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MEMS POWER SWITCH IMPLEMENTATION USING SUGAR SIMULATOR

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ABSTRACT

In this work, a study of MEMS (Micro electro mechanical system) and SUGAR simulator is presented. A MEMS power switch is implemented and the insertion loss, return loss with respect to frequency and ON and Off states of these loss with respect to frequency is studied. Ultra low ON state insertion loss, high off state isolation and high RF signal power handling characteristics are achieved .Many of the inherent problems associated with the more traditional switches is overcome with this power MEMS switch. The SUGAR simulator is used to obtain the performance analysis of the MEMS power switch.

Keywords— *MEMS, Power Switch, SUGAR Simulator,*

[1] INTRODUCTION

MEMS process is used to create tiny integrated devices or systems that combine mechanical and electrical components. These are fabricated using integrated circuit (IC) batch processing techniques and can range in size from a few micrometres to millimetres. These devices have ability to sense, control and actuate on the micro scale and generate effects on the macro scale. The complexity of MEMS is in the extensive range of markets and applications that incorporate MEMS devices and found system ranging across automotive, medical, electronic, communication and defence applications. It includes accelerometers for airbag sensors, inkjet printer heads, computer disk drive read/write heads, projection display chips, blood pressure sensors, optical switches, micro-valves, biosensors and etc.

MEMS are defined miniaturized mechanical and electro-mechanical elements that are using the techniques of micro fabrication, where it vary from one micron on the lower end of the dimensional spectrum, to several millimetres. MEMS consist of mechanical microstructures, micro sensors, micro actuators and microelectronics, all integrated onto the same silicon chip as shown in Figure 1.

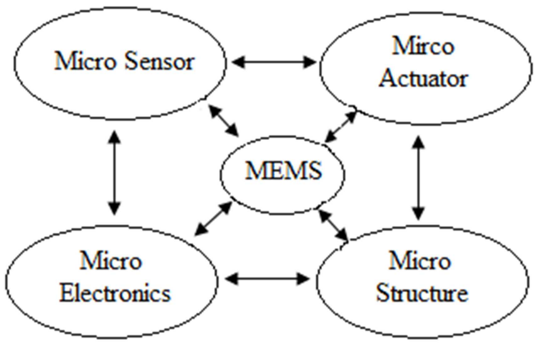

Fig. 1 Schematic Illustration Of MEMS Components

Micro sensors detect changes in the system's environment by measuring mechanical, thermal, magnetic, chemical or electromagnetic information or phenomena. Microelectronics processes the information and signals the micro actuators to react and create some changes to the environment. These devices are very small and their components are usually microscopic.

1.1 MEMS Applications

The MEMS and micromachining techniques advantages are,

[1] MEMS with its batch fabrication techniques enables components and devices to be manufactured with increased performance and reliability, combined with the advantages of reduced physical size, volume, weight and cost.

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[2] Provides manufacture products that cannot be made by other methods.
[3] MEMS potentially are more pervasive technology than integrated circuit microchips.

MEMS applications in various functional domains are used to refer to a domain in which the MEMS device performs a function (such as sensing or actuation). MEMS technology is used in various fields of the physical domain such as,

[1] Mechanical (e.g., Pressure sensors, Accelerometers, and Gyroscopes)
[2] Microfluidics (e.g., Inkjet nozzles), Acoustics (e.g., Microphone)
[3] RF MEMS (e.g., Switches and Resonators), and
[4] Optical MEMS (e.g., Micromirrors).

MEMS technology has demonstrated unique solutions and delivered innovative products in chemical, biological and medical domains as well. It penetrated into consumer electronics, home appliances, automotive industry, aerospace industry, biomedical industry, recreation and sports, etc.

1.2 Classifications of MEMS

The microsystems incorporate the use of microelectronics batch processing techniques for their design and fabrication. It is difficult to recently and have ability to perform high space-bandwidth product, as well as obtaining real-time encryption to unauthorized decryption and its portability [8]. Moreover, an encryption has the possibility of supporting biometric based approaches also. The polarization encryption (E_P) provides additional flexibility in the key encryption design by adding a polarization state manipulation to the phase and amplitude manipulation (conventionally used in optical encryption methods) and makes E_P method more secure.

categorise MEMS devices in terms of sensing domain and/or their subset of MST. The classifications of microsystems technology is shown in Figure 2.

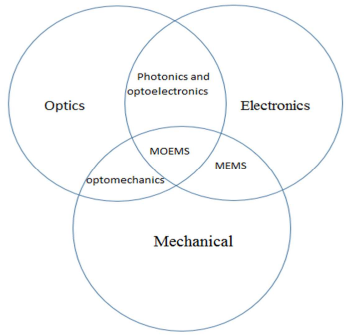

Fig. 2 Classifications Of Microsystems Technology

1.3 MEMS Description

MEMS technology is implemented using a number of different materials and manufacturing techniques are,

[1] Silicon- Ability to incorporate electronic functionality makes silicon attractive for a wide variety of MEMS applications and has significant advantages engendered through its material properties.
[2] **Polymers-** It produced in huge volumes with a variety of material characteristics and made from polymers by processes such as injection molding, embossing or stereo lithography. It is suited to microfluidic applications also (such as disposable blood testing cartridges).
[3] **Metals-** It exhibits very high degrees of reliability and deposited by electroplating, evaporation and sputtering processes.

2. PREVIOUS WORK

Jo-Ey Wong, et al., [2000] proposed an electrostatically actuated MEMS switch for power applications. It presented the design, analysis, fabrication and testing of an electrostatically actuated MEMS for power switch. Joo-Young Choi, et al., [2009] proposed three-dimensional RF MEMS switch for power applications. It presents a new concept in 3-D RF microelectromechanical systems switches intended for power applications. W. Simon, et al., [2002] proposed designing a novel RF MEMS switch for broadband power applications. It considers the RF power-handling capacity varies between architectural designs, which have number of diverse approaches to improve the RF power-handling capacity. D. Peroulis, et al., [2004] proposed RF MEMS switches with enhanced power-handling capabilities. The power handling capacity varies with many variables associated with the switch architecture, which has many diverse efforts to

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improve RF signal power handling capacity. S. Di Nardo, et al., [2013] proposed design of RF MEMS based switch matrix for space applications.F. Maury, et al., [2008] presented RF domain is using MEMS switching devices for medium power applications is RF power. S. G. Tan, et al., [2005] presented a study of the behavior of electrically actuated RF-MEMS switches with ohmic contact. C. L. Goldsmith, et al., [1999] presented shunt microwave switches and RF MEMS variables capacitors for tunable filters. S.P. Pacheco, et al., [2000] presented the capacitive shunt switches which are actuated electrostatically with DC voltages varying between 20V and 6V. E. Sovero [1999] presented key MEMS devices for current RF architectures are switches and micro-relays in radar systems and filters in communications systems.

3. MEMS DESIGN PROCESS

The basic building blocks in MEMS technology are,

[1] **Deposition Process-** The ability to deposit thin films of material on a substrate

[2] **Lithography -** Apply a patterned mask on top of the films by photo lithograpic imaging, and

[3] **Etching -** To etch the films selectively to the mask.

MEMS process is usually a structured sequence of the operations to form actual devices is shown in Figure 3.

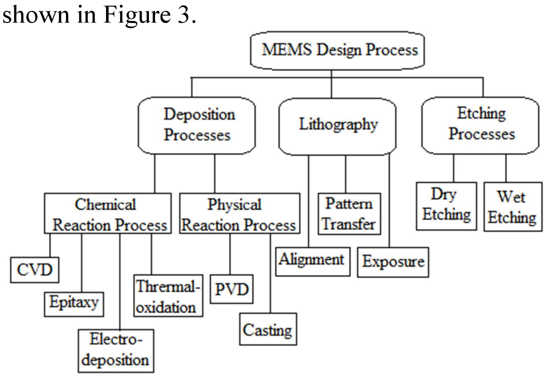

Fig. 3 Different Design Process used in MEMS

3.1 Fabrication process for ultra insertion loss.

MEMS devices employed in RF application are termed as RF MEMS. Requirement of RF MEMS system is for low weight, less volume, low power consumption. RF devices in which a breakthrough has been achieved are micro switches, tunable capacitor, micro machined antennas. RF MEMS are manufactured using conventional 3D structure technologies like bulk and surface micro machining but LIGA and SCREAM are also used for higher ascept ratio. the materials used as the substrate is Si,SiC,GaAs etc. RF MEMS has 0.45db insertion loss,40db isolation, 70dbm linearity,40db return loss. Fully compatibility CMOS IC fabrication needs advancement is improving RF performance silicon substrate.

Electroplating process.

Step-1 The whole system is coated with special grade Aluminium which is micro fine (600 mesh).

Step-2 Then by slow process copper is coated by pulse method [Pulse method means the system is coated with copper and make to dry for 10 minutes again it is coated with copper and the process continue] to get super fine structure.

Step-3 The whole system is kept in sodium hydroxide [warm solution] so the aluminium dissolves and the internal part alone will be there.

Step-4 Again it is coated with silver for the final structure in which the insertion loss is very less.

[4] SUGAR SIMULATOR AND DEVICE IMPLEMENTATION

SUGAR is an open source simulation tool for micro-electromechanical systems (MEMS) based on nodal analysis techniques from the world of integrated circuit simulation. Beams, electrostatic gaps, circuit elements, and other elements are modelled by small, coupled systems of differential equations. Sugar inherits its name from spice. It's a simulation tool that used for MEMS. A MEMS designer can describe a device in a compact netlist format and simulate the device's behaviour.

The main components of SUGAR are

[1] Netlist Interpreter (Based on LUA programming).

[2] Models written in Mat Lab or C language (Describing the characteristics of different components)

[3] Command line (for interaction and visualization of specific component)

[4] GUI (for interaction and visualization of specific component)

[5] SUGAR core (to handle Nodes, elements, Mesh assembly and analysis of the device)

The devices in SUGAR are described by input files called netlists (a derivative of the Lua language). By convention, the SUGAR model functions use the familiar MKS (meter-kilogram-

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second) system of units. This means that beam lengths, for example, are measured in meters instead of micrometers. In order to make it easier to type lengths of microns and pressures of giga-pascals, a standard system of metric suffixes that can be appended to SUGAR numbers is adopted. For example: A hundred micron length in SUGAR could be represented as 100u and in scientific notation (100e-6) or as a simple decimal (0.0001

4.1 Netlist Expressions for Length of a Beam

Expressions are often used for calculation and it's very simple inside a netlist. For example, a variable beamL for the length of a beam in a device is written as expressions,

beamL = 100u -- Make a beam one hundred microns long

A = node {0, 0, 0; name = "A"} ... (1)
B = node {name = "B"} ... (2)
C = node {name = "C"} ... (3)
D = node {name = "D"} ... (4)

4.2 Primitives in SUGAR

It includes reserved words like node, addpath, node, material, element and subnet. The expressions (1 to 4) is possible to combined to form a beam as,

beam3d {A, B ; material=p1, w=2u, l=beamL}

It assigns values to the variables to perform various conditional, arithmetic and logical operations as well as in any other language such as in C or Mat Lab.

Example:

```
if a then
        x = a
elseif b then
        x = b
else
        x = c
end
```

4.3 Operations in SUGAR

The operations are illustrated in Table 1 (LUA extension).

Table 1 Illustrated Operations

Levels	operators
7	| (logical or)
6	&(logical and)
5	== (equality), != (inequality), > (greater), < (less), >= (greater or equal), <= (less or equal)
4	- (add), + (subtract)
3	* (multiply), / (divide)
2	- (negate), ! (logical not)
1	^ (exponentiation)

Note: All operations are left associative, so a + b + c is evaluated as (a + b) + c rather than as a + (b + c).

The order of operations is from highest precedence to lowest precedence.

Non-zero numbers are interpreted as "true," and zero is interpreted as "false."

When a comparison or logical operation is true, it will evaluate to 1.

4.4 Rotation Angles

The orientation of structures is SUGAR, which provides user to specify how each piece is rotated from a model coordinate frame into its actual orientation in the structure. This specification can be done according to a global reference frame by specifying the exact positions of the nodes. Rotations are specified by a sequence of rotations about the x, y, and z axis. The amount to rotate about each axis is given by angles ox, oy, and oz given in degrees.

Example 1: beam3d {B, D; material=p1, w=2u, l=beamL/2, oz=90} expression is to create a beam in three dimensional space (i.e. x, y, z space) with the beam orientation of 90^o in z-axis plane.

4.5 Lexical Conventions

SUGAR 3.0 netlists are "free form"; white space characters like tabs and carriage returns are not significant. The keywords are reserved and cannot be used as names are given in Table 2.

Table 2 Reserved Keywords

and	break	do	else	elseif	end
false	for	function	goto	if	in
local	nil	not	or	repeat	return
then	true	until	while		

Note: Netlist begins with -- and extends to the end of the line and the language is case sensitive

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4.6 Use Statement (By Netlist)

It includes other files, which has the form use ("filename").

Example 1: many netlists use the data for MUMPS process layers defined in mumps. net, use ("mumps.net").

4.7 Addpath Statements

It specifies directories, so the use statement is not needed to specify the entire path, only a filename.

Example 1:

```
use ("src/lua/base/mumps.net")
use ("src/lua/base/std.net")
```

could be rewritten as,

```
addpath ("src/lua/base")
use ("mumps.net")
use ("std.net")
```

4.8 Node Statements

Nodes are connection points which have associated variables shared by attached elements.

Example 1: An absolute nodal declaration of node A at position (0, 0, 0) is

A = node {0, 0, 0; name = "A"}

Example 2: A relative nodal declaration of node B is B = node {name = "B"}

When relative node positioning is used, SUGAR ensures the node positions are generated for each of the elements. The syntax node "A" is used to refer to a node named "A" in the current scope. If no such node exists yet, then a new one is created.

4.9 Element Statements

The basic unit of a SUGAR netlist is an element line.

Example 1: crossbeam = element {A, B; model="beam2d", material=p1, l=100u, w=2u}, is an element line describing a beam. The above statement consists of a list of nodes. In this case, the beam connects nodes A and B. Elements are connected together by sharing a common node. For instance, to attach a wider 100 micron beam to the B end of the beam above, we might write element { B, C; model="beam2d", material=p1, l=100u, w=5u }

Note: Unlike in previous versions of SUGAR, node names in SUGAR 3.0 must begin with an alphabetic character.

4.9.1 Variables

SUGAR allows users to define variables in the Lua environment at load time.

Example:

```
params.nfingers = 10;
net = cho_load("comb.net", params);
```

To create an instance of comb.net with comb drives having ten fingers. To test inside the netlist whether a variable is defined and use the if statement

```
if not nfingers then
    nfingers = 10 -- default is ten fingers
end
```

OR

```
nfingers = nfingers or 10
```

SUGAR netlists may also include definitions, such as

```
long_length = 200u
short_length = 100u
avg_length = (long_length + short_length)/2
```

Netlist variables are scoped, so that a definition declared with the keyword, local, made inside a subnet will not affect top-level element statements.

4.10 Material Statements - Process Parameter Structures

Physical parameters associated with a particular layer of a particular material are process parameters.

Example: The baseline process information for the polysilicon layers in MUMPS (default) is provided,

```
default = material {
Poisson = 0.3,            --Poisson's Ratio = 0.3
thermcond = 2.33, --Thermal conductivity Si = 2.33e-6/C
viscosity = 1.78e-5, --Viscosity (of air) = 1.78e-5
fluid = 2e-6, --Between the device and the substrate.
density = 2300, --Material density = 2300 kg/m^3
Youngmodulus = 165e9, --Young's modulus = 1.65e11 N/m^2
permittivity = 8.854e-12, --permittivity: C^2/(uN.um^2)=(C.s)^2/kg.um^3
sheetresistance = 20 --Poly-Si sheet resistance [ohm/square]
}
```

In general a process definition has the form name = material {...}, where material is a keyword, name is the name to be given to the process information.

4.11 Arrays

SUGAR supports arrays of structures through the same syntax as Lua. Arrays are built enclosed in braces and referenced using brackets. The general syntax of a for loop is,

```
for index = lowerbound, upperbound [, increment] do
    ... code lines ...
```

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end;

where, index is the name of the index variable, lowerbound is an expression for the lower bound of the loop and upperbound is an expression for the upper bound of a loop.

4.12 Conditional Expressions

SUGAR supports if statements of the form

```
if expression then
        ... code lines ...
end
and
if expression then
        ... code lines ...
else
        ... code lines ...
end;
```

5. RESULTS AND DISCUSSION

Table 3 shows the insertion loss and return loss with respect to frequencyand we observed Low ON state insertion loss from Table 5 , from Table 4 the isolation characteristics is studied and oserved high off state isolation from Table 6 and high RF signal power handling characteristics can be achieved .

Table 3Insertion and Return loss

Sl. No	Frequency in db	Insertion loss	Return loss
1	40	-12	-4
2	42	-14	-3
3	44	-18	-2
4	45	-20	-2
5	46	-22	-2
6	48	-26	-2
7	50	-24	-2
8	52	-23	-2
9	54	-23	-2
10	55	-26	-2
11	56	-32	-3
12	58	-26	-3
13	60	-24	-4

Table 4 Isolation characteristics

Sl.No	Frequency	Insertion loss	Return loss
1	40	-2	-12
2	42	0	-14
3	44	0	-30
4	45	0	-32
5	46	0	-34
6	48	0	-32
7	50	-0.8	-30
8	52	--0.9	-26
9	54	-1	-28
10	55	-1	-25
11	56	-1	-24
12	58	-1	-24
13	60	-1	-22

Table 5 ON STATE

Sl.No	Frequency	Insertion loss	Return loss
1	0	-30	0
2	0.5	-28	0
3	1	-24	0
4	1.5	-18	0
5	2	-16	0
6	2.5	-20	0
7	3	-14	0
8	3.5	-16	0
9	4	-18	0
10	4.5	-19	0
11	5	-18	0
12	5.5	-20	0
13	6	-28	0

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14	6.5	-36	0
15	7	-38	0
16	7.5	-34	0
17	8	-20	0

Table 6OFF state

Sl.No	Frequency	Insertion loss	Return loss
1	0	0	-70
2	0.5	0	-58
3	1	0	-48
4	1.5	0	-42
5	2	0	-28
6	2.5	0	-40
7	3	0	-42
8	3.5	0	-44
9	4	0	-46
10	4.5	0	-68
11	5	0	-62
12	5.5	0	-50
13	6	0	-55
14	6.5	0	-65
15	7	0	-70
16	7.5	0	-70
17	8	0	-32

6. CONCLUSION

Power switch system is needed for more efficient safety and desire for enhanced performance for MEMS-based technology A MEMS power switch was implemented and the insertion loss, return loss with respect to frequency and ON and Off states of these loss with respect to frequency was achieved. Ultra low ON state insertion loss, high off state isolation and high RF signal power handling characteristics are achieved .Many of the inherent problems associated with the more traditional switches was overcome.MEMS based silicon ultrasonic sensors have many advantages over existing piezoelectric sensors in non-destructive evaluation, proximity sensing and gas flow measurement and provide improved performance in the areas of medical imaging and liquid level detection.

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