Dielectric Charging in Capacitive RF MEMS Switches: The Effect of Dielectric Film Leakage

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Radio frequency (RF) micro-electromechanical systems (MEMS) switches are one of the most promising applications of the RF MEMS technology. However, reliability issues still limit their application in wireless and communication systems. In capacitive MEMS switches, the most important reliability problem is charging of the dielectric [1]-[2]. In the case of silicon nitride MEMS switches, significant effort has been made to identify the dependence of dielectric charging on film thickness and deposition temperature [3]-[6]. The objective of these efforts has been to determine the most favorable deposition conditions to induce minimum dielectric charging in silicon nitride capacitive switches. Extending on our previous studies, in this work we focus on PECVD silicon nitride films deposited at the same temperature but with different nitrogen to silicon concentration ratios, and try to determine the dependence of dielectric charging on the silicon content hence the dielectric material conductivity. The goal is to address the uncertainty of whether the implementation of a leaky dielectric would reduce the charging effects in capacitive MEMS switches. Both RF MEMS switches and metal-insulator-metal (MIM) capacitors with silicon nitride films deposited at 150ºC and 250ºC are considered for this study.

Fig. 1 shows the stoicbiometry of the silicon nitride films used. The films are deposited at 150ºC and 250ºC with different gas flow ratios. The straight lines are drawn to show the stoichiometry trend. The TSDC spectra for the 150ºC Silicon nitride MIMs, inset of Fig. 2, were found to depend strongly on the film composition. In the case of sample A ([NH_3]/[SiH_4]= 1.33%), the current level at high temperatures (>380K) is almost two orders of magnitude larger than those of samples B ([NH_3]/[SiH_4]=2%) and C ([NH_3]/[SiH_4]=4%), indicating a significantly larger stored charge. Moreover, the envelope of the TSDC current in the high temperature region reveals activation energy of 0.45eV for sample A material decreasing to 0.20eV for sample C.

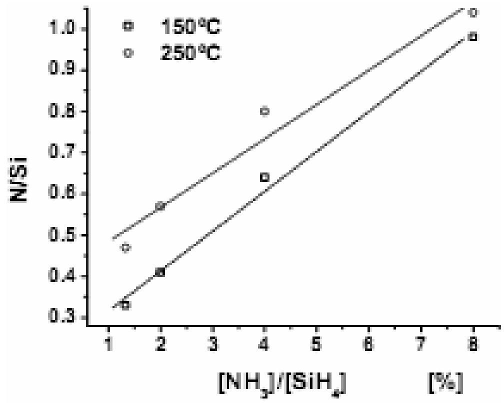

Fig. 1. Stoichiometry vs. gas flow ratio for 150ºC and 250ºC PECVD silicon nitride.

This behavior suggests that for sample A, a larger amount of charge is trapped in deep traps compared to sample C. This becomes obvious in the plot of the temperature dependence of charge measured in the external circuit Qext, which is calculated by integrating the TSDC spectra over temperature. Furthermore, Fig. 2 reveals that in the low temperature range (<350K), the values of TSDC charge do not differ significantly and are characterized by almost the same activation energy. A significant difference arises above 350K, where much deeper defects are activated in sample A leading to much larger charge trapping.

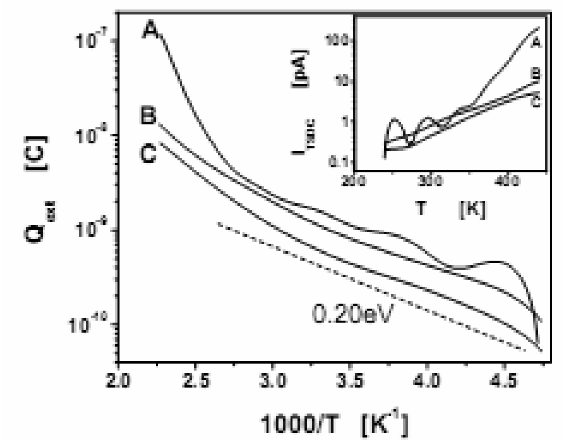

Fig. 2. Temperature dependence of stored charge measured in the external circuit. The inset shows the TSDC spectra. The films were deposited at 150ºC. Samples A, B, and C correspond to [NH3]/[SiH4] of 1.33%, 2%, and 4% respectively.

The total charge stored in the 150ºC silicon nitride MIMs were compared to the 250ºC ones for the three gas flow ratios mentioned above (Fig. 3). The total charge is calculated for all materials by integrating the TSDC spectra from 200K to 500K.

The total charge stored in the 250ºC silicon nitride is higher than the 150ºC one for all flow ratios.

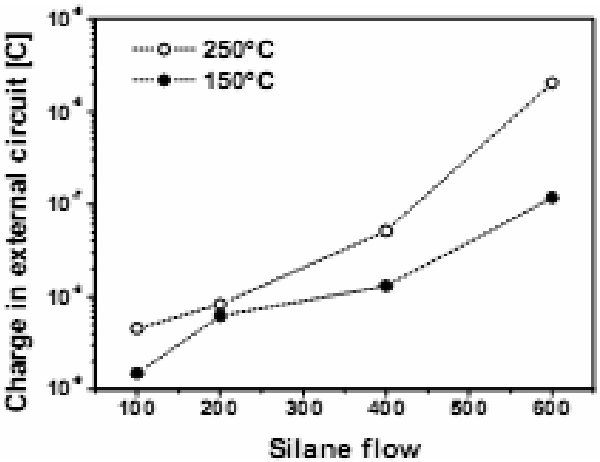

Fig. 3. Dependence of the total stored charge measured in the external circuit on silane flow for the 150ºC and 250ºC silicon nitride material.

The charging in MEMS switches can be monitored through the shift of bias for minimum capacitance (Vm). The bias for minimum capacitance (Vm) of sample A was found to shift rapidly with temperature from +12.6 volts at 300K to -5 volts at 380K (Fig. 4). On the other hand, Vm for sample C shifted only from -1.2 volts at 300K to -0.9 volts at 380K. The calculated activation energies were found to be 0.31eV, 0.22eV and 0.11eV for samples A, B, and C respectively, being in reasonable agreement with the ones obtained from TSDC assessment.

In summary, a systematic investigation was performed to relate the electrical properties of the silicon nitride insulating film of MEMS capacitive switches with the monitored dielectric charging. The investigation was focused on silicon-rich PECVD silicon nitride, which deviates significantly from the ideal material stoichiometry. Both assessment methods, the TSDC assessment in MIM capacitors and monitoring the shift of bias for capacitance minimum in MEMS switches revealed that charging increases when the silicon content increases in spite of the increasing leakage current. This is attributed to the formation of silicon nanoclusters, where potential barriers retain the trapped charges in the potential wells, as well as the generation of trapping sites by unsaturated bonds, etc. Taking all these into account, we are led to the conclusion that silicon nitride films that are closer to stoichiometry seem to be more promising materials for reliable switches. Since in such highly resistive materials the injected charges require a large time to be collected by the bottom electrode, investigation is in progress for the determination of optimum solution.

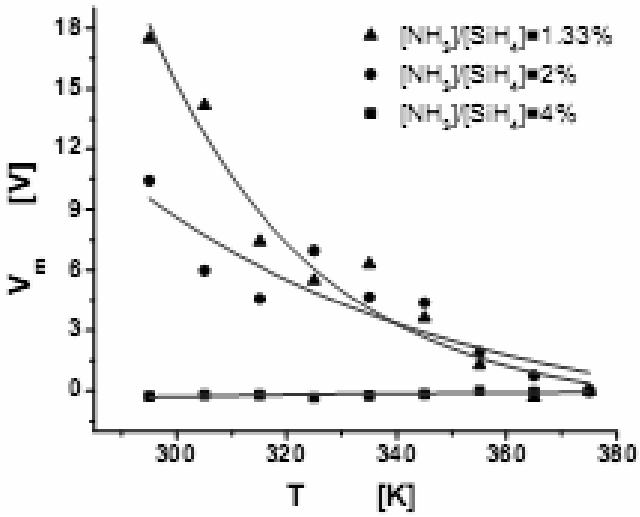

Fig. 4. Temperature dependence of Vm for 150ºC silicon nitride MEMS switches. $[NH_3]/[SiH_4]$ flow ratios of 1.33%, 2%, and 4% are used.

References

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