Microelectronic Engineering 157 (2016) 78–82

Contents lists available at ScienceDirect

Microelectronic Engineering

journal homepage: www.elsevier.com/locate/mee

Fabrication and characterization of MEMS cantilever array for switching applications

Deepak G. Khushalani [a,*], Rajesh S. Pande [a], Rajendra M. Patrikar [b]

[a] Shri Ramdeobaba College of Engineering & Management, Nagpur, India
[b] V. N. I. T. Nagpur, India

ARTICLE INFO

Article history:
Received 17 June 2015
Received in revised form 3 February 2016
Accepted 15 February 2016
Available online 16 February 2016

Keywords:
MEMS
Cantilever
Current
Switch matrix

ABSTRACT

The electromechanical switches have been playing an important role in technology particularly in the industrial applications. Along with many components, this switch is also miniaturized and showing many interesting properties. In this work, the design and development of micro-cantilevers switch array for increasing the current handling capacity of the device for switching applications is presented. The aim is to design an array of MEMS cantilever beam switch with low actuation voltage for large current handling applications. The aluminum interconnects having current density in the endurable range is the backbone for the designed cantilever switch. These switches are arranged in parallel to split the current in multiple interconnect. The switch is fabricated and electrically tested to compare the experimental values and theoretical model. The characterization results show an increase in current handling capacity with lower actuation voltage in these switches. This switch can also be configured for multiple numbers of cantilever beams for scaling up the current capacity with low actuation voltage. Thus MEMS-based switch can be used for various power electronic circuits and applications with added advantages.

1. Introduction

Electrical and mechanical switches play an essential role in directing the converted or controlled power in various switching applications like switch mode power supply. Solid state transistors and conventional electromagnetic relays have been commonly used in various switching applications. The choice of switch depends on the application; for example transistors are known for being physically smaller as compared with relays or mechanical switches however, their power handling capacity would be lower. The development of batch fabrication processes and planer technologies of emerging semiconductor devices also helped in the growth of micro-devices such as Micro-electro Mechanical Systems (MEMS or micro-systems) whose switching characteristics are similar to that of transistor with negligible power dissipation or losses.

A typical MEMS switch is a micro-machined device consisting of a membrane or strip of metal suspended over an electrode. Switch operation is caused by an electrostatic field induced by an applied voltage [1,2,3]. Several MEMS switch configurations have been investigated to date with varying degrees of success. Many of these switches have not been commercialized yet, because reliability of these switches is not yet ascertained as required for usable systems. The degradation phenomenon like stiction, creep, and micro-welding has been the research interest over the past few years. Various solutions have been suggested and most of them are design and application specific. One of the successful switch configurations is the cantilever-type. In our previous work, it was highlighted that the MEMS cantilever switches can have superior performance compared with semiconductor devices for requirement of some of the switching applications [4,5]. The main advantage of the switch is near to zero static power; making it an extremely efficient and attractive alternative. These miniature switches are becoming ubiquitous, and are hastily finding their way into a variety of commercial fields like automobile, electronics, bio-medical and defense. A lot of work related to the reliability of these switches is being done [3–10]; still the application of this switch in high power applications is limited to few [10–14].

A power switch with greater current handling capacity and least possible on-state resistance is desired along with high off-state resistance and capability of withstanding high standoff voltages. MEMS cantilever switches are playing a very significant role in developing the world of miniaturization while maintaining the required qualities of switches. Its design and development to replace semiconductor devices along with the advantages of batch fabrication are the need and subject of interest. Depending on the feature size, the current handling capacity of MEMS cantilever switches ranges in few milliamperes (less the feature size, less is amount of current handling) [6,8,9]. For successful substitution of semiconductor device with MEMS switch requires different approaches in which high power can be handled. The approaches based on material improvements, power splitting and

* Corresponding author.
E-mail addresses: khushalanidg@rknec.edu (D.G. Khushalani), panders@rknec.edu (R.S. Pande), rajendra@computer.org (R.M. Patrikar).

http://dx.doi.org/10.1016/j.mee.2016.02.022
0167-9317/

increasing power handling using thick metal topologies are the important ones explored.

In this paper focus is on the design and development of MEMS cantilever interconnected switch array having higher current handling capacity. For this, current splitting in the array of switching elements is explored and utilized for high power switching applications with reduction in thermal issues. This approach will allow us to configure the switch array for different power and isolation requirements; while maintaining a low actuation voltage at each individual switching element (an additional advantage with respect to low power consumption [13]. The rest of the paper is organized as follows. In Section 2, the design of these devices has been explained. In Section 3, performance of these devices for power handling capability is discussed. The process for fabrication of these devices is described in Section 4. The electrical characteristics of these devices are presented in Section 5 followed by conclusion.

2. Device design

The performance of the switch depends upon the many physical and material parameters. For optimizing these parameters in the switch design in general, a factorial design of an experiment where every combination is exercised should be evaluated. This is a monotonous process consuming a great amount of time hence less preferred. The iterations during the design phase with the use of the computer aided design tools are less costly and made effective by using design of experiments in the earlier work [4]. In the design of switch, designing the physical parameters is of utmost importance. The dimensions of electromechanical systems affect spring constant, resonance frequency and thermal mass, leading to drastic changes in power consumption and switching speed. The parameters of prime importance for device performance during working of the switch are enlisted in here.

2.1. Current

The current capacity of a conductor is related to its electrical resistance (a lower-resistance conductor can carry a larger value of current). The resistance, in turn, is determined by the material and the size of the conductor. For a given material, conductors with a larger cross-sectional area have less resistance than conductors with a smaller cross-sectional area. Our objective is to design a cantilever switch for high power; hence the current carrying capacity of the transmission line (Fig. 1) plays a very important role to decide the width and thickness of the beam with respect to current density [4]. The current carrying capacity of the conductor can be estimated from Eq. (1) [14,15].

$$I = ad^{\frac{3}{2}} \tag{1}$$

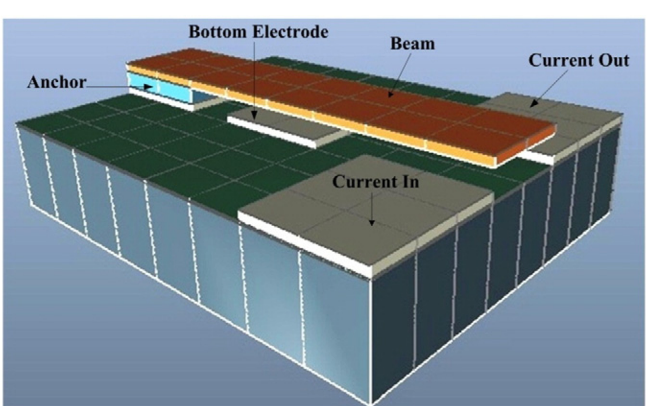

Fig. 1. Transmission of current in broadside switch.

where I = current in ampere, d = diameter of the wire in inches, and a = constant that depends on the material.

For the investigation of current handling property of metals, which is the amount of current that can be handled by a unit cross-section area with respect to time, requires proper understanding of heat dissipation. The quantity of heat that is transmitted due to temperature gradient and the thermal coefficient of resistance in unit time under steady conditions requires balancing of thermal conductivity. The reciprocal of thermal conductivity is called thermal resistivity. The thermal conductivity of a material may also depend on temperature. Lower resistive paths offer high flow of current causing temperature instability. This instability leads to non-linear effects and losses such as micro-welding. This requires balancing to overcome the heat loss/dissipation (Eq. (2)) [9,14,15].

$$I = A\left(\frac{\log\left(1+\frac{Tm-Ta}{234+Ta}\right)}{33s}\right)^{\frac{1}{2}} \tag{2}$$

where I = current in amps, A = cross-sectional area in circular mils, Tm = melting temperature of the

material in degree centigrade, Ta = ambient temperature in degree centigrade and s = time in seconds.

2.2. Pull-in voltage

The development of charge on application of voltage that causes the cantilever beam to deflect singularizes electrostatic force. For a MEMS switch it is given by the below equation [1,4,9].

$$V_{Pin} = \sqrt{\frac{8\ \ kg_0{}^3}{27\varepsilon_0 S}} \tag{3}$$

where ϵ_0 = permittivity of air, S = overlap area between bottom electrode and the beam, g_0 = distance between the plates and k = spring constant of the cantilever beam.

Changing the physical parameters such as higher cantilever thickness and smaller length will help us increase the resonance frequency while maintaining lower actuation voltage. To have maximum current handling capacity with lower actuation voltage the response time also plays a crucial role. The response time decides the load of peak current.

A simple equation, derived by Barker and Rebeiz [16,17] that accurately predicts the switching time (on-time) is given as

$$t = 3.67\,\frac{V_{pin}}{V_s\omega_0} \tag{4}$$

where V_{pin} = pull-in voltage, V_s = snap down voltage, and ω_0 = resonant frequency.

$$\omega_0 = \sqrt{\frac{k}{m}} \tag{5}$$

where k = spring constant of cantilever beam, and m = mass of cantilever.

Table 1
Material comparison for cantilever having dimensions 100 μm × 35 μm × 0.5 μm.

Parameters	Materials			
	Aluminum	Nickel	Copper	Silicon
Density (kg-m^3)	2700	8908	8900	2350
Young's modulus (GPa)	71	200	110	130
k_t (N/m)	0.077	0.21	0.12	0.14
m (p kg)	4.725	15.5	15.4	4.112
V_p(V)	1.44	2.6	1.9	2