Available online at www.sciencedirect.com
ScienceDirect
Sensors and Actuators A 134 (2007) 600–605
SENSORS AND ACTUATORS A PHYSICAL
www.elsevier.com/locate/sna

Influence of metal stress on RF MEMS capacitive switches

Richard E. Strawser [a,*], Kevin D. Leedy [a], Rebecca Cortez [a], John L. Ebel [a], Steven R. Dooley [a], Cari F. Herrmann Abell [b], Victor M. Bright [c]

[a] *Air Force Research Laboratory, Sensors Directorate, Wright-Patterson AFB, OH 45433, USA*
[b] *Departments of Chemistry and Biochemistry, University of Colorado, Boulder, CO 80309, USA*
[c] *Departments of Mechanical Engineering, University of Colorado, Boulder, CO 80309, USA*

Received 8 February 2006; accepted 9 June 2006
Available online 31 July 2006

Abstract

The electrical and mechanical response of radio frequency (RF) microelectromechanical systems (MEMS) switches depends critically on the profile of the released structure. Stress gradients within the material can significantly alter the structural profile thereby changing the spring constant and the resulting switch release times. To investigate the influence of metal stress on spring constant and release time, a series of RF MEMS electrostatically actuated capacitive microswitches was fabricated with varying beam metallizations. The total thickness of the beam was fixed at 700 nm consisting primarily of Au while thin (5 nm or 20 nm thick) Ti layers were inserted at different positions within the beam. Changes in the location of the Ti layer within the bridge thickness resulted in distinct structural profiles across both the width and length of the released microswitches. Profile differences were quantified using white light interferometric microscopy. As the Ti layer moved toward the bottom of the tri-layer stack, beam deformation increased, spring constants increased, and release times decreased. Results demonstrated that release times could be reduced by an order of magnitude when compared to all Au switches.

Keywords: RF MEMS switches; Spring constant; Release time; Switching speed; Microbridge metallizations; Beam deformation; Radius of curvature

1. Introduction

The potential military and commercial applications for RF MEMS switches are numerous due to the advantages of MEMS in terms of low loss and low power requirements. The switches exceed the performance characteristics of active devices (transistors and diodes) except in switching time. The switching times of active devices are on the order of nanoseconds, while they are in microseconds for MEMS switches. For MEMS switches, the switching cycle consists of the voltage dependent turn-on and release times. The release time dominates the switching cycle and is dependent upon the mechanical design and material characteristics of the structure.

An overview of RF MEMS technology [1] identified film stress as an important factor influencing switch performance. Other research has indicated that choices in device materials affect the profile of released microstructures [2–4]. An examination of Au-based cantilevers and bridges indicated that the addition of a small (20 nm thick) second metal layer (Ti, Pt, and W:Au) underneath a nominally 1 μm thick Au microstructure dramatically changed the curvature of the structures [2]. Analytical and experimental examination of the buckling behavior of 0.3–1.0 μm thick SiO_2 microbridges indicated that the buckling behavior of the structures could be tailored through judicious choice of film thickness, beam length, and film intrinsic stress [3]. Non-linear [5] modeling of fixed–fixed beams incorporated the effect of intrinsic stress on switch performance and accurately characterized the dynamics of flat beams.

Stress gradients within the beam thickness can significantly modify the beam profile thereby changing the spring constant and resulting switching speed. To date, the correlation between beam profiles and stress gradients has received only limited examination. Yao [1] summarized many of the seminal RF MEMS switch designs and their performance characteristics but the influence of metal stress on the electrical characterization of the switches was not discussed. The intent of the present research was to examine the effect of the metal stress on the performance of RF MEMS switches, with particular attention

* Corresponding author. Tel.: +1 937 255 4557; fax: 1 937 255 8656.
E-mail address: richard.strawser@wpafb.af.mil (R.E. Strawser).

0924-4247/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.sna.2006.06.024

to the influence of beam curvature on the spring constant and release time.

2. Switch fabrication and testing procedure

RF MEMS shunt capacitive bridge switches were fabricated on an R-plane sapphire wafer using a four level mask process. The RF pattern was formed using an evaporated metal lift-off process and consisted of a 20 nm Ti adhesion layer followed by 300 nm Au. The dielectric layer consisted of 220 nm alumina blanket-deposited using an atomic layer deposition technique [6]. The alumina was patterned and dry etched for the dielectric pull-in pad. A nominal 3 μm thick sacrificial photoresist layer was then deposited and patterned to form the bridge post material. The bridge structure was patterned and then the wafer was diced to allow variations of the bridge metallization to be made with all other wafer processing conditions held constant.

The total bridge thickness was held constant at 700 nm for each of the sapphire pieces. Bridge metallization consisted of evaporated Au with a single 5 nm or 20 nm layer of evaporated Ti incorporated within the film. The as-deposited intrinsic stress of the Au/Ti/Au films was measured on films deposited onto 75 mm Si wafers metallized in conjunction with each bridge condition. Stress measurements were based on the wafer curvature technique using a Tencor FLX-2900 laser reflectometry system described earlier [2]. Table 1 summarizes the bridge metallizations and intrinsic stresses.

The release process consisted of wet photoresist dissolution to remove the sacrificial layer, followed by a supercritical CO_2 dry. A released microswitch, shown in Fig. 1, has a center span width of 120 and 300 μm length. The microbridge anchor points were 150 μm wide and 25 μm long. The device was designed in a coplanar waveguide (ground-signal-ground) configuration. In the off-state, the RF signal passes unattenuated beneath the overarching bridge. When actuated, the bridge is pulled down onto the signal line providing a high capacitance path to ground. The dielectric prevents electrical shorting of the bridge and signal lines.

Released bridge profiles were measured using a Zygo New View 5000 white light interferometric microscope with representative images shown in Fig. 2. Wafer probe marks are visible on the metal traces of (a) and (b). The all-Au and 340/20 beams were nearly flat as shown in (a), while the remaining metallizations produced increasing deformation as shown in (b) and (c). Profiles shown in Fig. 3 were measured across the device width to quantify radius of curvature (RoC) values. These measurements were based on an area average taken at the center of the switches. Profile measurements are listed in Table 2. The nominal gap spacing for all samples was 3 μm, except for the all-Au sample which was 2 μm. The 340/20 samples appeared flat, but had a slight tilt as shown by the angle of tilt (<0.3°). The all-Au samples exhibited a slight upward deformation at the bridge center. The remaining metallizations produced increasing downward deformations.

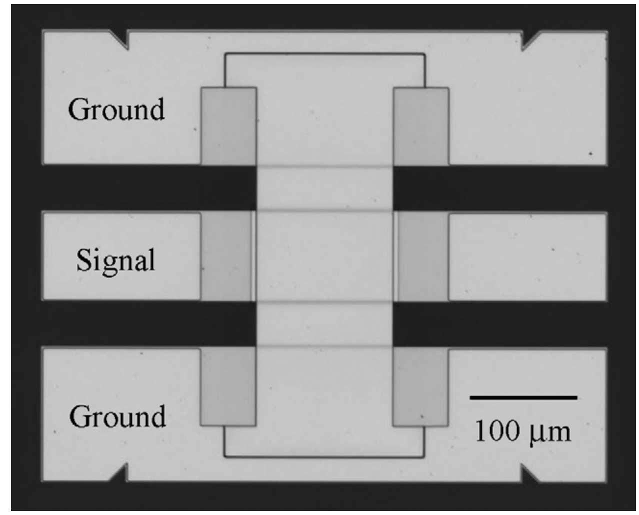

Fig. 1. Optical micrograph of an RF MEMS capacitive switch. The overall beam length is 350 μm with a center span length of 300 μm. The beam width at the root is 150 μm and the center span width is 120 μm.

Switch spring constants were measured by incrementally actuating the switches and measuring the deflection. Actuation was provided by a 50% duty cycle, 1 kHz dual polarity pulse supplied by an Agilent 33250 Arbitrary Function Generator. The pulse voltage was adjusted from 0 to 100 V using an Avtech AV-112A power supply. Switch deflections were measured at 1 V intervals using an interferometric microscope. The slope of the force versus deflection plots, shown in Fig. 4, provided the spring constants. The linear regions of the deflection curves (i.e. initial 1/3 gap spacing) were used in the plots. The force was calculated using the electrostatic force Eq. (1)

$$F_{\text{elec}} = \frac{\varepsilon_0 A V^2}{2(t_D/\varepsilon_R + g)^2}, \tag{1}$$

where ε_0 is the permittivity in vacuum (8.854×10^{-12} F/m^2), ε_R the relative permittivity (7), A the hold down area (9.6×10^{-9} m^2), V the actuation voltage, t_D the dielectric thickness, and g is the gap spacing as the beam is deflected.

Table 1
Bridge metallization and intrinsic stress summary

Sample ID	Evaporated bridge metallizations	Intrinsic stress (MPa)
All-Au	1000 nm Au	8
340/20	340 nm Au/20 nm Ti/340 nm Au	10
150/20	150 nm Au/20 nm Ti/530 nm Au	14
100/20	100 nm Au/20 nm Ti/580 nm Au	1
50/20	50 nm Au/20 nm Ti/630 nm Au	24
50/5	50 nm Au/5 nm Ti/645 nm Au	15

Table 2
Switch profile data

Sample ID	Shape	RoC (μm)	Gap (μm)
340/20	Tilted (0.07–0.3°)	15,000	3.60
All-Au	Bowed up	2500	1.77
150/20	Bowed down	−544 to −8000	0.17–1.09
100/20	Bowed down	−220	0.16–0.51
50/20	Bowed down	−250	0.17–0.74
50/5	Bowed down	−150	0.05