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Effect of SiO_2 Underneath Layer on $LaAlO_3$ High Dielectric Constant Material for Gate Oxide Application

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Introduction

With the increasing demand of microelectronic device technology, the device dimension is shrinking rapidly and it becomes necessary to replace SiO_2 by oxides with higher dielectric constant. $LaAlO_3$ (LAO) has some unique properties such as large conduction band offset value, less reactivity with Silicon and better thermal stability. These properties give it an edge over other candidate materials. However, excellent electrical properties of Si/SiO_2 interface cannot be achieved with Si/high-k heterostructures. So many works has been done to grow SiO_2 layer on Silicon prior to high-k oxide deposition [1,2,3]. It not only showed better interface properties but also higher capacitance value. In this work SiO_2 was grown in-situ inside the e-beam chamber followed by LAO deposition.

Experimental

Oxide layer stack has been grown on p-type Si (100) type substrate of high resistivity (8-10 ohm-cm). HF last sample has been immediately loaded on the e-beam chamber. SiO_2 has been grown by flowing oxygen in the chamber at high temperature (650^{o}C) at different oxygen pressure and for varying time. After SiO_2 growth LAO of 40 A thickness has been deposited at $8X10^{-6}$ Torr oxygen partial pressure at room temperature. For comparison, LAO was also deposited on bare Silicon substrate. The rate of LAO growth was 2-3 Angstrom per minute. After oxide deposition capacitor was made using platinum as metal electrode by sputtering. The pattern has been made by conventional photolithographic technique. After the metal deposition at both sides of the sample, forming gas annealing was done at 400^{o}C for 20 minutes. C-V and I-V measurement was done in the HP 4284 LCR meter and HP 4155A parameter analyser respectively. The EOT value has been calculated considering the Maxwell-Boltzman correction and by comparing it with ideal C-V curve using MathCad program. The X-ray photoelectron spectroscopy (XPS) was done on two samples with (LAO1) and without SiO_2 (LAO2) interfacial layer for analyzing the oxide film and the interface.

Results and Discussion

C-V and I-V curve is shown in figure 1(a) and (b) at different SiO_2 growth conditions with varying oxygen pressure and time respectively. In comparison with LAO2 sample the EOT tends to decrease in all cases. From both figures it can be said with increasing SiO_2 thickness EOT tends to decrease up to a certain limit. This may be due to more stable interface formation which can prevent further reaction between the Si and oxide. Severe Si segregation in the high-k oxide materials is also reported recently [4]. For LAO2 sample, creation of interface roughness on silicon surface has been studied [2]. Improvement on leakage current (as shown at the inset of Fig.1) of two orders also supports the fact that better quality interface has been formed. In figure 2, the leakage current density versus EOT for all the samples is summarized. From this plot the best condition for the SiO_2 growth is tried to determine and found to be around $8X10^{-6}$ Torr PO_2 for 10 min time at 650^{o}C. The measured EOT is 10.9 A with a leakage current of 0.085 A/cm^2. The interface trap density (D_{it}) for all the samples was measured using the conventional conductance method and all samples showed very similar value in the order of $2x10^{12}$ cm^{-2}eV^{-1}.

XPS analysis of Si 2p, La 3d, Al 2p and O 1s has been done and presented here for further understanding the phenomena that is occurring into the interface and bulk oxide. Figure 3 shows the Si 2p peak for both LAO1 and LAO2 sample at near interface region. The peak positions for Si-Si and Si-O are found at 99.4 eV and 103.46 eV respectively. There is another peak found at higher binding energy (106.9 eV) which is believe to be La $4d_{3/2}$ peak that overlaps with Si 2p peak [5]. Comparing the Si-O peaks for both samples, the intensity of the peak for sample LAO2 in the bulk region is much higher but it decreased considerably with every sputtering sequence (not shown) and disappears after 6th sputter near the interface. On the other hand, for LAO1 sample, Si-O peak is still well visible near the interface region. This reveals the presence of SiO_2 at the interface and also the interface is more stable. We intentionally grew the SiO_2 underneath layer and it's still present at the interface as SiO_2. For LAO2 sample the interface is intermixed with the Silicon substrate. This presence of SiO_2 layer at the interface is also the reason behind the low leakage current and also low interface charge density previously mentioned.

Further analysis about the nature of film for sample LAO1 is presented from here. Figure 4 shows the La 3d peak for both La $3d_{3/2}$ and La $3d_{5/2}$ and the respective binding energies are 853 and 835.8 eV respectively. With increasing sputtering sequence, the energy is observed to shift towards higher binding energy from bulk to interface, which means higher oxidation state at the interface. Al 2p peak, as shown in figure 5 also showed similar behavior but no Al metal peak was observed, which is understandable as aluminum is more easily oxidized. The binding energy values for the La-O, Al-O and Si-O are 531.0, 531.1 and 532.5 respectively. Figure 6 shows the O 1s peak positions. The peaks after different sputter are positioned in between Si-O and M-O bond energy. So from this data it can be conclude that the film is neither SiO_2 nor metal oxide but a mixed composition of silicon metal and oxygen.

Conclusion

LAO has been grown on SiO_2 underneath layer which showed reasonable EOT and leakage current for future gate dielectric material application.

References

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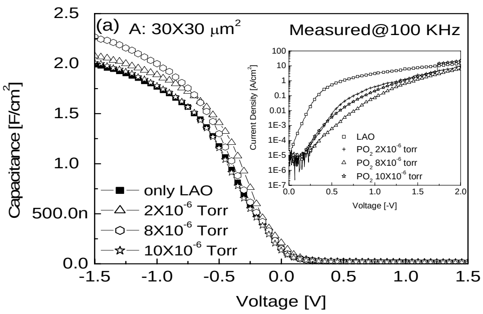

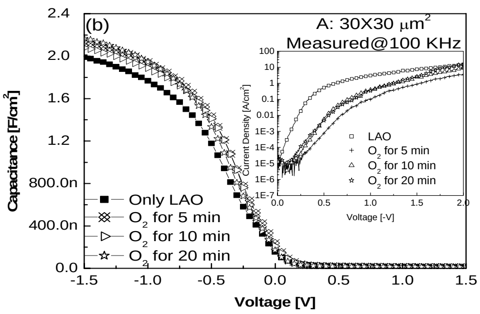

Figure 1: C-V curves for (a) LAO on SiO_2 grown at different PO_2 from $2x10^{-6}$ to $1x10^{-5}$ Torr at constant O_2 flowing time of 10 min. (b) SiO_2 grown at different oxygen flowing time from 5-20 minutes. PO_2 is constant to $2x10^{-6}$ Torr. Inset showing the I-V curves.

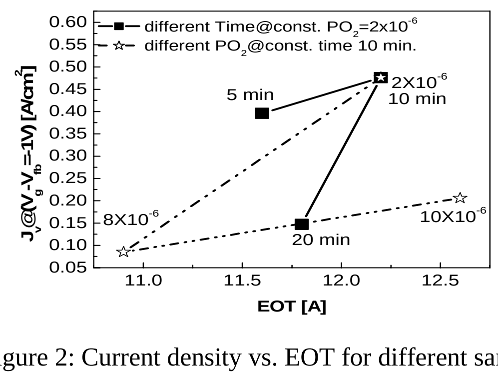

Figure 2: Current density vs. EOT for different samples.

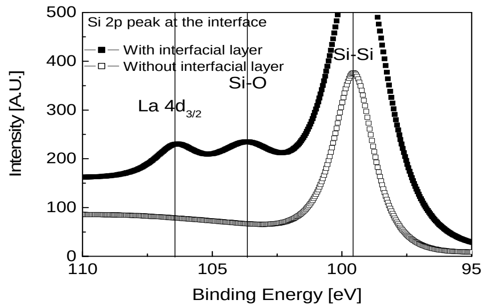

Figure 3: Si 2p XPS peak energy for LAO sample with and without SiO_2 at the near interface region.

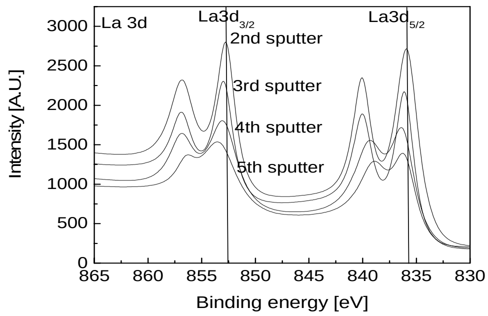

Figure 4: La 3d peak for LAO with SiO_2 layer. Peak tends to shift towards higher energy from the bulk to interface.

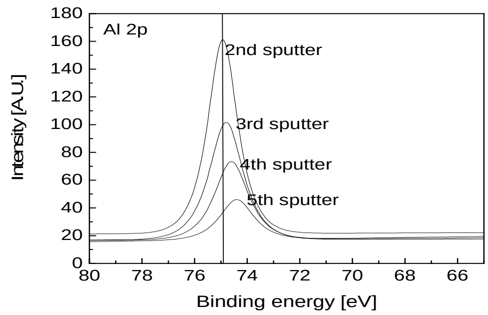

Figure 5: Al 2p peak with no Al metal peak which normally around 72.9 eV.

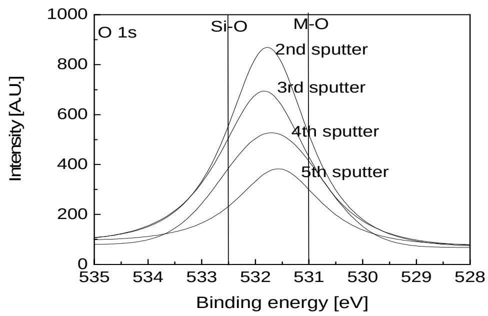

Figure 6: O 1s peak showing a mixed structure of metal-oxide-Si throughout the whole oxide dielectric film.