MEMS Design for LSI Tester Applications

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abstract – This paper describes our MEMS research with analog circuit design sense for LSI tester applications; especially design of switches and inductors with MEMS technology. The switch is very important component in an LSI tester system and we design a MEMS switch using heat expansion mechanism. Also we show three ideas of implementing *variable* inductors with MEMS technology.

Keywords : MEMS, MEMS Switch, Heat Expansion, Variable Inductor, LSI Tester

I. Introduction

The performance of electronic devices is continuously improving, and accordingly there is an ever-growing demand for fast new instruments such as LSI testers to measure their performance [1]. LSI testers have to be designed with today's (relatively low performance) devices to measure tomorrow's (higher performance) devices, and hence performance (speed and accuracy) is the first priority in their development. Low power consumption, small size, and implementation with popular monolithic CMOS consumer devices, are desirable but of lower priority.

As VLSI technology progresses and device sizes are scaled down, electronic circuits operate faster, more integration becomes possible and supply voltage is decreased. Also low power circuit design becomes more important. Thus a major trend of circuit design using fine semiconductor devices is high-speed, large integration, low voltage and low power. However Micro Electro Mechanical System (MEMS) technology is expected to supplement system functions which cannot be implemented with such fine semiconductor devices, such as high-voltage operation, mechanical and sensor parts, high-Q inductance and capacitances [2, 3, 4, 5]. In this paper, we investigate whether MEMS technology is applicable to IC tester systems which require several functions that cannot be implemented with fine CMOS circuits, and we will describe the following two MEMS designs:

(1) LSI test systems require many switches with low-resistance and linear characteristics in ON state as well as good isolation in OFF state. CMOS switches cannot meet these requirements and in many cases a large number of mechanical relay switches are used in an IC tester. However mechanical relay switches are costly and of large size, and also their reliability is not good; in today's practical LSI tester systems, their life time is determined by that of the relay switch. So we investigate whether MEMS technology can realize switches for LSI tester applications, and we try to design MEMS switches using heat expansion mechanism.

(2) Inductor implementation with MEMS would be promising because MEMS technology may realize inductors of relatively high-Q and large value. High-Q inductors can be used for high-frequency circuitry such as high-frequency LC filters and oscillators, and also the ones with large values can be used for power electronics circuitry such as on-chip switching regulators. On-chip implementation of variable inductors (whose values can be controlled externally) may be also feasible with MEMS technology, and they could lead to very flexible analog systems. We try to implement variable inductors with MEMS technology for RF IC testing systems.

Recently MEMS technology has been booming up, and most of MEMS research are being done by device, process, sensor or mechanics researchers. However only limited number of analog circuit researchers have been involved in this area. So we have started MEMS research from analog circuit point of view, and in this paper, we report on our trial to design analog circuit with MEMS and fabricate it through foundry, and measure it; we would like to show here that such an approach of analog circuit design sense is feasible for the MEMS research.

II. MEMS Switch with Heat Expansion

We design MEMS switches using heat expansion mechanism; they consist of four layers of Au, Ti, SiO2, and P-SiO2 (Fig.1). Since their heat expansion coefficients are different, they bend mechanically when a current flows and temperature becomes high; they can work as an actuator of a switch. By putting an electrode at the edge of the bending plate and also putting another one on the substrate, an electrical switch can be implemented (Fig.2). We simulate this actuator using MEMS design CAD (CoventorWare software) and we see that the plate bends down by 1.1μm for 1 degree up of temperature (Fig.3).

A two-way switch would be also possible with this heat expansion mechanism (Fig.4). Here when a current flows and temperature goes up at the right part, the plate bends to the right hand side. On the other hand, when they do at the left part, it bends to the left.

III. Variable Inductors with MEMS Technology

It is well-known that there are three basic passive elements in electronic circuits: R (resistor), C (capacitor) and L (inductor). Resistors and capacitors are integrated in LSI and recently also inductors can be integrated in Si LSI. Furthermore, *variable* resistors are realized on-chip using MOSFETs in triode region by changing their gate voltages. Also *variable* capacitors are implemented on-chip utilizing such as 1) depletion capacitance in PN junction by changing its bias voltage, or 2) Miller capacitance by changing its associated-amplifier gain. These variable resistors and capacitors are useful to optimize the circuit performance and realize adjustable circuits, such as tunable filters/oscillators and automatic gain control amplifiers.

However, there are very few which report on implementation of on-chip variable inductors. If variable inductors were also realized on Si LSI, very flexible analog integrated circuits would be implemented; for example, so-called reconfigurable RF front-end with very wide range tunable LC bandpass filter [4, 5], and on-chip low-ripple yet fast-transient-response switching regulators [6], which could be used also for LSI tester systems. We consider to implement on-chip variable inductors in three ways.

(1) The first idea is to change the self-inductance by moving a core. As Fig.5 shows, we move a core of high permeability mechanically into (or out from) a coil employing an actuator. When the core is inside the coil, its inductance value becomes large.

(ii) The second idea is to change the mutual inductance by moving one coil *vertically*. As Fig.6 shows, we make two spiral inductors with upper and lower metal layers, and we move the upper spiral inductor vertically with MEMS technology. When it moves down and is close to the lower layer, their mutual inductance value becomes large. On the other hand, when the upper moves up and is far from the lower their mutual inductance value becomes small.

(iii) The third idea is also to change the mutual inductance but by moving one coil *horizontally*. As Figs.7 (a), (b) show, we make two inductors with upper and lower metal layers, and we move the upper inductor horizontally with MEMS technology. When their relations are as shown in Fig.8 (c), their mutual inductance is maximum, while when they are in Fig.8 (d), it is minimum.

As a first step, we have designed a test spiral inductance with MEMS CAD tools, fabricated it through a MEMS foundry, and measured its characteristics (Figs.8, 9). The spiral inductance is made of the upper layer AlSi metal with 1μm thickness on SiO2 substrate. The lower layer AlSi metal is used to have an electrode and both metal layers are isolated with PSiO2 of 1μm thickness. Simulated inductance value is 230nH, measured parallel capacitance value is 13pF, while simulated and measured series resistance is 165 Ω; since the design is not optimized, the series resistance and parallel capacitance values are relatively large. As a next step, we now consider to design (with MEMS CAD tools) and implement (through MEMS foundry) the above three variable three structures.

IV. Summary

We have shown MEMS design of switches and inductors for LSI tester applications. We have designed and simulated MEMS switches utilizing heat expansion mechanism. Also we have shown three ideas of implementing *variable* inductors with MEMS technology.

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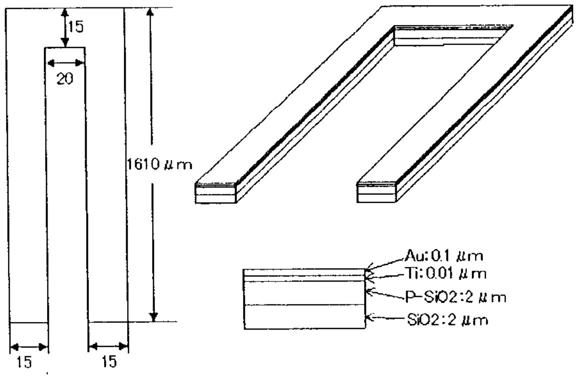

Fig.1: Structure of the designed MEMS switch actuator which uses heat expansion mechanism. CoventorWare software is used for the design. The top layer is Au, the second layer is Ti, the third layer is P-SiO2, and the bottom one is SiO2.

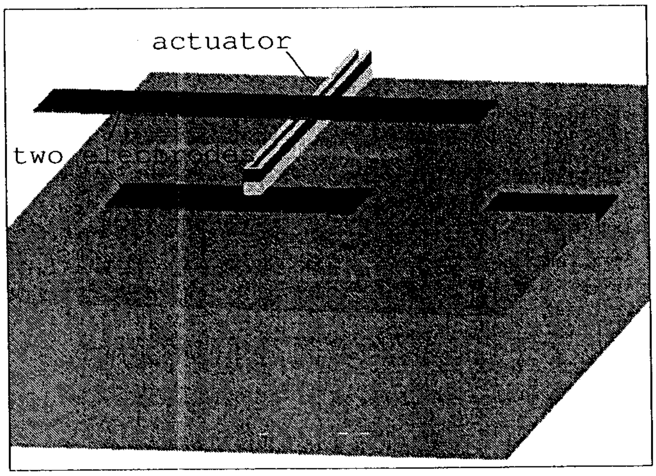

Fig.2: A whole MEMS switch with an actuator and two electrodes.

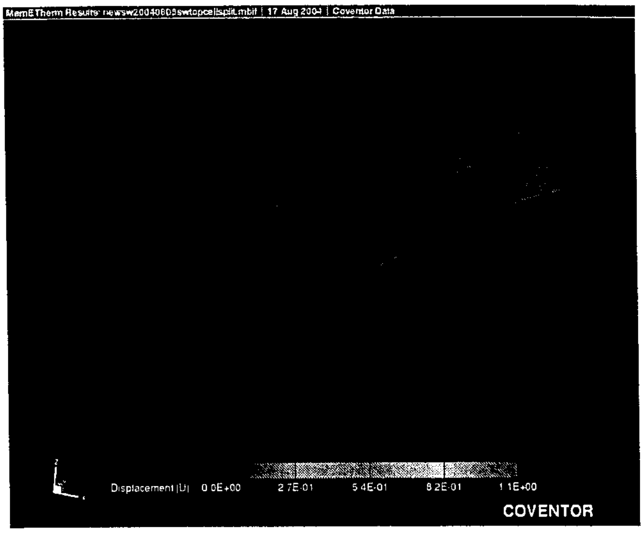

Fig.3: Simulation result of the designed MEMS switch actuator in Fig.1. We see that the plate bends down at the edge by 1.1μm for 1 degree up of temperature.

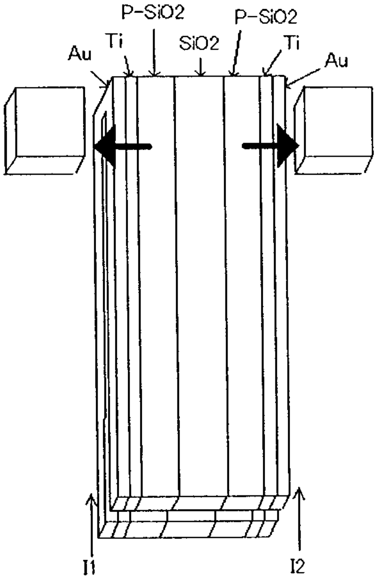

Fig.4: A MEMS two-way switch with heat expansio mechanism.

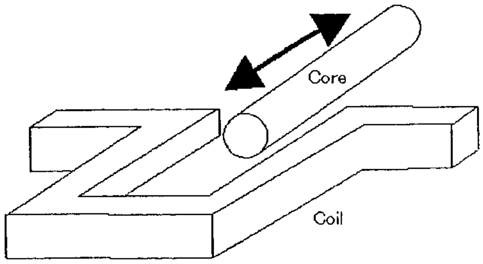

Fig.5: Structure of variable self-inductance. A core o high permeability mechanically into (or out from) a coi with an actuator.

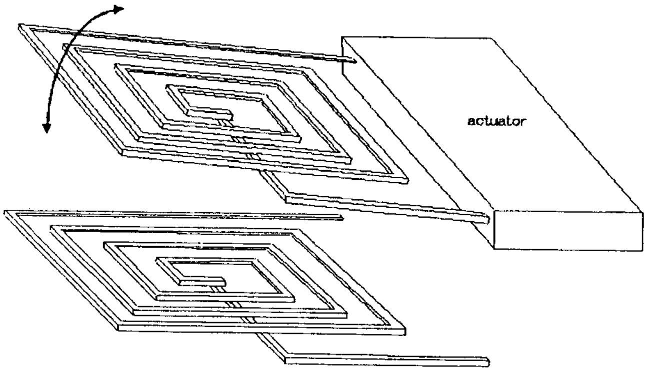

Fig.6: Structure of variable mutual-inductance. In two spiral inductors with upper and lower metal layers, the upper one is moved *vertically* with MEMS technology.

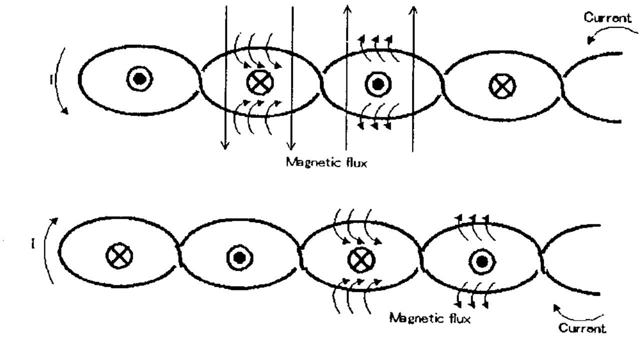

Fig.7: (a) Another structure of variable mutual-inductance. In two spiral inductors with upper and lower metal layers, the upper one is moved *horizontally* with MEMS technology.

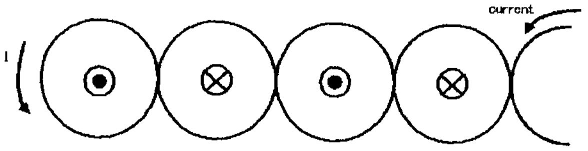

Fig.7: (b) Top view of each inductor.

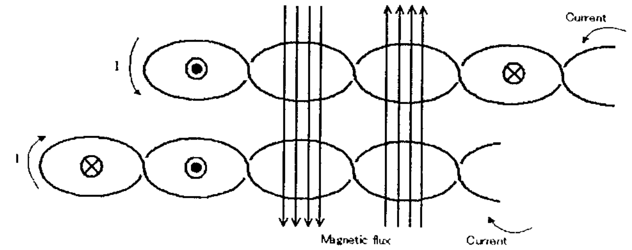

Fig.7: (c) Upper and lower inductors relationship when their mutual inductance is maximum.

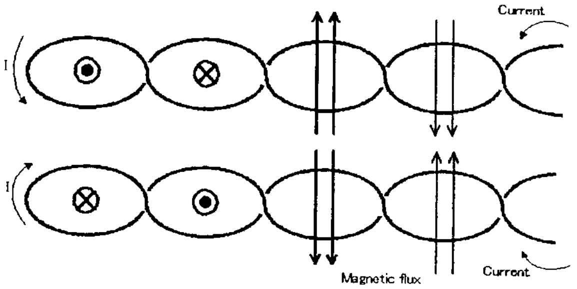

Fig.7: (d) Upper and lower inductors relationship when their mutual inductance is minimum.

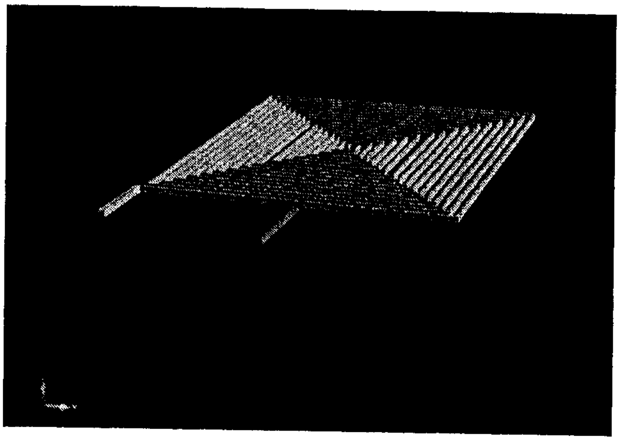

Fig.8: Structure of the designed test spiral inductance in MEMS technology. CoventorWare software is used for the design.

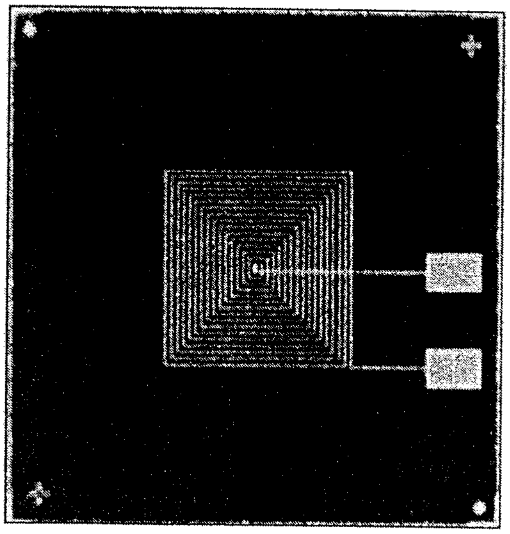

Fig.9: Chip photo of the fabricated spiral inductance in MEMS technology.