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# Stress induced degradation and reliability of $Al_2O_3$ thin film on silicon

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ABSTRACT

The electrical properties of metal insulator semiconductor (MIS) devices with $Al_2O_3$ as dielectric layer deposited by reactive RF (radio frequency) magnetron sputtering were investigated using Capacitance-Voltage (C-V) and Current–Voltage (I-V) to determine the quality of oxide layer and oxide/silicon interface. To assess the reliability of $Al_2O_3$/Si interface constant current stress of 1 mA for varying time period was also investigated. The effect of post deposition annealing (PDA) on electrical behavior of Al/$Al_2O_3$/Si MOS (metal oxide semiconductor) capacitors was studied. Annealed devices show substantial improvement in interface trap charge density ($D_{it}$), fixed oxide charge density ($Q_f$) and leakage current. Improved electrical and interface properties are achieved at annealing temperature of 425 °C. Incorporation of nitrogen gas improves the thermal stability of $Al_2O_3$ films which exhibited fewer shift in flat band voltage ($V_{fb}$) as compared to the samples grown in pure argon atmosphere. Breakdown voltage for nitrogen doped $Al_2O_3$ of 30 nm thin films was enhanced from 15 V to 19 V. Results indicate that reactive sputtering in $N_2$ containing plasma is a promising approach as reduction in gate leakage current and power dissipation is utmost essential for integrating high-k material into semiconductor processing.

## 1. Introduction

As the dimension of complementary metal oxide semiconductor (CMOS) devices continues to scale down, use of traditional $SiO_2$ as a gate dielectric material is facing the structural and electrical limits [1–3]. Thinning of the gate dielectrics results in higher leakage current and power dissipation. This adversely affects the reliability of the devices. Introduction of high-k dielectrics has ignited the research towards selecting the most suitable material which permits higher physical thickness, increased gate capacitance with less leakage current and power dissipation [3,4]. Several metal oxides of group III like $Y_2O_3$, $La_2O_3$, $PrO_3$ and $Al_2O_3$ and their silicates and aluminates has been widely studied as potential substitute of $SiO_2$. Aluminum oxide is stable and robust material and has been extensively preferred for various optical and microelectronics applications. Alumina has many favorable properties like large band gap (~9eV), considerable band offset, high permittivity (8.6–10.0) and thermodynamic stability so that it remains amorphous up to large temperatures [5–8].

Among several methods used for deposition of N-doped $Al_2O_3$ [9,10], reactive sputtering is considered as one of the most efficient method on account of its possibility for controlling a wide range of properties in thin film technology [11]. However, previous studies show that excessive concentration of nitrogen by conventional sputtering sources lead to amorphous film even after thermal annealing [9,12]. Low crystallization temperature problem is associated with various high-k dielectric oxides. These crystalline structures increase the gate leakage current and causes dielectric breakdown. The crystallization temperature has been improved by incorporation of elements such as N, Si and La etc. Nitrogen incorporation in dielectric materials leads to improved electrical properties as well as crystallinity at the cost of decreased band gap and reduced mobility [13]. Post deposition annealing abruptly increases $Al_2O_3/SiO_2$ interfacial dipoles and simultaneously reduces the amount of positive charge near the interface [14]. Whereas, incorporation of nitrogen during deposition process restricts oxygen vacancies, trap sites in the channel and channel/dielectric interface thereby improving thermal stability [15]. Further, nitrogen doping in the oxidized surface enhances specific capacitance [16] and charge storage capacity in several dielectric materials [17]. The objective of this work is to study the stress induced degradation and reliability of RF sputtered $Al_2O_3$ thin films deposited in pure argon and argon plus nitrogen atmosphere. MOS capacitor was used as a test structure to determine the electrical properties of the dielectric material. Electrical and reliability characteristics like

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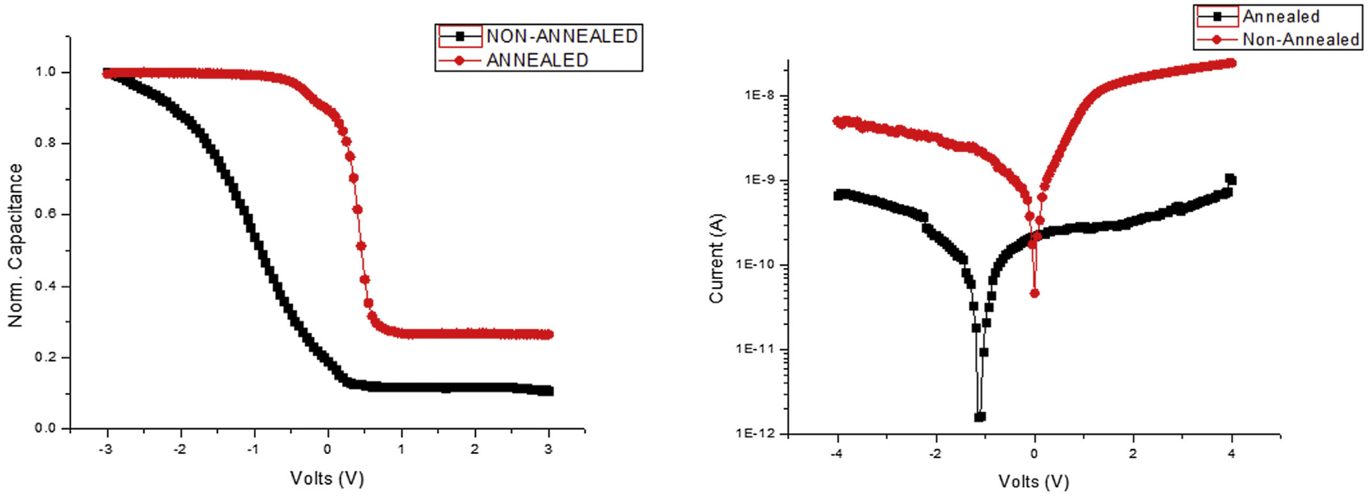

(a) (b)

**Fig. 1.** (a) C-V and (b) I-V characteristics of non-annealed and 425 °C annealed device grown in pure argon atmosphere.

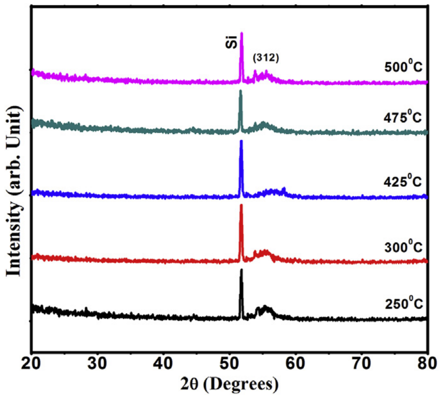

**Fig. 2.** XRD spectra of annealed $Al_2O_3$ thin film at various temperatures.

**Table 1**
Comparison of samples before and after annealing.

| Parameters | Non-Annealed | Annealed |
|---|---|---|
| Flat band voltage (V) | −1.95 | 0.45 |
| Fixed oxide charge (C) | $-2.7 \times 10^{11}$ | $3.18 \times 10^{11}$ |
| Leakage current (A) | $-2.42 \times 10^{-9}$ | $1.06 \times 10^{-10}$ |

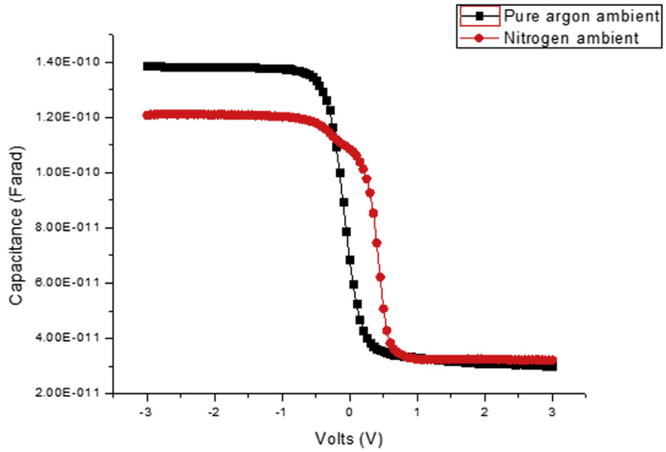

**Fig. 3.** C-V plot of $Al_2O_3$ with $N_2$ and without $N_2$.

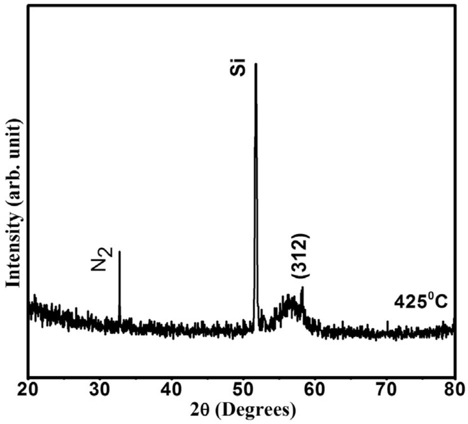

**Fig. 4.** XRD spectra of $Al_2O_3$ MOS capacitor grown in $N_2$ ambient annealed at 425 °C.

flat band shift, fixed oxide charge density, breakdown voltage and leakage current were compared for MOS capacitors grown in $N_2$ plasma and pure argon atmosphere under constant stress.

## 2. Experimental details

$Al_2O_3$:N/Si MOS capacitors were fabricated using a p-type <100> silicon wafer having 2″ diameter, resistivity 1–10 Ω-cm and thickness of 275 μm. Inorganic and organic contaminants were removed using standard RCA (Radio Corporation of America) cleaning procedure. Reactive RF magnetron sputtering was used for deposition of $Al_2O_3$ film in pure argon (flow rate of 20 sccm) and argon plus nitrogen containing plasma (flow rate of argon kept constant at 20 sccm and nitrogen flow rate of 30 sccm) at RF power of 100 W for 10min. The film thickness of 30–35 nm was measured using profilometer. Post deposition annealing of structures was carried over the temperature range 250 °C to 500 °C for 15min in $N_2$ ambient and analyzed through X-ray diffractometer operating in 2θ mode with Cu Kα radiation. Gate electrodes were made by thermal