High dielectric constant gate insulator technology using rare earth oxides

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Abstract

Among the high-k gate dielectrics, ZrO_2 and HfO_2 are regarded as the most promising candidates. However, these materials still have some problems such as interfacial layer and micro-crystal formations during the post deposition annealing process. These problems lead to the increase of EOT and gate leakage current. In this paper, present status of rare earth oxides as possible candidates for post HfO_2 gate dielectrics is reviewed.

Introduction

With recent acceleration of the advanced CMOS down-scaling, demands for replacing conventional oxinitride gate insulator with high k-gate dielectrics has increased significantly. Although, high-performance operation of 30 – 15 nm gate length CMOS's with ultra-thin oxinitride gate insulator of 0.8 – 0.7 nm EOT has been reported, extremely huge direct-tunnelling current is a big problem. High-k gate insulator is the key technology to suppress the gate leakage current.

Among the high-k gate dielectrics, ZrO_2 and HfO_2 are regarded as the most promising candidates. However, these materials still have some problems such as interfacial layer and micro-crystal formations during the post deposition annealing process. These problems lead to the increase of EOT and gate leakage current, respectively. Recently, excellent results of rare earth oxides thin films such as La_2O_3, Pr_2O_3, Gd_2O_3 have been reported. Those rare earth oxides are regarded as possible candidates for next generation high-k dielectrics after HfO_2.

In this paper, current status of the rare earth oxides for advanced CMOS gate insulator use is reviewed.

Experiments

Amorphous rare earth oxide films were deposited on HF-last and chemically oxidized n-type Si (100) substrates by MBE equipments. Oxide targets are heated by e-beam radiation and evaporated for deposition. H_2O_2 were used to form chemical oxide on Si. The deposition temperatures were room temperature (R.T.) to 400°C. The pressures in the chamber during depositions were 10^{-9}~10^{-7} Torr. E-beam deposition method has some advantages to CVD and sputtering in terms of film purity and damage to the deposited films, respectively. The deposited films were annealed by RTA in N_2 or O_2 ambient with various temperatures for 5 – 90 min. Finally, Al electrode was deposited through a metal mask.

Results

It was found that properties of rare earth oxide ultra-thin films deposited on Si were quite different each other. Some of the oxides are easily crystallized and others are not. Some of them required chemical oxide pre-treatment of Si wafer before the deposition for obtaining good interfacial properties, but others do not. Some of them are relatively resistant to the moisture absorption, but others are not.

Among the rare earth oxides, La_2O_3 was found to show excellent characteristics for most of the items required. Its smooth interface without any crystallization and interfacial layer was confirmed. On the other hand, it was found that Lu_2O_3 was found to be easily crystallized. In Figure 1, EOT vs. leakage current data obtained by our experiments and from published results [1] are plotted fir various high-k materials. It should be noted that La_2O_3 shows the best EOT vs. J characteristics among the high-k materials.

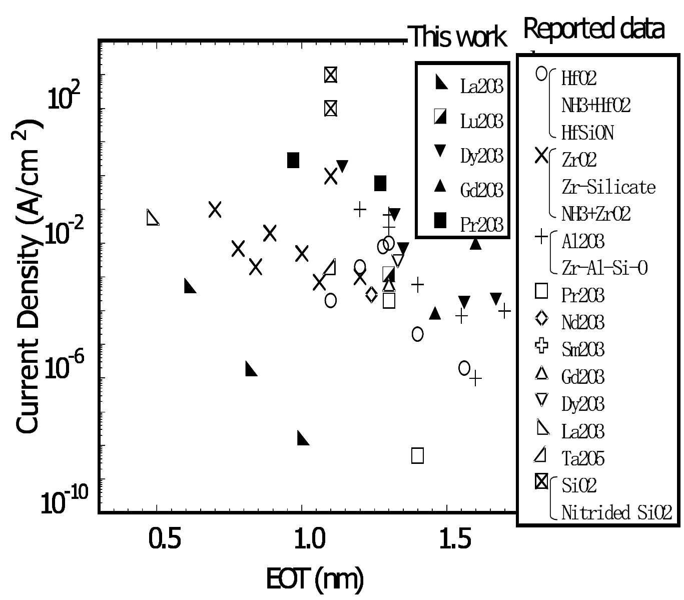

Figure 1. EOT vs. J (leakage current density @|Vg |= 1V)

Conclusions

Current status of rare earth gate oxides for CMOS gate insulator was reviewed. It was found that properties of rare earth oxide ultra-thin films deposited on Si were quite different each other. Among the rare earth oxides, La_2O_3 shows excellent properties even better than those of ZrO_2 and HfO_2.

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Reference

[1] Taken from published papers from Sym. on VLSI Tech. 2000. 2001, IEDM 2000, 2001, IWGI 2001