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Neutron and gamma radiation effects on MEMS structures

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Abstract

MEMS technology is expected to play a significant role in future space missions provided the effects of radiation on the reliability of MEMS devices is well understood [1]. Radiation induced dielectric charging has been identified as a mechanism which can potentially limit the reliability of electrostatically actuated MEMS devices [2]. The response of piezoresistive and PZT actuated MEMS was also found to change after exposure to different types of radiation [3]. It is however necessary to further investigate the effect of radiation and especially neutrons on the electromechanical properties of various materials that are used in microfabrication [4]. In this work we present results from mechanical and electrical tests on different materials before and after exposure to neutrons radiation.

Keywords: MEMS reliability; radiation; mechanical properties; dielectric charging

1. Introduction

This work reports on the effects of neutron and accompanying gamma photons radiation on the electromechanical properties of different materials that are typically used in MEMS fabrication. So far the effects of displacement damage due to neutrons on the elastic properties of single crystal Si and Si_3N_4 thin films have been investigated. Radiation induced charging of different dielectric films was studied using metal insulator semiconductor (MIS) structures. For these tests a thermally grown SiO_2 film, an Al_2O_3 film obtained by atomic layer deposition (ALD) and a Si_3N_4 film deposited by low pressure chemical

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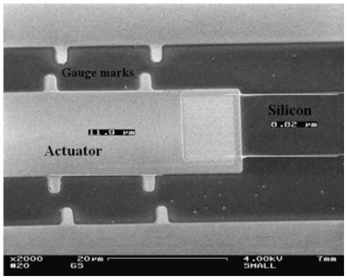
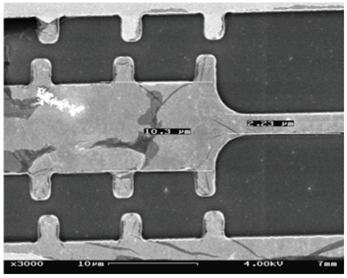
vapor deposition (LPCVD), were used. Results from tests on commonly encountered in MEMS, MIM capacitors fabricated from sol gel deposited ferroelectric PZT and PST films are also presented.

2. Experimental Methodology

Mechanical testing was performed using the on-chip testing structures which have been developed in UCL [5] (figures 1 (a), (b)) and take advantage of the built in thermal strain in the LPCVD deposited Si_3N_4 film (actuator part) in order to exert a load on the tested film, upon release of the entire structure by etching the appropriate sacrificial layer.



(a)



(b)

Fig. 1. (a) SEM micrograph of a test structure for Si testing; (b) SEM micrograph of a Si_3N_4 self-actuated structure.

In figure 1 (a) a SEM micrograph of a micromachine with a 275 nm thick Si_3N_4 beam serving as the actuator and a 100 nm thick Si sample is shown. The thermal stress which is built into the Si_3N_4 film was measured equal to 1 GPa by the wafer curvature technique. The elastic properties of the actuator film can be evaluated by combining this result with the actuator mismatch strain which is obtained experimentally from the displacement of special self-actuated structures as the one depicted in figure 1 (b). For this particular study resonant tests of the self-actuated Si_3N_4 beams were also performed using a Polytec MSA 500 laser Doppler vibrometer (LDV). A thin highly reflecting Au film was deposited on top of the Si_3N_4 structures in order to improve the signal return of the laser beam in the LDV.

Trapped charges in the dielectric films were calculated from the capacitance vs voltage characteristics of MIS structures [6]. Quasi-static and high frequency measurements obtained at 1 MHz, were combined to calculate the interface-state charge [6]. The Al top electrodes of the capacitors were deposited and patterned by a lift-off bi layer process and had a surface area between 0.01 and 0.05 mm^2. The capacitors were annealed in forming gas prior to irradiation. The ferroelectric films on the other hand were prepared by a sol gel deposition process on platinized Si substrates. The MIM capacitors were formed by depositing the Cr/Au top electrodes by evaporation through a shadow mask. The diameter of the circular electrodes is 750 μm. HF etched vias on each sample allowed for electric measurements. Electric characterization of both types of capacitors was performed using an AGILENT B1500A semiconductor device analyser connected to a Suss PM8PS probe station. During irradiation the capacitors were kept at zero bias voltage.

Table 1. Characteristics of the dielectric films used for testing.

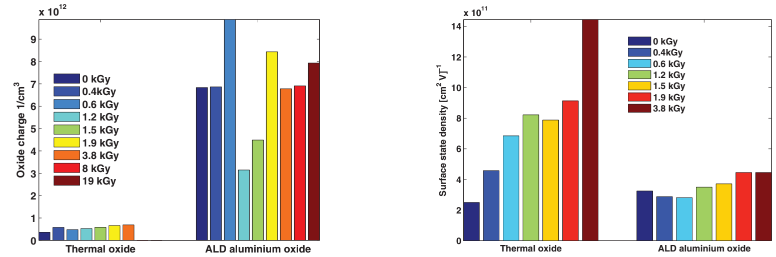
Dielectric	SiO_2	Al_2O_3	Si_3N_4	PZT 30/70	PST 40/60
Thickness	400 nm	20 nm	300 nm	620 nm	420 nm
Deposition	thermal	ALD	LPCVD	Sol gel	Sol gel

Neutron irradiations were performed at room temperature in CYCLONE at Louvain la Neuve, using the high flux fast neutron beam facility [7]. The energy spectrum comprises mainly of fast neutrons accompanied by 2.4% gamma radiation. After irradiation the samples were kept refrigerated. The exact dose received by each sample was calculated from alanine probes that were attached on each specimen.

3. Results and Discussion

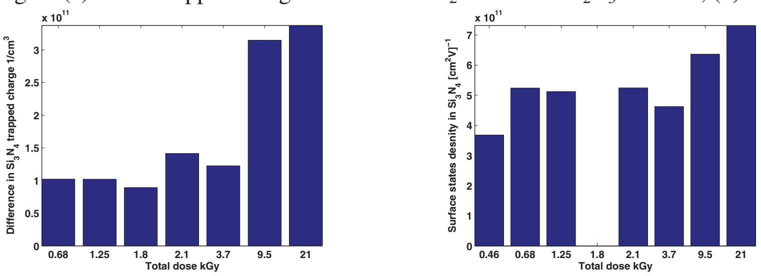
Table 1. 90 % confidence intervals of the actuator mismatch strain and the Young's modulus of Si before and after neutron irradiation. Resonant frequencies of self- actuated structures before and after neutron irradiation.

	f_1 Hz	f_2 Hz	f_1 Hz	f_2 Hz	f_2 Hz	ϵ_{mis} x 10^{-3}	E_{Si} (GPa)
Irradiated	55000	117310	55000	117310	117310	3.01±0.18	163±29
Non irradiated	55063	117340	55063	117280	117280	3.25±0.15	173±25



(a) (b)

Fig. 2. (a) Oxide trapped charge in thermal SiO_2 and ALD Al_2O_3 vs dose; (b) Surface state charge vs dose.

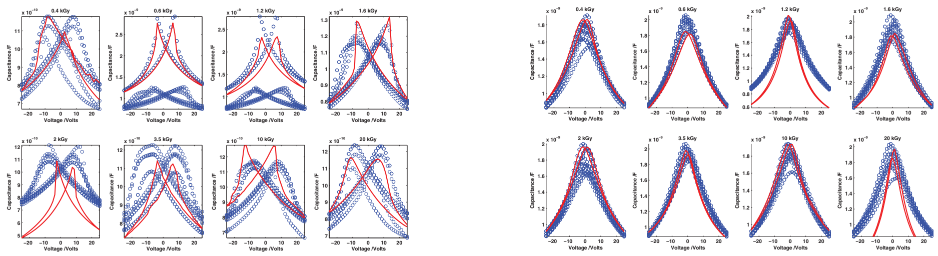


(a) (b)

Fig. 3. (a) Oxide trapped charge in irradiated LPCVD Si_3N_4 film vs dose; (b) Surface- state charge vs dose

In table 1 the calculated 90% confidence intervals of the actuator mismatch strain and the Young's modulus of Si before and after a total dose of 15.9 kGy (alanine) are summarized. Some of the samples broke during testing so these measurements were not performed on exactly the same structures. For these calculations the elastic properties of the actuator were assumed unchanged. Results from resonant tests of three Si_3N_4 structures have not revealed significant changes in the frequencies after exposure to 8.6 kGy (Si) dose (table 1), with differences in the measured frequency being in some cases less than the resolution of the measurement setup (31.25 Hz).

In figures 2 (a), (b) the mean trapped charge and the mean interface-state charge in the SiO_2 and in the Al_2O_3 MIS capacitors as a function of the dose are plotted. In figures 3 (a), (b) the mean difference between the calculated trapped charge and the interface-state charge in the MIS Si_3N_4 capacitors before and after irradiation as a function of the dose is presented. The increase in both types of charge with the dose is clear in the case of the thicker dielectrics [8]. It should be noted that this increase with dose is primarily attributed to secondary process of recoils [6]. Finally in figures 4 (a), (b) the C-V hysteresis loops obtained from the PZT and the PST MIM capacitors before and after neutron irradiations are plotted. No obvious distortion of the C-V characteristics is observed after irradiation.



(a) (b)

Fig. 4. (a) C-V characteristics (100 MHz) of PZT 30/70 MIM capacitors before (blue dots) and after (red lines) irradiation; (b) C-V characteristics of PST 40/60 MIM capacitors before (blue dots) and after (red lines) irradiation.

4. Conclusions

The effect of fast neutrons on the mechanical and electrical properties of various materials that are typically used in microfabrication has been investigated. The elastic response of the tested samples and the C-V characteristics of the PZT/ PST films do not seem to degrade after testing. Charge trapping is observed especially in the thicker dielectrics.

Acknowledgements

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