Process Development of GaAs Based RF MEMS Switch

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Keywords: RF MEMS, Sacrificial Layer, Stress in metal beam, On/Off capacitance

Abstract

Processes for realizing GaAs based RF MEMS are described in detail. Polyimide, OIR 17 PR and polymethylglutarimide (PMGI) were used as sacrificial layers. SEM investigations were carried out on MEMS structures. The Beam profiles were mapped with Optical Profilometer(OP). The OP data were correlated with SEM data. PMGI is found to have good process compatibility and is easy to remove. Metals like Au, Ti/Au, Au/Ti/Au and NiCr/Au were studied as beam metal. E-beam deposited 8000 °A Au metal beams and optimized Ti/Au stack exhibited good beam structures. For a 1000 °A field nitride, electrical C-V data of various RF MEMS gave OFF capacitance of around 0.2pf and ON capacitance of up to 2 pf which is dependent on beam metal width. The switching voltage of Meander structure is lower than the plane or perforated beams.. RF measurements were carried out up to 40 GHz. In some structures RF measurements show less than 0.4 dB insertion loss and more than 25dB isolation.

INTRODUCTION

RF MEMS Technology is expected to have an impact on Microwave Communication Systems, Phased Array beam former , EW Transmitters and Space based Radar Systems. At present most commonly used switch devices are PIN diodes, GaAs FETs and conventional mechanical switches. All the above systems use switches which are limited by insertion losses. RF MEMS Switch are preferred as they have i)Very good isolation and low insertion losses, ii) Low circuit power consumption in either on or off state, iii) Switching speed is sufficient for control, and iv)Process is technology compatible.

In our earlier paper [1] a process was reported on the development of RF MEMS Switch Technology compatible to GaAs MMIC Process Technology in which polyimide is used as sacrificial layer and 0.6 µm Au as beam metal. The MEMS realized using this process had (a) problem of removal of the sacrificial layer and (b) showed beam metal sagging (fig.1) (c) poor RF performance [2].Here we have used polymethylglutarimide (PMGI) which has outstanding planarity over steps with a Tg of approximately 190 °C . It produces thermally stable images up to 180 °C, is chemically stable to around 350 °C and has a better compatibility to MMIC process than other PRs. Optimized PEB Time and temperatures can yield positive slopes in Photo Resist (PR) profiles.

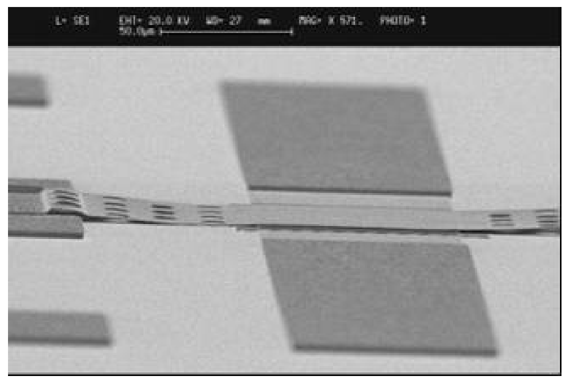

FIG.1: RF MEMS SHOWING BEAM SAGGING.

This paper will describe the process development of PMGI PR as sacrificial layer, it's removal, stress related issues in metal beams formed with Au, Ti-Au, Au-Ti-Au, and NiCr-Au using either e-beam evaporation or RF sputtering techniques. The realized RF MEMS were characterized with SEM, Optical profilometer, switching voltages with C-V measurements and RF measurements up to 40GHz.

EXPERIMENTAL

Five level masks were used to complete the RF MEMS process. The mask levels were designed after RF simulation of structures [3]. In the first step, CPW structures and transmission line metal is deposited on GaAs wafers with a double PR lift-off process using e-beam evaporation technique. The Ti/Au metal thickness used is 7000 A°. This was followed by deposition of 1000 A° PECVD nitride on transmission line for field dielectric. PECVD dielectric silicon nitride is deposited on metal patterned wafers. Mask 2 is used to define field dielectric. The PECVD Nitride is etched with BHF chemistry. Plated Au is used for thickening CPW structure. A sputter deposited 1000 A°

Ti/Au Metal stack is used as Seed layer. Au plating Compatible PR is coated and patterned using Mask 3 followed by Au platting up to 2 microns height. Seed layer Au is etched with KI solution and Ti is etched with BHF. PMGI or OIR17 PR is used as sacrificial layer and spin coated up to 3 microns thickness. Soft bake conditions of PMGI is 175 ^{o}C for 15 min. Image layer is coated over PMGI and Mask 4 is used for anchor windows. Optimum rocess is evolved to get positive slope of the anchor windows by playing post exposure bake (PEB) and hard bake, so that the beam metal has good conformal step coverage. 0.8microns thick Au and Ti/Au film is deposited with e-beam and/or sputter system and. mask 5 is used to define the metal beams. The beams are realized by removing the sacrificial layer with proper remover solvents. Stress in the beam metal films measured as a function of temperature up to 300 ^{o}C. DC capacitance as a function of voltage up to 40V**.**

SEM studies were carried to examine the beam metal topology and air gaps both in plan view as well as in tilted configuration. RF measurements were carried out up to 40GHz using Agilent E83683 vector network analyzer.

RESULTS AND DISCUSSION.

PMGI PR is found to have good process compatibility with e-beam metal deposition as well as sputter deposition. Photo resist OIR 17 is compatible with E-beam metal deposition but gets affected during sputter metal deposition. While removing the sacrificial layers, PMGI PR is removed completely with developer . E-beam metal deposited OIR 17 PR could not be removed completely. The results are tabulated in Table-1. Fig.2 and 3 show cantilever and Guckel ring structures which give information on the tensile stress in the deposited metal films. RF MEMS realized with 8000 A ^{o} Au metal deposited with e- beams have good air gap as shown in Fig. 4 and 5.

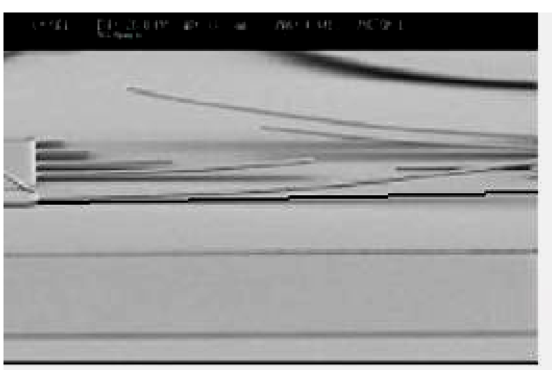

Fig 2 : Cantilever of Au metal showing increasing of height with cantilever length.

Table 1:

Summary of Process compatibility of Sacrificial layers and Beam Metal of RF MEMS

SNO	Beam Metal/ Thick	Metal deposition Technique	Sacrificial layer	Results
1	Au/0.8 microns	E-beam	PMGI	Air bridges are sagging
2	Au/0.8 microns	E-beam	OIR-17	PR removal Problem
3	Au/0.8 microns	Sputter	PMGI	Process compatibility, but Beam metal got sagged.
4	Au/0.8 microns	Sputter	OIR-17	PR affected at sputter metal deposition.
5	Ti/Au; /0.03/0.67	E-beam	PMGI	Good air gap.

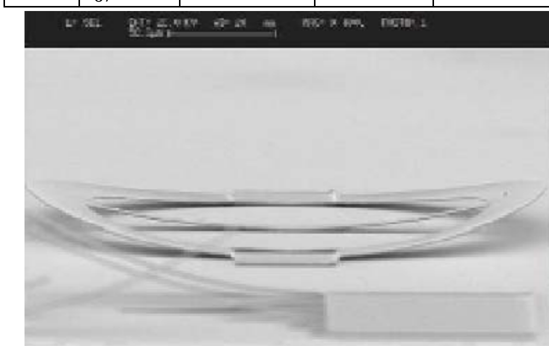

Fig. 3 : Guckel ring for e beam Au films with tensile stress

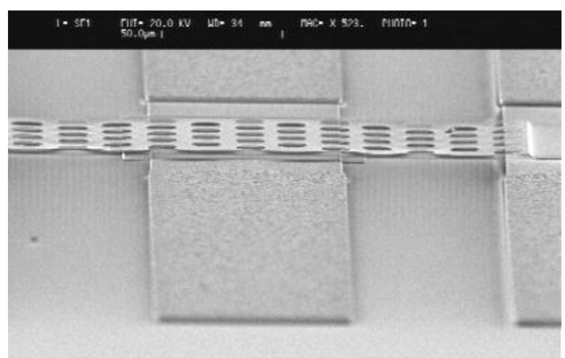

Fig.4 : Perforated Au beam metal

It can be seen from the figure that the 80 micron metal beam is flat and hanging between 240 microns anchor spacing. The beam profile with optical profilometer shows beam height / air gap is around 2 microns as shown in Fig.5

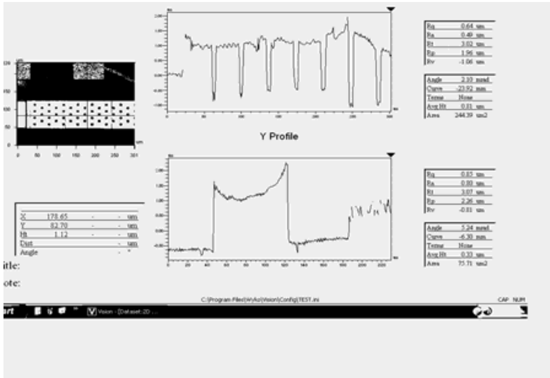

Fig.5: Au Beam Profile of RF MEMS

SEM pictures in Figs 7 to 9 show that Sputtered Ti/Au and NiCr/Au beams had curling due to tensile and compressive stress respectively in the beam metal.

Capacitance variation as a function of voltage up to 40 V was measured. At 0 V capacitance is around 0.2 pf. Switching of the capacitance up to 2 pf is observed around 15 to 20 V and depends on geometry of the RF switch capacitor.

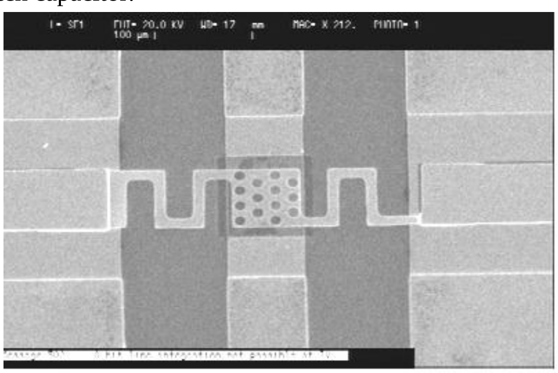

Fig.6: SEM picture of meander RF MEMS showing Au beam hanging between anchors

We have used shorted structures in the PCM (Process Control Monitor) to compare these data. From the shorted structures, the measured capacitance (80 µm X 80µm micron) was 3.5 pf for 1000 A PECVD field dielectric. The possible reason for the low capacitance observed in the C-V data may be due to smaller area of contact of the metal beam

Planarization of the sacrificial layer and optimization of metal beam process may improve the performance of the devices. The metal beams which got sagged and/or curled do not show capacitance variation with voltage. RF measurements of the realized resonator MEMS show less than 0.4 dB insertion loss and more than 25dB isolation as shown in Fig.11.

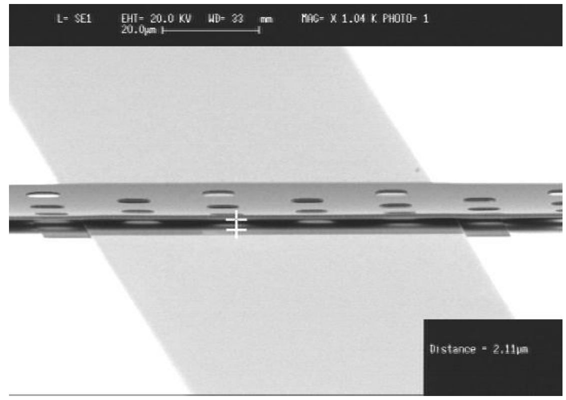

Fig. 7: Ti./Au (300 A ^{o}/7700 A^{o}) beam curled due to tensile stress

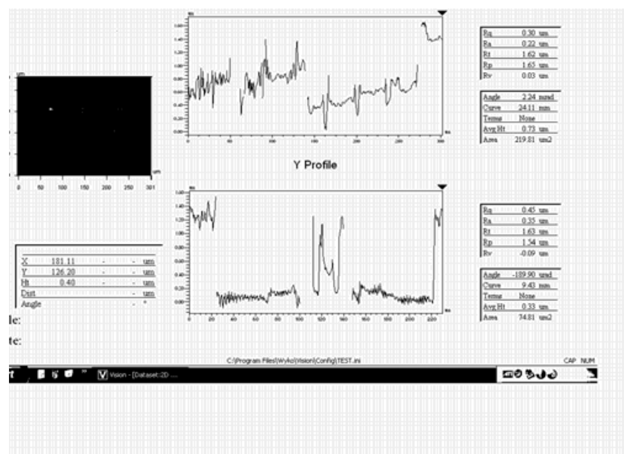

Fig.8: Optical profile of the beam showing the curvature of beam

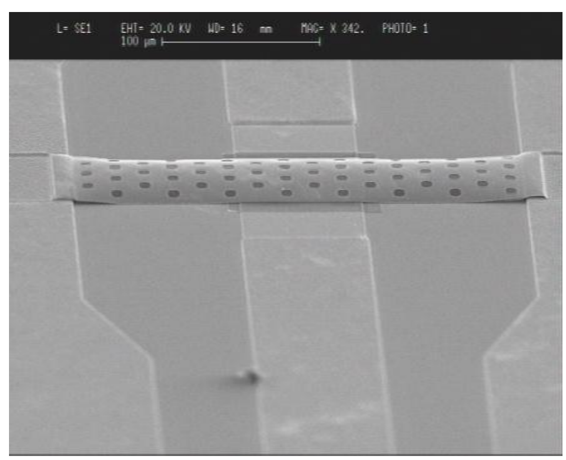

Fig. 9: SEM picture of NiCr/Au metal beams showing compressive stress

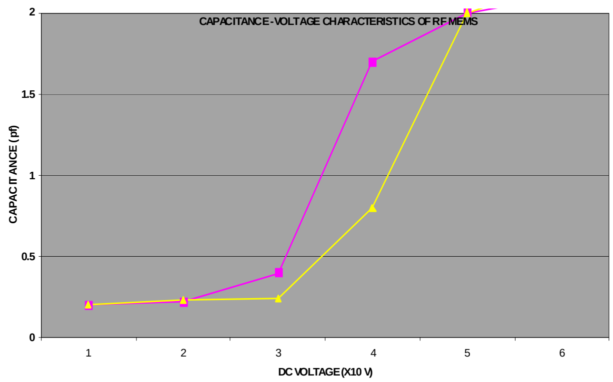

Fig. 10: C-V characteristics of RF MEMS

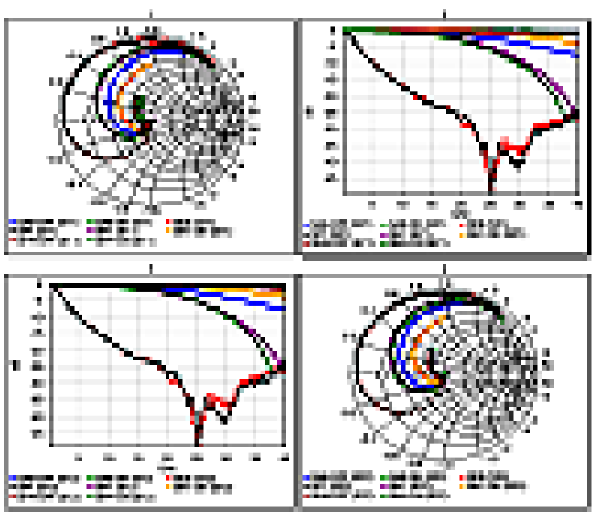

Fig. 11: RF performance of RF MEMS

CONCLUSIONS

In conclusion, a systematic work has been carried out to optimize process conditions of sacrificial layers and beam metals for GaAs based RF MEMS. PMGI photoresist was found suitable for sacrificial layer and E-beam deposited Au and Ti/Au for beam metal. SEM ,and Optical profilometer were used to inspect air bridge structures and beam profiling. The switching voltage of the RF MEMS strongly depends on their geometry. C-V data of RF MEMS in pulled condition show less capacitance as compared to that of PCM MIM structures of same size indicating that the RF MEMS may have less surface contact area over field nitride. Further work is in progress to improve the yield and performance of the RF MEMS.

REFERENCES

[1] P.Suryanarayana, A.A.Naik et al , 14th IWPSD Dec. 2007, held at IIT Mumbai, India

[2] Richard Strawson et al ,Sensors and Act.A , Physical Vol.134,issue 2,March 2007. pp600-605

[3] Preeti Sharma, Shiban K. Koul, et al International Conference on Recent Advances in Microwave Theory and Applications. 21-24 November, Jaipur (India) Microwave-2008 conference, Nov. 21 – 24, 2008 at Jaipur, India

[4] P.Suryanarayana, A.A.Naik et al Development of GaAs RF MEMS switch " International Conference On MEMS 2009, IIT , Madras, India Jan 2009

ACRONYMS

PGMI: PolymethylGlutariMide
PR: Photoresist
C-V : Capacitance –Voltage
SEM: Sacnning Electron Microscope
OP: Optical Profilometer
MEMS : Micro Electro Mechanical Switch