$

Where A=wW is the electrode area, g_0 is the zero bias gap height, ϵ is the permittivity of the air, V is the voltage between the electrode and the beam. The cantilevers beams are designed in such a way so that both the beam have equal pull-in voltage.

The pull down voltage of the switch depends on gap height, g_o, spring constant of beam structure and area of thr electrode. There are two methods to reduce the actuation voltage of the switch : To increase the actuation area of the switch. By doing this, the reliability and compactness of the switch is affected. The second method is to offers the maximum design flexibility is to lower the spring constant of the switchand hence, designing a compliant switch.

The spring constant of the cantilever beam due to a uniform force applied is-

$$K = \frac{2Ew}{3}(\frac{t}{l})^3$$

Where k is the spring constant of the cantilever beam, E is the Youngs modulus , t is the thickness of the beam and l is the length of the beam.

The spring constant of the cantilever beam is extracted from-

$$K(springconstant) = F(force)/Z(maximumdisplacement)$$

7.3 Parameter extraction

The extraction of circuit model parameters for the RF MEMS capacitive shunt switches is described by this section. The dimensions of the RF MEMS switch, are: bridge width is 90μm, gap height is 2μm, and dielectric layer thickness is 0.15 μm. The characteristic impedance (Z_o) of the CPW central conductor is taken as 50.

7.3.1 Up-state bridge capacitance

Ansys HFSS electromagnetic simulation tool is used for study the effect of up-state capacitance on the return loss in unactuated state of RF MEMS capacitive switch in the frequency range of 0-40 GHz. It is to be observed that the computed and simulated return loss are in very close agreement to each other. To extract the up-state capacitance when both the cantilever in up-state from the simulated return loss, the frequency of 5 GHz is chosen because the switch behaves as the capacitor below the LC resonant frequency. It is to be observed that the resonant frequency (f_o) of the switch is 25 GHz and at 5 GHz the simulation shows that the return loss is 33 dB. This value provides the extracted upstate capacitance of 32 fF, which is somewhat similar to the calculated value of up state capacitance i.e. 22 fF. There is slight difference in the calculated and simulated values due to the fringing fields effects present at the bridge edges, which are not to be considered during the mathematical calculation. The up-state and down state capacitance is shown in figure 7.3.

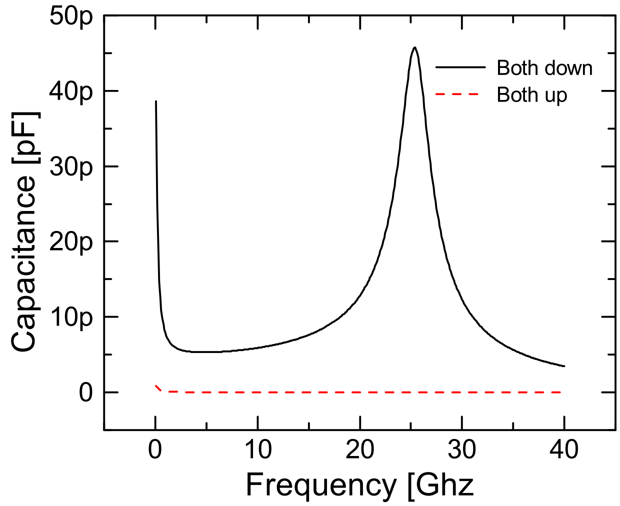

Figure 7.3: Capacitances of switch in up and down state.

7.3.2 Down-state bridge capacitance

In the down state position, the RF MEMS capacitive switch behaves as a LC resonance circuit, so that the isolation can be expressed in terms of down-state capacitance. THe theoretical calculated isolation plot and then simulated plots coexist with each other below 5 GHz. Hence we have to chose a frequency of 3 GHz to extract the down-state capacitance which correspond to the isolation of 14 dB, This value gives the down-state capacitance of 5.47 pF which is considerably quite similar to the calculated down state capacitance of 5.31 pF.

7.3.3 Bridge inductance and bridge resistance

In order to extract the bridge resistance from the simulated isolation plots, the resonant frequency is to be chosen, because at LC resonance frequency the MEMS switch behaves as bridge resistance. It is observed that the resonance occured at 25, 12 and 13 GHz and the resulting isolation obtained when both the beam is in down, right cantilever is in down and left cantilever is in down position about 46 dB, 41 dB and 40 dB. The value of isolation will yield an extracted bridge resistance. figure 7.4 shows the resistance in up-state and down state of the RF MEMS capacitive switch.

Table 7.2: Specification of RF MEMS switch

S. No.	Extacted component	Value
1	C_d calculated	5.31 pF
2	C_{up} calculated	21.46 fF
3	$(\frac{C_d}{C_{up}})$ calculated	247
4	C_d simulated	5.47 pF
5	C_{up} simulated	32.33 fF
6	$(\frac{C_d}{C_{up}})$ simulated	170
7	Inductance, when both down	41 pH
8	Inductance, when right down	54 pH
9	Inductance, when left down	56 pH
10	Resistance (R)	0.4 Ω
11	Stress	40.7 Mpa
12	Air-gap height	2 μm
13	Spring constant	4
14	Actuation voltage	35 V

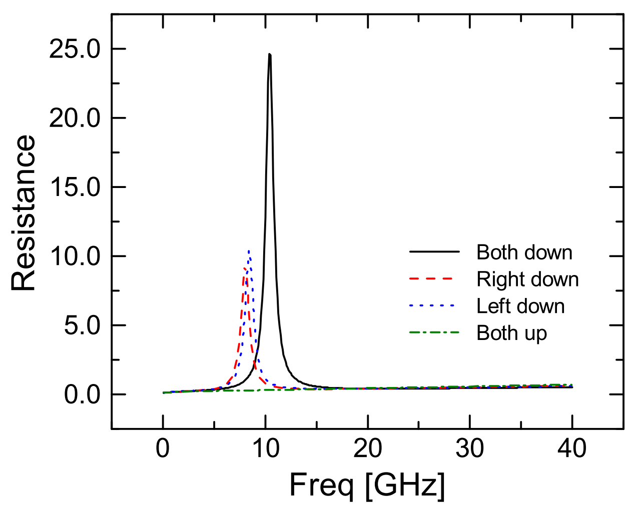

Figure 7.4: Resistance of switch in up and down state.

To extract the bridge inductance from simulated isolation, the frequency of 40 GHz is chosen because the RF MEMS capacitive shunt switch behaves as bridge inductance above the resonant frequency. From Figure 7.5 it is to be observed that at the 40 GHz frequency , the resulting isolation plot shows of 29 dB, 13 dB and 12 dB when both cantilever in down position, right cantilever is in down position and left cantilever is in down position respectively yields brings out the bridge inductance of 41 pH, 54 pH and 56 pH.

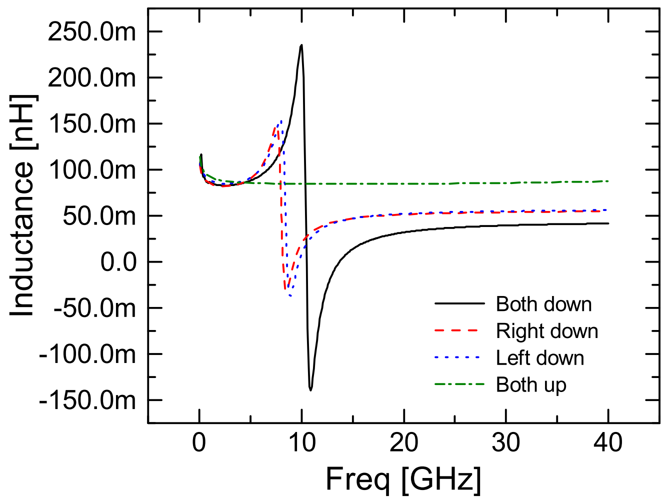

Figure 7.5: Inductance of switch in up and down state.

7.3.4 Electrostatic actuation and spring constant

When voltage is applied between the cantilever beam and the pull down electrode, an electrostatic force is induced on the cantilever beam. The electrostatic force applied to the cantilever beam is calculated by considering the power delivered to the time-dependent capacitance. This electrostatic force is induced in the beam is approximated as being distributed across the cantilever beam section above the electrode. The cantilever beam starts to move downward as the electrostatic force is applied, increasing the electrostatic pressure on cantilever beam and decreasing the gap g_o . The increased electrostatic force is greater than the increased restoring force at $(\frac{2}{3g_0})$, so that the membrane becomes unstable and collapsing of the beam to the downstate position occured. The pull down voltage is-

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Where A=wW is the electrode area, g_0 is the zero bias gap height, ϵ is the permittivity of the air, V is the voltage between the electrode and the beam. The cantilevers beams are designed in such a way so that both the beam have equal pull-in voltage.

The pull down voltage of the switch depends on gap height, g_o, spring constant of beam structure and area of the electrode. There are two methods to reduce the actuation voltage of the switch : To increase the actuation area of the switch. By doing this, the reliability and compactness of the switch is affected. The second method is to offers the maximum design flexibility is to lower the spring constant of the switchand hence, designing a compliant switch.

The spring constant of the cantilever beam due to a uniform force applied is-

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Where k is the spring constant of the cantilever beam, E is the Youngs modulus , t is the thickness of the beam and l is the length of the beam.

The spring constant of the cantilever beam is extracted from-

$$K(springconstant) = F(force)/Z(maximumdisplacement)$$

The spring constant of the switch is 4 N/m and actuation voltage of the proposed switch is 35V.

7.4 RF performance analysis

RF performance is the most critical parameter that primarily shows the performance of the RF MEMS switch that is intended for. Electromagnetic simulation has been performed in Ansys HFSS in order to determine the RF response. In RF MEMS capacitive shunt switch, the RF response is the function of ratio of the up-state

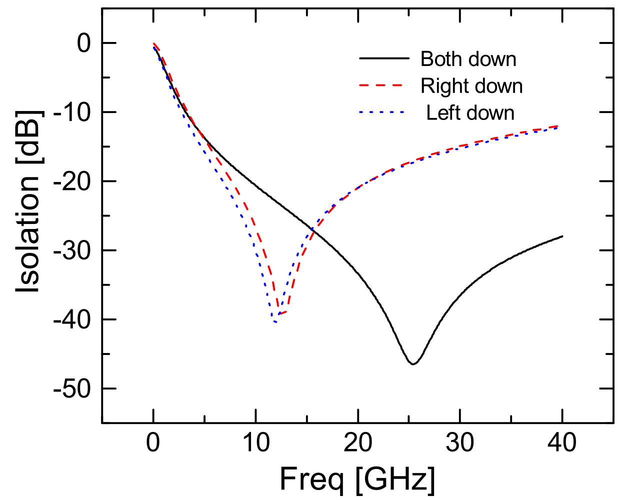

Figure 7.6: Isolation characteristics of the presented switch.

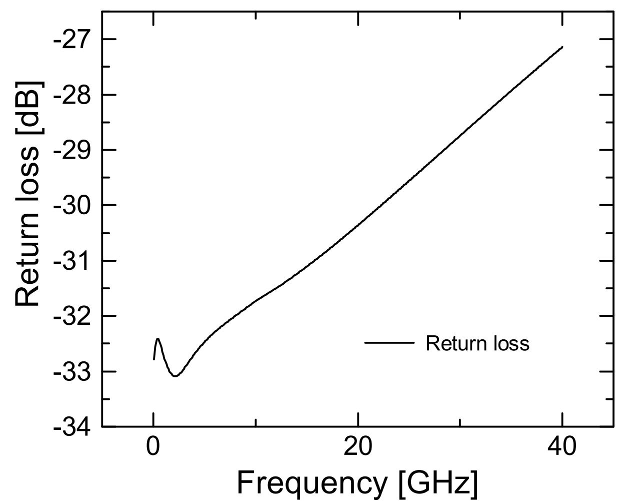

Figure 7.7: Return loss characteristics of RF MEMS switch.

capacitance to the down-state capacitance. For good RF response, a high capacitance ratio is desirable. The capacitance in the up-state of shunt switch can be minimized by utilizing the oat metal concept. RF performance of the RF MEMS capacitive shunt switch is observed between frequencie range of 140 GHz. Figure 7.6 shows the isolation characteristics of RF MEMS switch.

A peak value of 46 dB, 41 dB and 40 dB has been observed at 25 GHz, 12 GHz and 13 GHZ when both, right and left cantilevers are electro-statically actuated in down-state position respectively. As the resonant frequency is the function of the

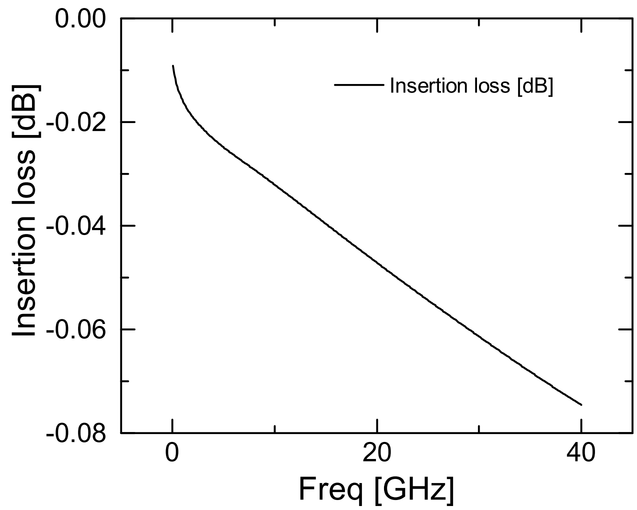

Figure 7.8: Insertion loss of presented RF MEMS switch.

inductance and capacitance. Insertion loss of 0.012-0.075 has been observed in ON state of the switch. Figure 7.8 shows the insertion loss of 0.054 dB at 25 GHz. figure 7.7 shows the Return loss of 30db at 25 GHZ.

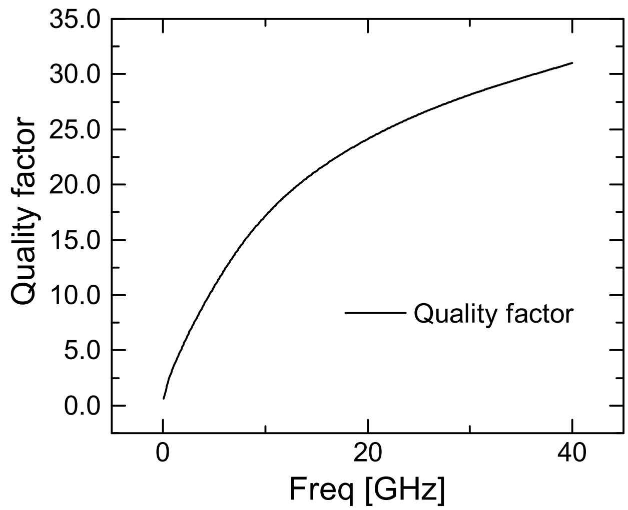

Figure 7.9: Quality factor of presented RF MEMS switch.

High Q-Factor is regarded RF MEMS switches. Generally Q-Factor of above 20 is considered for varie RF MEMS switches.The presented design has shown the great Q-factor of above 25 as shown in Figure 7.9. Q-factor of MEMS switches can theoretically calculated using-

$$Q = |\frac{Im(Y_{11})}{Re(Y_{11})}|$$

where Re(Y_{11}) and Im(Y_{11}) are the real imaginary part of the two-port network respectively as shown in Figure 7.1.

7.5 Design optimization

The modification can only affect the membrane of the switch. For a fixed value of central conductor and all other parameters are varying, we can observed the performance of RF MEMS switch. In the ON state, the insertion loss is varied with capacitance. By decreasing the capacitance in the ON state, we can increase the insertion loss. By varying only the bridge width and all other parameters are kept fixed, the up-state capacitance is effectively varied and hence changes the insertion loss of the switch. The magnitude of S_{11} increases with the increase in bridge width.

In the OFF state both the capacitance and inductance determine the switch resoponse. If we vary the bridge width and all other parameter kept fixed then the variation of resonant frequency can be observed. Both the capacitance and inductance are varied, if the variation of bridge occured along the length. The bridge inductance is determined by that portion of the bridge which is over the CPW slot and is independent of that portion which is over the center conductor. The center conductor bridge area determines the capacitance. Hence the resonant frequency varied with the bridge width.The study observed that narrow bridge width and wider CPW slot results in large inductance value. The spring constant varies linearly with bridge width. So, pull in voltage is actually independent of bridge width. Changing the electrode area by varying the bridge width can tune the switch into different frequencies.

7.5.1 T-line characterstics

The return loss in the both states, isloation in the OFF state and the insertion loss in ON state are the parameters which are to be measured for RF performances. The mismatch between the switch and characterstics impedance of the line causes the insertion loss. The insertion loss of the switch is also affected by the beam metallization and contact resistance.

The coplaner wave guide (CPW) facilitate the insertion loss of both shunt and series passive and active devices. The transmission line characterstics are very much dependent on the conductor spacing, S, width, W, height of substrate, H and substrate permittivity, ϵ_r to obtain the characterstics impedance, Z_0. The configuration of signal line is shown in figure. The transmission line consist of thin metallic strip deposited on surface of the dielectric film with the two conducting ground plane which are parallel to the strip.

$$\frac{S}{H} \leq \frac{10}{3(1 + \log \epsilon_r)}$$

and

$$\frac{W}{H} \geq \frac{80}{3(1 + \log \epsilon_r)}$$

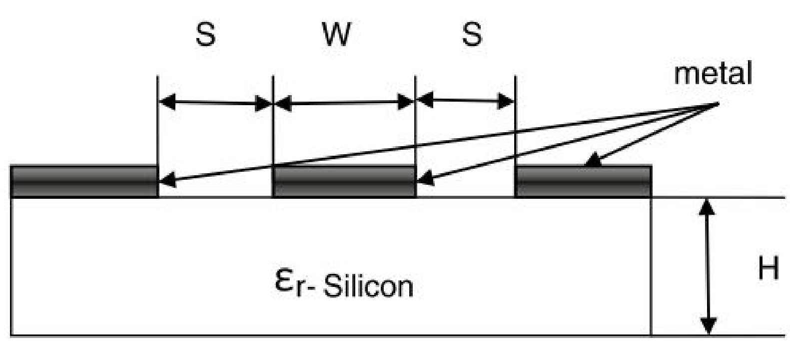

Figure 7.10: The CPW signal line configuration.

In this design, with the signal space, S of 70 um and and the signal line width,W of 60 um, and dielectric thickness is 3.78 um, determines the impedance, Z_0, which must be equal to 50 Ω. The height of silicon substrate is found to be 96 um at 50 Ω.

7.5.2 Effect of bridge thickness

The switch resistance comprises of the two components, R_s and R_{s1}. R_{s1} is due to the signal line loss and can be calculated as

$$R_{s1} = 2\alpha Z_0 I$$

Where α is the line loss. R_s is due to the MEMS bridge.

If the thickness of the bridge is smaller than the two skin depth, the resistant of the switch is constant with the frequency and the thickness of the bridge is greater than two skin depth. The switch resistance varied with frequency as the function $\sqrt{f}$ due to the skin depth effect.The skin depth is calculated by

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}}$$

where,

$$\omega = 2\pi f_0$$

, f_0 is the resonant frequency,

$$\mu_0 = 4\pi 10^{-7}$$

μ is the free space permeability. σ is the metal conductivity.

The switch resistance comprises of the two components, R_s and R_{s1}. R_{s1} is due to the signal line loss and can be calculated as

$$R_{s1} = 2\alpha Z_0 I$$

Where α is the line loss. R_s is due to the MEMS bridge. If the thickness of the bridge is smaller than the two skin depth, the resistant of the switch is constant with the frequency and the thickness of the bridge is greater than two skin depth. The switch resistance varied with frequency as the function $\sqrt{f}$ due to the skin depth effect.The skin depth is calculated by

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}}$$

where,

$$\omega = 2\pi f_0$$

, f_0 is the resonant frequency,

$$\mu_0 = 4\pi 10^{-7}$$

μ is the free space permeability. σ is the metal conductivity.

The spring constant K is the function of t^3, thus the pull in voltage increases exponentially with thickness of bridge t.

7.5.3 Effect of dielectric thickness and Material

The thickness of the dielectric layer and dielectric material is very important parameter for designing a switch. The dielectric material and its thickness determines the resonant frequency. Dielectric layer is deposited on the CPW center conductor to have the capacitive coupling between the CPW center conductor and MEMS bridge. In this section we investigated the effect of dielectric layer thickness on the loss characterstics of the switch in the two operational states.

The variation in dielectric layer can change the resonant frequency. A very small change of dielectric thickness can vary considerable amount of resonant frequency. The dielectric layer can decide the pull-in voltage, bridge capacitance and dielectric

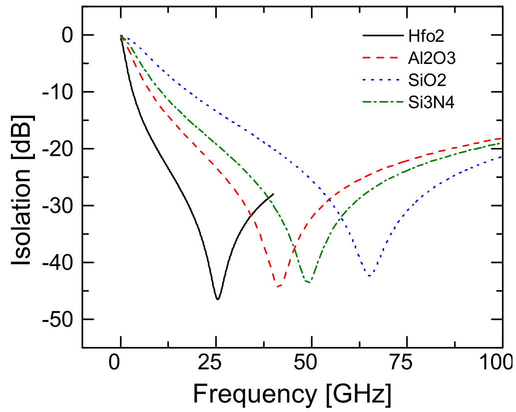

Figure 7.11: Isolation when both the cantilever is in down position for different dielectric material.

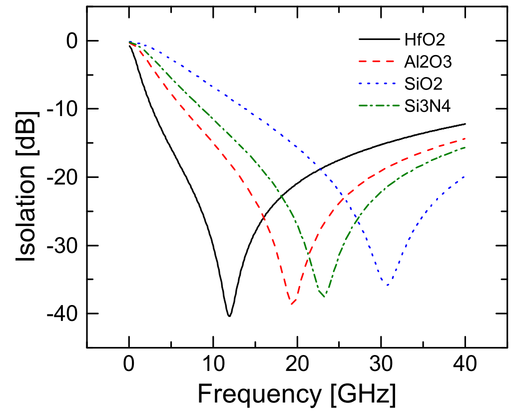

Figure 7.12: Isolation when right cantilever is in down position for different dielectric material.

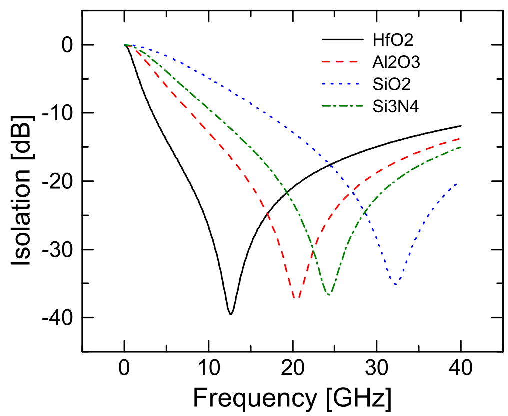

Figure 7.13: Isolation when left cantilever is in down position for different dielectric material.

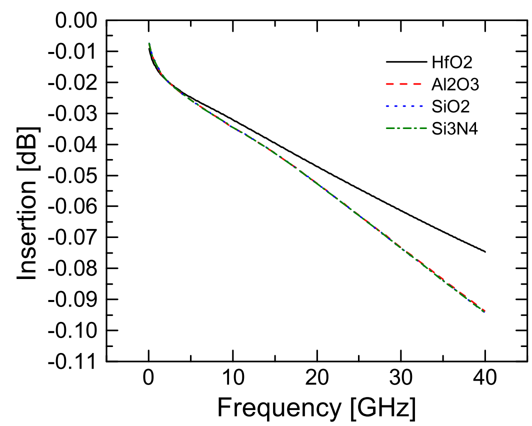

Figure 7.14: Isolation when the switch is in up-state position for different dielectric material.

charging. If the ϵ_r is very high then the capacitance ratio is very hign, resulting very high isolation and small switch size. The reliability of the switch is directlyt depends upon the dielectric types. The typical value if dielectric thickness is in between 0.1-0.5 um. The lower value of dielectric thickness is limited by dielectric breakdown and quality of dielectric layer. The upper value of dielectric thickness is limited by the dielectric charging. If the dielectric layer is thick, then it is more susceptible to dielectric charging. The results shows that as we increase the dielectric thickness, there is variation of resonance frequency is observed. It is also clear that, dielectric

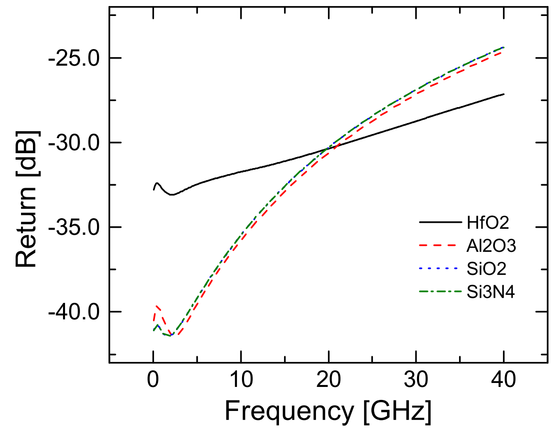

Figure 7.15: Return loss of the switch in ON state for different dielectric material.

thickness shifts the resonance frequency of the switch more as compared to the bridge width.

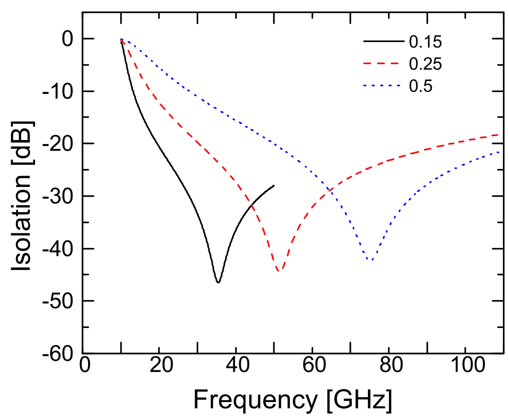

Figure 7.16: Isolation when both the cantilever is in down position for different dielectric thickness.

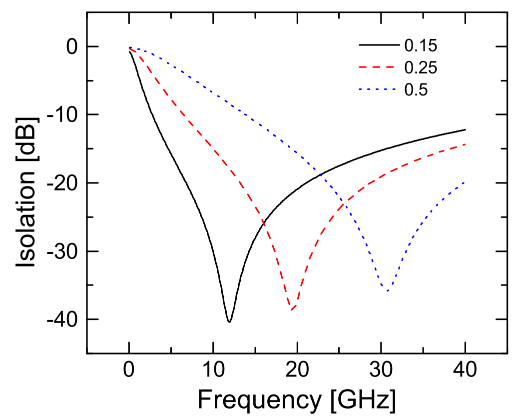

Figure 7.17: Isolation when right cantilever is in down position for different dielectric thickness.

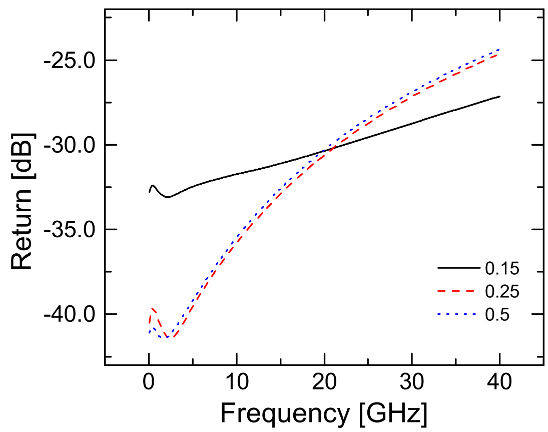

Figure 7.18: Return loss of the switch in ON state for different dielectric thickness.

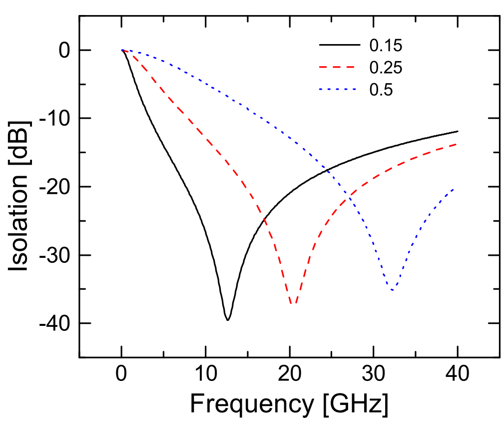

Figure 7.19: Isolation when left cantilever is in down position for different dielectric thickness.

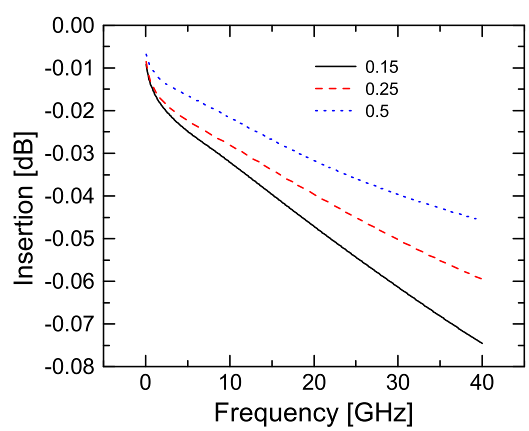

Figure 7.20: Isolation when the switch is in up-state position for different dielectric thickness.

7.5.4 Air-gap height effect

If we increase the air-gap height, the up-state capacitance decreases and hence decreasing the reflected power by a factor $|S_{11}|^2$. The ratio of down-state capacitance to up-state capacitance is directly proportional to gap-height. Figure 7.21 and figure7.22 shows the variation of insertion lioss and return loss with different value of air-gap height. The is isolation characterstics are same for different value of air-gap height.

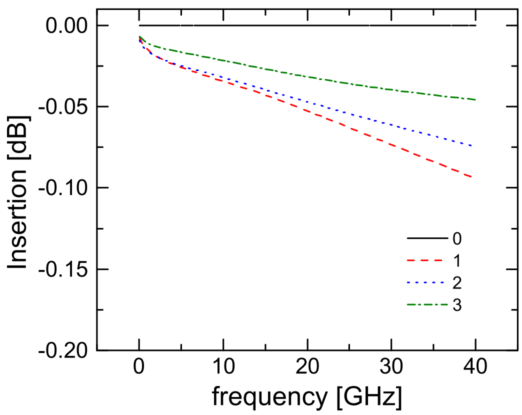

Figure 7.21: Insertion loss with variation of different value of gap height.

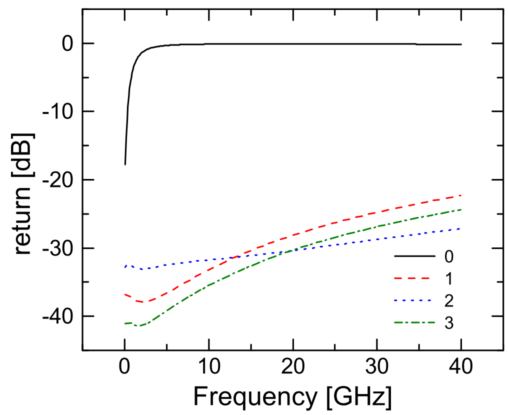

Figure 7.22: Return loss with variation of different value of gap height.

Usually the gap-height is restricted to 1.5-2 μm, because large actuation voltage is needed to pull-down the membrane. The study shows that the dielectric thickness is very important to determine the resonance frequency. The capacitance in up-state position is

$$C_{up} = \frac{\epsilon_0 w W}{g + t_d/\epsilon_r}$$

The down state capacitance of MEMS capaccitive shunt switch is -

$$C_d = \frac{\epsilon_0 \epsilon_r w W}{t_d}$$

The ratio of capacitance in down state to up state is called figure of merit.

$$C_{ratio}(\frac{C_d}{C_{up}}) = \frac{\epsilon_r A_{down} g}{t_d A_{up}}$$

7.6 Stress analysis

Finite element modelling is needed to analysis the Spring constant, von mises stress and pull in voltage for actuation mechanism. Comsol multi physics is used for analyzing the parameters as finite element modeler. The operation of radio frequency MEMS switch is determined by actuation voltages. RF signal travels through the armature switch into the grounded planes during the down state. Stress analysis is required to observe the maximum stress gradient and improve the areas which are prone to fatigue. The analytical calculation of very complex design is analyzed by FEM because the formulas are available only for simple membrane structure. To calculate stress and spring constant of the membrane FEM can be used for better analyzation. The gold membranes can withstand stress of 100 MPa. Both the membranes are made of Gold. Figures 7.23 shows the effective stres of 40.7 Mpa in capacitive shunt membrane.

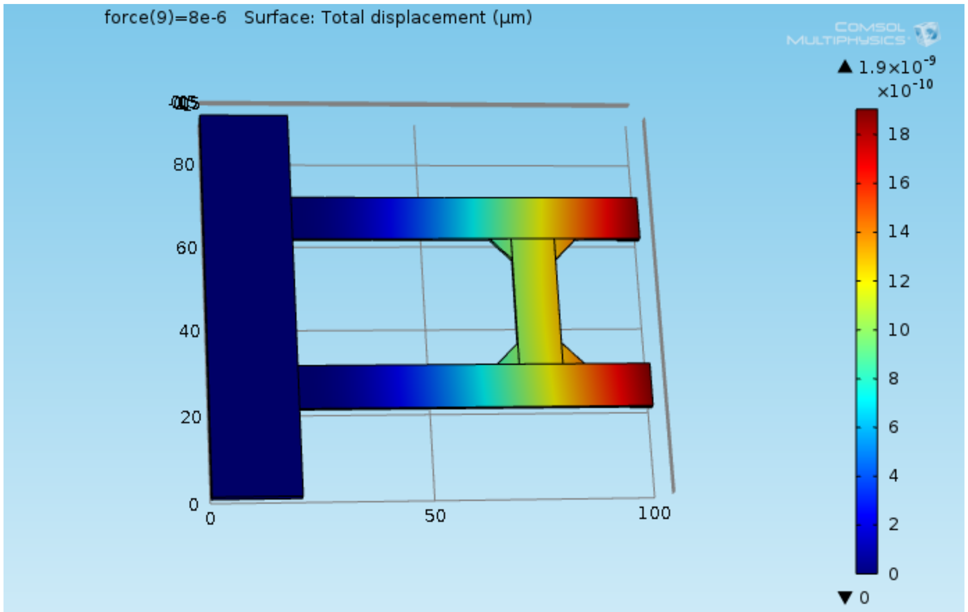

Figure 7.23: Figure shows the displacement of shunt membrane when force is applied.

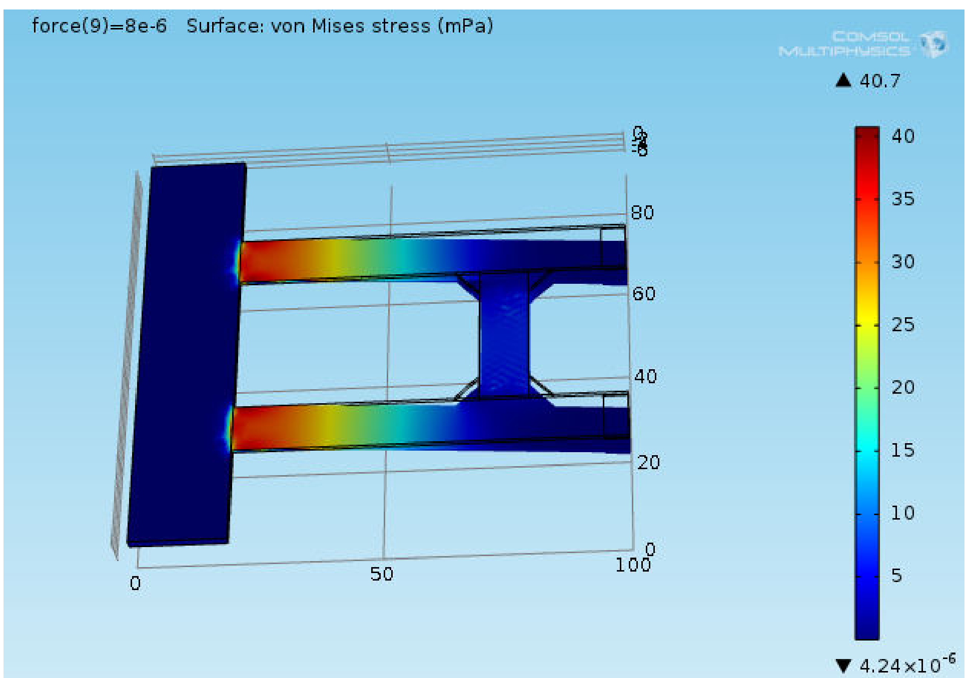

Figure 7.24: Capacitive Shunt switch membrane stress analysis for 2 μm gap height, showing maximum stress of 40.7 MPa.

Chapter 8

Conclusion

Table 8.1: RF MEMS performance comparison with different dielectric material

Dielectric material	Isolation both off (dB)	Isolation right down (dB)	Isolation left down (dB)	Insertion loss (dB)	Return loss (dB)
HfO_2	46	41	40	0.054	30
Al_2O_3	45	39	37.5	0.1	24
SiO_2	43	37	36	0.16	25
Si_3N_4	44	38	37	0.094	25

Table 8.2: Various capacitances and their ratio with different dielectric material

Dielectric material	C_d both down (pF)	C_d right (pF)	C_d left (pF)	C_{up} (fF)	C_d/C_{up} both down	C_d/C_{up} right down	C_d/C_{up} left down
HfO_2	5.47	5.31	5.21	32.33	170	164	161
Al_2O_3	2.3	2.72	2.54	10.8	212	251	235
SiO_2	1.35	1.48	1.54	11.2	120	132	137
Si_3N_4	1.8	2.06	2.003	7.44	241	276	269

The modification can affect the performance of the switch. For a fixed value of central conductor and all other parameters are varying, we can observed the performance of RF MEMS switch. In the ON state, the insertion loss is varied with capacitance. By decreasing the capacitance in the ON state, we can increase the

Table 8.3: Inductance and resistance due to different dielectric material

Dielectric material	**Inductance both off (pH)**	**Inductance right down (pH)**	**Inductance left down (pH)**	**Resistance (Ω)**
HfO_2	41	54	56	0.4
Al_2O_3	5.5	24	22	0.9
SiO_2	4	23	21	1.4
Si_3N_4	3.75	18.75	18	0.8

Table 8.4: RF MEMS performance comparison with different dielectric thickness

Dielectric thickness μm	**Isolation both off (dB)**	**Isolation right down (dB)**	**Isolation left down (dB)**	**Insertion loss (dB)**	**Return loss (dB)**
0.15	46	41	40	0.075	27
0.25	37	38	37	0.058	25
0.5	34	35	33	0.04	25

insertion loss. By varying only the bridge width and all other parameters are kept fixed, the up-state capacitance is effectively varied and hence changes the insertion loss of the switch. The magnitude of S_{11} increases with the increase in bridge width. By varying the dielectric thickness the isolation and insertion characterstics of the MEMS switch is varied. Also, the RF performance of the switch is strongly depends on the dilelectric material. The dielectric material and its thickness determines the resonance frequency of the switch. We can vary the resonance frequency by varying the dielectric thickness and using different dielectric material. Also, by varying the air-gap height, we can varied the insertion and return loss characterstics.

Chapter 9

Result and discussion

The proposed switch has conventional approach and this switch using fixed central capacitor to improve the insertion loss. The purpose switch is the type of capactive shunt radio frequency MEMS switch. An electromagnetic modeling is used to examine the RF performance in the down-state and up-state of RF-MEMS switch. There is good similarity between the simulated and computed results confirms the validation of the presented RF MEMS switch design. This proposed RF MEMS switch design show the return loss of 30 dB and isolation peaks of 46dB, 41 dB and 40 dB from dc 40 GHz frequency range. The proposed switch also shows the improved insertion loss of 0.075 dB. The switch is very compact in terms of area occupied by the switch. Various parameters like bandwidth, RFperformance, stress analysis, spring constant, pull-down voltage and Q-factor are analysed in this paper.

The reliability of the switch is increased because the reliability of the switch is directlyt depends upon the dielectric types. The typical value of dielectric thickness is in between 0.1-0.5 um. The lower value of dielectric thickness is limited by dielectric breakdown and quality of dielectric layer. The upper value of dielectric thickness is limited by the dielectric charging. Dielectric thickness of 0.15 is taken in this switch to increase the reliability of the switch. Also, actuation area of the switch is very small, hence compactness and reliability of the switch is increased. By doing this, dielectric charging effect is removed by taking dielectric thickness very small. The design is optimized with the variation of several parameters like, bridge width, bridge thickness, dielectric thickness, dielectric material and air-gap height.

The considerable improvement in the insertion loss has been achieved in the case of cantilever based design having fixed central capacitor as compared to the equivalent conventional RF MEMS switch with the movable bridge. In OFF-state, isolation peaks have been tuned in X, Ka and K bands by varying the downstate inductance through either or both cantilevers. The switch shows high isolation for large bandwidth operation. The voltage requirement is very less as compared to the other high isolation operation devices. This RF MEMS switch can be used in the application where the RF performance is the main concern over switching speed such as space systems and wireless communication.

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