RARE EARTH METAL OXIDES FOR HIGH-K GATE INSULATOR

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Introduction

High-dielectric constant (High-k) materials for alternative gate insulator, such as ZrO_2, HfO_2, Al_2O_3 etc. [1-3], have much attention to overcome the leakage current issue of ultra-thin SiO_2 that has been used for more than 30 years in MOSFETs. Recently, rare earth metal oxides such as amorphous La_2O_3 [4], epitaxial Pr_2O_3 [5] films, Nd_2O_3, Sm_2O_3 and Dy_2O_3 [6] deposited on Si(100) were reported for next generation high-k gate insulator, and they showed excellent electrical properties such as high dielectric constant and small equivalent oxide thickness (EOT) with low leakage current density. However, the properties of the rare earth oxides, such as lattice energies or band gap, are quite different. Therefore, the electrical characteristics would be expected to be different even though the same lanthanide oxide system.

In this paper, various rare earth metal oxides (La_2O_3, Pr_2O_3, Eu_2O_3, Yb_2O_3 etc.) thin films deposited on Si(100) substrates were investigated to make clear the properties of rare earth metal oxides system.

Experiments

Rare earth metal oxides thin films were deposited on chemically cleaned and HF dipped Si(100) substrates by molecular beam deposition (MBD) system equipped with electron beam evaporators. The deposition temperatures were room temperature (R.T.) – 400˚C. The pressure in the MBD chamber during deposition was around 10^{-9} – 10^{-7} Torr. The deposited films were subsequently annealed by rapid thermal annealing system (RTA) at the temperatures of 200 – 600˚C in N_2 or O_2 ambient for 5 min. Aluminum contacts (ϕ100 µm) were deposited by evaporation through a shadow mask. Electrical and physical measurements were performed to characterize these films.

Results

Excellent electrical properties were obtained for amorphous La_2O_3 films, which has the lowest lattice energy value among the rare earth metal oxides, deposited on n-Si(100) at 250°C or 400°C, such as EOTs of 0.8 – 1.2 nm (Fig. 1). The lowest leakage current densities reported so far were obtained for these films, such as 5.5×10^{-4} A/cm^2 for EOT of 0.88 nm and 1.7×10^{-8} A/cm^2 for 1.26 nm at 1 V. The crystallized temperature of La_2O_3 was higher than 900°C. On the other hand, Yb_2O_3, which has the second highest lattice energy among the rare earth metal oxides, showed good electrical characteristics, but it seemed to crystallize even at the temperature of 250°C, which leads to increase the leakage current. Several rare earth metal oxides, which have intermediate lattice energy values (Pr_2O_3, Eu_2O_3), showed good interface properties, and the crystallized temperatures were relatively high, such as 700°C. This result suggested that the crystallized temperature seemed to depend on their lattice energy value.

Conclusions

Various rare earth metal oxides were investigated for high-k gate insulator applications. Most of the rare earth metal oxides showed excellent electrical properties especially for La_2O_3. The crystallized temperature was found to be related to their lattice energy value. From this point of view, La_2O_3, which has the lowest lattice energy value among the rare earth metal oxides, is considered to be the most promising materials for high-k gate insulator applications.

Acknowledgements

This work was partially supported by Semiconductor Technology Academic Research Center (STARC) and Grant-in-Aid for Scientific Research Priority Areas (A): Highly Functionalized Global Interface Integration. The authors would like to thank Drs. N. Nakayama, T. Arikado, J. Yugami, T. Kitano, K. Fujita, Y. Tsunashima, K. Hara, T. Chikyow, K. Nakajima, for their technical support and useful discussions in evaluation of the films.

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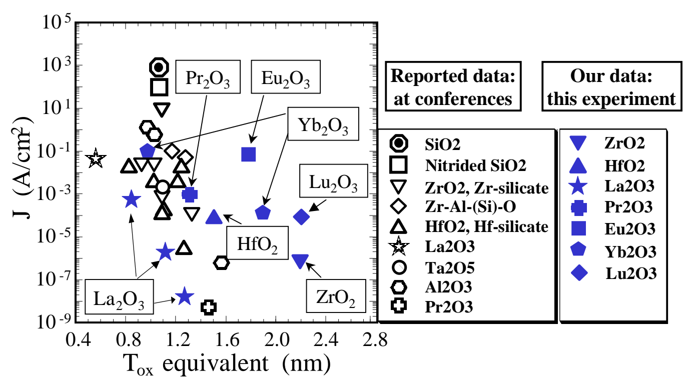

Fig. 1. J vs. T_{ox} equivalent.