Shri Ramdeobaba College of Engineering & Management, Nagpur
Department of Electronics Engineering

Date: 07/06/2013

To,

The Chief Investigator,
INUP,
Indian Institute of Technology, Bombay
Powai, Mumbai 40076

Subject - Submission of Project proposal under Indian Nanoelectronics Users Programme
[INUP] (Medium - Term- Projects)

Sir,
Under the INUP (Medium - Term- Projects) scheme, we hereby submit our proposal for 06 Months duration as follows

Name of Department	Name of Proposal	Name of Principal Investigator
Electronics Engineering (Accreditated) **F.NBA/ACCR-50/50(II)/713/2001/2004, Dated : 18/05/2007**	Fabrication & Characterization of MEMS Cantilever Switch for Power Applications	Dr. Rajesh S. Pande

Looking forward for your kind consideration.
Thanking You.

Yours Sincerely

Dr. V. S. Deshpande

Principal, RCOEM, Nagpur

Project Proposal

Under

Indian Nanoelectronics Users Programme [INUP]

Submitted to

Indian Institute of Technology, Bombay

Submitted by

Department of Electronics Engineering
Shri Ramdeobaba College of Engineering & Management
Katol road, Nagpur-440013
www.rknec.edu

PROJECT PROPOSAL

1. Project Title : Fabrication & Characterization of MEMS Cantilever Switch for Power Applications

2. Duration in months : 6 months

3. Investigators

	Principal Investigator	Co-Principal Investigator
Title and Name	Dr. Rajesh S. Pande	Mr. Deepak G. Khushalani
Designation	Vice Principal	Phd Scholar
Department	Electronics Engineering	Electronics Engineering [Place of Research]
Organization	Shri Ramdeobaba college of Engineering & Management, Nagpur www.rknec.edu	Shri Ramdeobaba college of Engineering & Management, Nagpur www.rknec.edu
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Government/private	Private	Private
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4. Project abstract

Employment of MEMS in a variety of fields has opened new avenues for the improvement in the attributes of applications. Thus we may see Power applications and MEMS going hand-in-hand in the near future. The Power domain specific applications can be redesigned using MEMS components proving numerous advantages. One such component, the MEMS cantilever switches have demonstrated superior performance compared to semiconductor switches. Based on these lines a case study of Switched Mode Power Supply (SMPS) replacing the semiconductor switches with MEMS counterpart has been performed. Preliminary studies show promising results. One of the limitations associated with use of MEMS switch in the power field is the current handling capacity of the MEMS cantilever switch. A current splitting approach, thereby, having matrix of switches has been suggested for this purpose. So, an attempt to fabricate switch matrix has been proposed.

5. Key words: current splitting, switch matrix

6. Technical details

   a. Introduction

MEMS represents an extraordinarily emerging technology that promises to transform industries by helping reduce cost, bulk and power consumption while increasing performance, production volume and functionality by orders of magnitude [1].

Largely, MEMS uses the tools and techniques that were developed for the Integrated Circuit industry to build microscopic machines. These miniature machines are becoming ubiquitous, and are quickly finding their way into a variety of commercial fields like automobile, electronics, bio-medical and not leave out defense. In one viewpoint, MEMS products are categorized by type of application they cover.

Switches and relays are vital components of all automated systems, switching provides for an interface between a system and devices with the capability for automatic redirection of signals, enhancing their flexibility and expandability. MEMS switches have demonstrated superior performance compared to semiconductor devices. The MEMS switch is a micro-machined device consisting of a membrane or strip of metal suspended over an electrode. Activation of the switch is caused by an electrostatic field induced by an applied voltage [1][2][3]. The main advantage is near to zero static power making MEMS switch an extremely efficient device. Several MEMS switch configurations have been investigated to date with varying degrees of success.

One of the more successful reported switch configurations is the cantilever-type with a series-connected metal-metal contact. Reliability issues like stiction (one moving part sticking to another part) [2][3], operational wear (the erosion of sliding surfaces and particulate contamination after billions of operational cycles), micro-welding (High temperature gradients induced by large electric current, rough surfaces and friction) are matter of concern. Despite these reliability issues, the near-zero power consumption and other advantages; make it an attractive alternative. The MEMS cantilever switch is essential device and widely used in state-of-the-art electronic systems, but the limitation with respect to current handling due to its minimal feature size is holding back its deployment in the area of high power circuit applications. Surmounting this limitation, high power applications and MEMS can be seen together in near future.

A high power circuit like switched-mode power supply replaced linear supplies due to cost, weight, and size improvement. A SMPS is an electronic power supply that incorporates switching regulators like MOSFETS, SCR, IGBT etc each having its requirements, advantages and disadvantages associated to convert electrical power efficiently. Several topologies can be used to implement SMPS, which can then be used to work for any specification. However each topology has its own unique features, which make it best suited for the certain application.

An SMPS is usually employed to efficiently provide a regulated output voltage, typically at a level different from the input voltage. As the core voltage decreases and the current increases a must requirement for many applications, the challenges for providing this power have been steadily mounting. Higher current results in exponentially higher dissipative losses both in synchronous MOSFETs and in copper distribution paths. With the requirement of low power consumption having higher current capacity, the efficiency of the semiconductor devices plays a broad but important role. As we shift from SCR, diac to IGBT & MOSFET the efficiency of the device increases. Due to negligible gate drive power requirement, better switching performance & flexible commutation facility, gate commutation devices are preferred.

Now due to high on state losses, IGBT's, MOSFET's need to be replaced by some switch offering advantage of the low power dissipation. MEMS cantilever switches offering the advantage of the near zero static power dissipation is thus a good alternative. Comparison shows that performance parameter like the low power dissipation and high isolation of the MEMS cantilever switches have made it a better substitute over the semiconductor devices.

To use the advantages of MEMS cantilever switch for replacing the semiconductor switch with the MEMS cantilever switch in power applications is the area of interest and is under investigation. Limitations associated with the MEMS switches at high power are feature size, interconnect issues, switching on frequency of cantilever switch as excessive vibration across beam can induce noise in circuit, deformations respect to thermal issues. One of the limitations that we are taking into consideration is the feature size and thus the current handling. Depending on the feature size, the current handling capacity of MEMS cantilever switches ranges in few milli-Amperes (less the feature size, less is amount of current handling) [6, 7, 8]. So, there is an emergent need to seek for an approach for development of the MEMS cantilever switches with high current handling capability which can then be employed in high power circuit applications.

b. Definition Of Problem:

We propose to use the current splitting approach to improve the current handling capacity. By exploring a current splitting/combining concept, an increase in the number of rows of the switch array can effectively increase the current handling. This approach allows us to configure the switch matrix to be customized for different current requirements while maintaining low actuation voltage of each individual switching element.

From the project "Reliability Characterization of MEMS Cantilever Switch" at IITB under INUP we successfully fabricated the MEMS cantilever switch by considering the design issues to remove stiction from the design point of view. The same device dimensions of a single device has been minutely modified dimension wise and reconstructed for the requirement of current handling capacity. The size dimension calculated with the help of formula reference keeping ideal current density of material and current capacity in mind [6, 7, 8].

$$I = a^{*} d^{3/2}, \qquad (1)$$

The device 100µm x 35 µm x 0.5 µm has been tested via simulation with the help of COMSOL Multi-physics to evaluate characteristics of a MEMS cantilever switch for the requirement of high current handling in comparison to solid state devices. The device can to carry analytically 20mA of current which is tested via simulation in room temperature ambience (1). The current density, capacity increase in temperature range with the application of current for longer durations has been established and simulated. The device material boundary condition like joule heating effect need to be kept below damage limits to avoid micro welding.

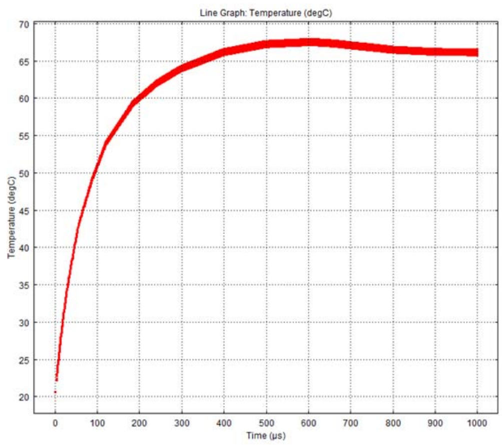

FIGURE (1a) Temperature vs Time

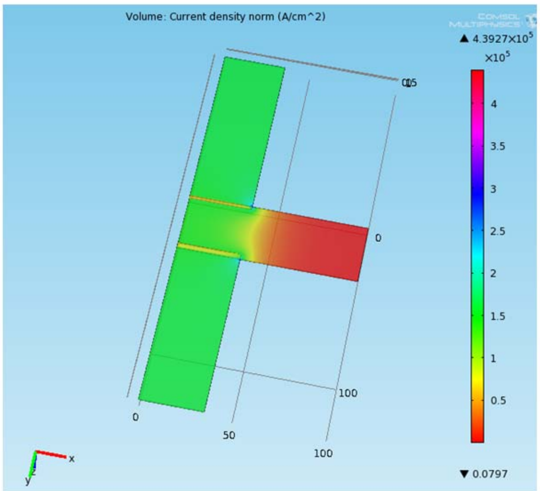

FIGURE (1b) Volume Current Density.

With the help of the earlier project fabricated switch parameters, the simulation tested modifications and constraints we propose to fabricate a matrix of cantilever switches, that will help us increase the current handling along with reduction in the second order effects from the circuit point of view as compared to solid state switches.

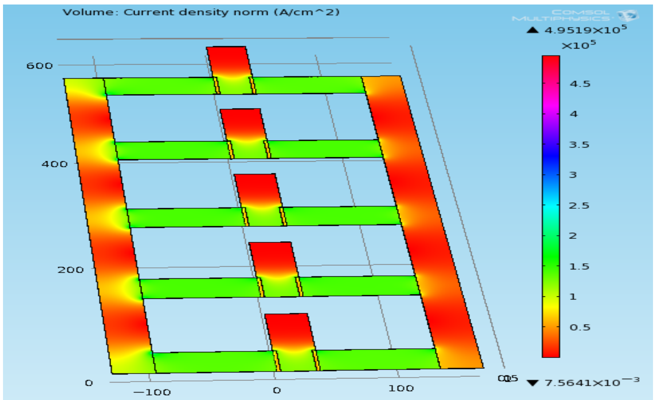

FIGURE (2) Volume Current Density in parallel Connection

Considering a design as shown in figure 2 which can handle 100mA of current analytically respect to feature size, has resistive heat losses of the order very less compared to solid state devices. These simulation results performed at National MEMS design center, VNIT need to be validated with the help of fabrication, for achieving a matrix that has a higher range current handling capacity.

To achieve the matrix a single device needs to be tested first for single device current capability by varying dimensional parameters to validate equation "1". Further more for increase in reliability of fabrication we need to test few sets of devices in different ways of topologies for achieving a break even in design parameters, methodologies by performing minimum steps of lithography.

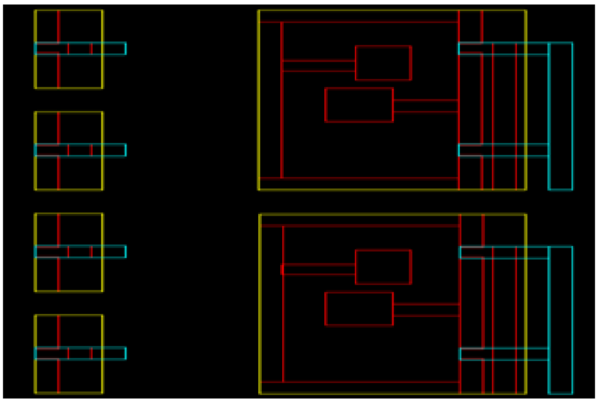

Fig 3: 2d Mask Layout

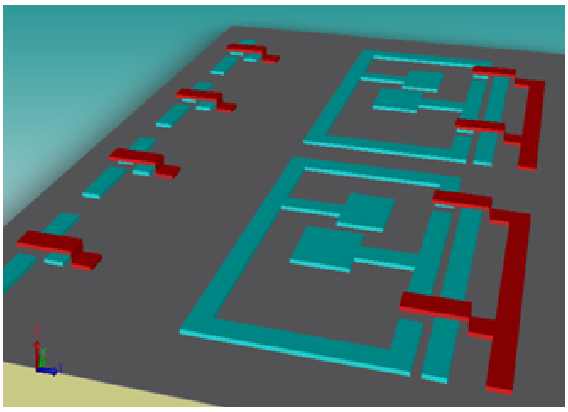

Fig 4: 3d Layout

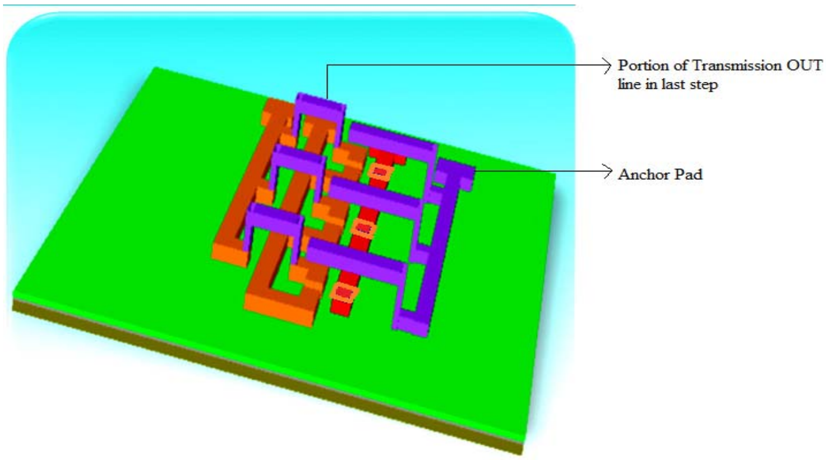

Fig 5: 3 switches in parallel configuration

Next the working of array of switches together requires a development of control circuitry that can help us control the switching on and off of so many devices together. To achieve higher efficient current handling capacity the associated second order effects are to be minimized. Moreover the maximum operating frequency is to be achieved practically for successful implementation of the MEMS Cantilever switches in high power circuits like SMPS.

For the requirement of electrical testing of the fabricated devices Dr. Rajendra Patrikar (Dean Academics, VNIT) and MiNag (Microelectronics and Nanoelectronics group) of VNIT extend their constant support and guidance. The fabricated devices will be electrically tested at electrical characterization lab at VNIT. VNIT has a SUSS Microtech PM8 probe station with probe shield, anti vibration table and chiller for variable temperature RF and DC measurement. A keithley 4200 SCS system along with kiethley 237 high voltage source measure unit provides a four probe resistivity measurement set up. This set up will be utilised to perform various characterization like IV, stressed IV under varying temperature and many more for validating the single devices and the array matrix. The temperature analysis will help us validating the current carrying capacity of the single device which in turn is connected in parallel array matrix to increase the current carrying capacity. The stressed IV analysis will help us validate the working behaviour of the switch and the array of switches for longer durations.

c. Research Methodology:

- Specified Dimensions:
  i. Length of cantilever beam = 100µm
  ii. Width = 35µm
  iii. Thickness = 0.5µm
  iv. Length of bottom electrode = 35µm
  v. Distance between bottom electrode & anchor = 15µm
  vi. Distance between bottom electrode & transmission line =15µm

- Fabrication Process Flow

Aluminium Cantilevers were successfully fabricated earlier under the INUP midterm project “Reliability Characterization of MEMS Cantilever Switch” at IITB [5]. Process flow for MEMS Cantilever Switch for Power Applications is formulated utilising the earlier experience of aluminium cantilever switch. The new process flow comprises of three steps of optical lithography as listed below:

i. P-type wafer <100> of high resistivity.
ii. Wafer cleaning- **RCA Cleaning**.
iii. Thermal Oxidization- **Dry Oxidation** (100nm)
iv. Metal deposition (Aluminium) for bottom electrode & transmission line (fraction)– **Thermal Evaporation** (500nm)
v. **1st level Optical Lithography** for patterning the bottom electrode and transmission lines (fraction) **– MASK 1**
vi. Deposition of Sacrificial layer (PPR) – using **Spinners**.
vii. **2nd level Optical Lithography** to form the anchors (cantilever beam and transmission OUT lines) **– MASK 2**.
viii. Deposition of metal (Aluminium) for the formation of the beam and remaining transmission line - **Thermal Evaporation** (500nm).
ix. **3rd level Optical Lithography (without dehydration step)** to pattern the metal layer to form the beam and remaining transmission line**– MASK 3.**
x. Removal of sacrificial layer **- O_2 Plasma Ashing**

d. List of references:

[1] J Jason Yao, "RF-MEMS from a device perspective", J. Micromech. Miroeng.10 (2000) R9-R38.

[2] Rajesh S. Pande, Rajendra M. Patrikar, "Modeling and Simulation of RF-MEMS devices", WSEAS Transactions on Electronics, Issue 4, Volume 5, April 2008.

[3] Roberto Gaddi, Antonio Gnudi, Augusto Tazzoli, Gaudenzio Meneghesso, Enrico Zanoni, "Reliability of RF MEMS", 13th GAAS Symposium- Paris 2005.

[4] Rebeiz, G.M.; Muldavin, J.B. RF MEMS switches and switch circuits. *IEEE Microw. Mag.* 2001.

[5] Dr. Rajesh Pande, Principal Investigator of project "Reliability Characterization of MEMS Cantilever Switch", INUP, IITB, 2009-2011.

[6] D. Brooks, "Fusing Current When Traces Melt Without a Trace," Printed Circuit Design, a Miller Freeman publication, December, 1998.

[7] D. G. Fink and H. W. Beaty, "*Standard Handbook for Electrical Engineers"*, McGraw Hill, 15th edition, 2007.

[8] Jayu P. Kalambe, Rajendra M. Patrikar, " Design ofMicrocantilever-Based Biosensor with Digital Feedback Control Circuit", Journal of Sensors, Volume 2012, Article ID 586429.

7. Work plan

a. Time schedule of activities giving milestones in a bar diagram

Research Milestones	Duration in Months					
	1	**2**	**3**	**4**	**5**	**6**
Fabrication of array of MEMS switches [**IITB**]	**x**	**x**	**x**	**x**	**x**	
Characterization of the array of switches [**IITB + VNIT**]			**x**	**x**	**x**	**x**
Analysis of the obtained results					**x**	**x**

b. End usage of the research outcome:

The array of switches fabricated in this manner has increased current handling capacity (> 3A) and can now be used for power applications like switched mode power supply giving the mentioned advantages.

c. Suggested plan of action for utilization of research outcome expected from the project:

There is an emergent use of increase in the current handling capacity for assorted applications. This array of MEMS switches can be used as a replacement to the traditional semiconductor switches in high power applications like SMPS which then can be used in many applications like the space applications etc. The research outcome will be useful for the fabrication house & MEMS design community.

8. Budget Estimates

a. Consumables

Wafer to fabricate the array of switches.

b. Funding for your project

Shri Ramdeobaba College of Engineering and Management will support the faculty members for the project. Only student accommodation and travel needs to be taken care of.

c. Travel

Sr. No.	Travel/lodging/boarding at IITB (Amount in Rs.)
01	75,000/-

9. Research infrastructure required

Equipments required from IIT, Bombay

1. Ellipsometer
2. Olympus MX61 Industrial microscope
3. Surface Profilometer – AMBIOS XP2
4. Fully shielded probe station with triax thermo-chuck
5. Inductively Coupled Plasma CVD
6. Metal Sputtering System (NORDIKO)
7. Furnace Stack 6”
8. Sentech Plasma Etch System (RIE)
9. MJB-3 mask aligner
10. Wet cleaning and etch stations

a. Indicate if training would be required.

Attended workshop on familiarization and hands on training on Nanofabrication technologies at IITB under INUP.

b. List those available in your organization, if any, for the proposed project.

The modelling, simulation and characterization of array of MEMS cantilever switch will be carried out in RCOEM, Nagpur and VNIT, Nagpur.

10. Proposal Review

a. Are you aware of any faculty member in IIT Bombay who is working on the same or related field? Please provide the name and department.

1. Prof. Ramgopal Rao ,Electrical engineering Department
2. Prof. P. R. Apate, Electrical Engineering Department

b. You may suggest name, institute, address, telephone number and e-mail address of researchers who could review your proposal.

11. Detailed Bio-data of the Investigator/Co-Investigator

Bio-data of Principal Investigator

1] Name : Dr. Rajesh S. Pande
2] Experience as regular teacher : 20 Years
3] Academic Qualification

Sr. No.	Qualification	Board / University	Year	Percentage / Division
1.	B.E. (Electronics & Telecomm. Engg.)	Govt. Engg. College, Jabalpur/ Rani Durgavati Vishvavidyalaya, Jabalpur	1990	77 % 1st Div
2	M.Tech. (Electronics Engg.)	VRCE, Nagpur (now VNIT, Nagpur) (Deemed University)	1992	71 % 1st Div
3	Ph.D. Thesis Title: Modeling and Simulation of RF- MEMS Passive Devices Guide: Dr. R. M. Patrikar	VNIT, Nagpur (Deemed University)	Nov. 2008	

Bio-data of Co-Investigator

1] Name : Mr. Deepak G. Khushalani
2] Experience as regular teacher : Nil
3] Academic Qualification

Sr. No.	Qualification	Board / University	Year	Percentage / Division
1.	B.S. (EEC)	AIUMT, California	2008	85% (3.44 CGPA)
4	M.Tech. (VLSI)	RCOEM, Nagpur (RTMNU)	2010	70 % 1st Div
6	Ph.D. (Pursuing) Guide: Dr. Rajesh S. Pande	RCOEM, Nagpur (RTMNU)	2011	-

12. Most relevant publications of the investigators

List of Research papers of Principal Investigator [Dr. Rajesh S. Pande]

1. Rajesh S. Pande, Rajendra M. Patrikar, “Modeling and Simulation for RF MEMS devices,” WSEAS Transactions on Electronics, Issue 4, Vol.5, April 2008, pp.155-165.

2. Rajesh S. Pande, R.M. Patrikar, “Effect of surface roughness on RF MEMS shunt switch,” International Conference on MEMS and semiconductor nanotechnology, MEMSNANO, Indian Institute of Technology, Kharagpur, Dec.20-22, 2005, pp.7-8.

3. Rajesh S. Pande, R.M. Patrikar, “Finite element analysis and optimization of RF MEMS devices,” International Conference on Computer Aided Engineering (CAE 2007), Indian Institute of Technology, Madras, Dec. 13-15 2007.

4. Rajesh S. Pande, Anoop P. Jalgaonkar, Rajendra M. Patrikar, “A 3-D FEM based extractor for MEMS inductor with Monte-Carlo sampling,” International workshop on

physics of semiconductor devices (IEEE-IWPSD-2007), Indian Institute of Technology, Bombay, Dec. 17-20 2007.

5. Rajesh Pande, Rajendra Patrikar, “A CAD tool for RF MEMS devices,” 13th Asia and South Pacific Design Automation Conference, IEEE ASP-DAC-2008,Seoul, Korea, Jan 21-24 2008.

6. Jayu Kalambe, Anju Gupta, Rajesh Pande, R.M. Patrikar, “Modeling and simulation of MEMS cantilever for Bio-sensor application,” International Conference on MEMS, IIT Madras, Jan 3-5, 2009.

7. Rajesh Pande, Sumeet Deshpande, “Implementation of configurable adaptive FIR filter on Xilinx FPGA,” National level conference VLSI Design And Test (VDAT), I I Sc, Bangalore, Aug. 2000.

8. Rajesh S. Pande, K.A. Borikar, R.M. Patrikar, “Tool development for modeling of RF MEMS shunt switch,” IMAPS India National Conference on Microelectronics & VLSI, Indian Institute of Technology-Bombay, Dec.20-21 2005.

9. Rajesh S. Pande, Anoop P. Jalgaonkar, Rajendra M. Patrikar, “Modeling of RF MEMS shunt capacitive switch with FEM,” Proceedings of the IMS conference-2007 Macmillan advanced research series, Trends in VLSI and embedded systems,Punjab Engg. College, Chandigarh, Aug 17-18 2007 pp 346-349.

10. Deepak Khushalani, Prof(Mrs.) Jayu Kalambe, Dr. R. S. Pande,” Design and Analysis of MEMS Cantilever Switch”, International conference on MEMS & Optoelectronics.

11. Divya Shrivastava, Deepak Khushalani, Pallavi Shahapurkar, Nikhil Muley, Prof. (Mrs.) Jayu Kalambe, Dr. R. S. Pande ,” Reliability of RF-MEMS Switch”, 51st national seminar on industrial productivity, safety and disaster management, RCOEM, Nagpur.

12. Deepak Khushalani, Prof(Mrs.) Jayu Kalambe, Dr. R. S. Pande , Dr. R. M. Patrikar, “Fabrication of MEMS Cantilever Switch”, 4th national conference, ISSS.

List of Research papers of Co-Investigator [Mr. Deepak G. Khushalani]

1. Deepak Khushalani, Prof(Mrs.) Jayu Kalambe, Dr. R. S. Pande,” Design and Analysis of MEMS Cantilever Switch”, International conference on MEMS & Optoelectronics.

2. Divya Shrivastava, Deepak Khushalani, Pallavi Shahapurkar, Nikhil Muley, Prof. (Mrs.) Jayu Kalambe, Dr. R. S. Pande ,” Reliability of RF-MEMS Switch”, 51st national seminar on industrial productivity, safety and disaster management, RCOEM, Nagpur.

3. Deepak Khushalani, Prof(Mrs.) Jayu Kalambe, Dr. R. S. Pande , Dr. R. M. Patrikar, “Fabrication of MEMS Cantilever Switch”, 4th national conference, ISSS.

13. Most relevant patents of the investigators: No Patents

14. List of Projects implemented, if any

1. Dr. Rajesh Pande was the Principal Investigator of project “**Reliability Characterization of MEMS Cantilever Switch**” which was completed successfully.

a) Fabrication of Metal- Insulator- Metal capacitor of different dimensions, shapes and materials were carried out for our proposed test structure. Test structures were characterized for electrical characterizations along with the effect of change of dielectric deposition methods and variations in deposition parameters. The shifts in IV curves were analyzed on application of various stimuli (square wave, dual pulse, trapezoidal wave) to study the phenomenon of charge trapping in dielectric on application on constant stresses. MIM structure which represents the permanent on state of the cantilever switch was also analyzed with respect to surface roughness, for the preliminary parameter extraction of MEMS cantilever switch. The parameters were modeled for the reduction of stiction at the design level itself.

b) MEMS Cantilever switch was fabricated successfully after comparative study of various ways of releasing the cantilever beam. The cantilever switch was characterized with different sweep voltages for observing the change in capacitance for validation of charging parameters extracted from the capacitor on switches.

2. Dr. Rajesh Pande was Principal Investigator of AICTE sponsored MODROBS proposal Rs. 10 Lac, "Up-gradation of Electronic design automation facilities in the field of digital design and CMOS VLSI design."

3. Dr. Rajesh Pande was Principal Investigator of AICTE sponsored MODROBS proposal Rs. 14.75 Lac, "Upgradation of Digital Communication Networking facilities in the field of Communication Engg."

15. Any other relevant information

1) **Dr. R. M. Patrikar from VNIT, Nagpur** is collaborator and part of the MEMS work team at RCOEM. The department of Electronics Engineering of RCOEM, Nagpur is having full time M. Tech. (VLSI) Program. 3rd & 4th semester project work is proposed to be carried out at IIT, Bombay under the same scheme.
2) For the requirement of electrical testing of the fabricated devices Dr. Rajendra Patrikar (Dean Academics, VNIT) and MiNag (Microelectronics and Nanoelectronics group) of VNIT extend their constant support and guidance. The fabricated devices will be electrically tested at electrical characterization lab at VNIT. VNIT has a SUSS Microtech PM8 probe station with probe shield, anti vibration table and chiller for variable temperature RF and DC measurement. A keithley 4200 SCS system along with kiethley 237 high voltage source measure unit provides a four probe resistivity measurement set up. This set up will be utilised to perform various characterization like IV, stressed IV under varying temperature and many more for validating the single devices and the array matrix. The temperature analysis will help us validating the current carrying capacity of the single device which in turn is connected in parallel array matrix to increase the current carrying capacity. The stressed IV analysis will help us validate the working behaviour of the switch and the array of switches for longer durations.

Dr. Rajesh S. Pande
Principal Investigator

Mr. Deepak G. Khushalani
Co-Principal Investigator

Dr. V. S. Deshpande
Principal, RCOEM, Nagpur