Extended Abstracts of the 2008 International Conference on Solid State Devices and Materials, Tsukuba, 2008, pp. 14-15

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Amorphous High-k $LaLuO_3$ Dielectric Film for Ge MIS Gate Stack

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1. Introduction

A Ge MOSFET with a high-k gate dielectric film is an attractive candidate for high performance devices [1]. It has been recently reported that rare earth oxides (RE-oxides) with high permittivity are better for Ge than HfO_2 for Si [2-4]. It has been also found that 10at% Ge introduction makes Y_2O_3 amorphous, while it is not the case of HfO_2 [5]. Thus, a reasonable gate dielectric film for Ge will be amorphous RE-oxides with high-k. RE-oxides are, however, easily crystallized at relatively low temperatures. In this paper, we propose $LaLuO_3$ as an amorphous RE-oxide with high-k on Ge, and show its dielectric properties of Ge MIS characteristics.

2. Experimental

To raise the crystallization temperature of dielectric films, it is a conventional knowledge that covalent bonding dominated materials such as SiO_2 or Al_2O_3 are mixed with host materials. There is, however, another way to achieve an amorphous structure. We reported that the crystallization temperature of HfO_2 was increased by mixing La_2O_3 up to 950°C due to a large ionic radius difference between Hf and La [6]. This is a guiding principle for making amorphous RE-oxide. In the lanthanoid elements, the ionic radius decreases with atomic number increase due to the lanthanide contraction [7], and La has the largest ionic radius, while Lu has the smallest one. So, the (La_2O_3+Lu_2O_3) compound should have a high crystallization temperature than any binary RE-oxides. In fact, $LaLuO_3$ system has been studied for gate dielectric films on Si [8], but a real advantage of this material on Si has not so far been shown.

We deposited $LaLuO_3$ by rf co-sputtering of La_2O_3 and Lu_2O_3 on HF-last p-Ge(100) wafers, and then annealed (Post deposition Anneal :PDA) in N_2 or (N_2+x%O_2) (x :0.001~1) ambient for 30sec from 450 to 600°C. Since the stoichiometry of the deposited film was determined by XPS after the deposition, La(48%)Lu(52%)O_3 and La(60%)Lu(40%)O_3 are discussed for $LaLuO_3$ in this paper. We checked that there was no difference between those films within our experiments. Au and Al were evaporated for gate electrode and the back ohmic contact of MIS capacitors, respectively. The thickness of high-k film was accurately estimated by the combined technique of grazing incident X-ray reflectivity with spectroscopic ellipsometry measurements [9]. XRD measurement was used for analyzing the crystal structure. FT-IR and TEM analyses were performed for selected samples. C-V characteristics were measured for MOS samples annealed in various conditions.

3. Result and Discussion

The dielectric constant of $LaLuO_3$ is shown in **Fig. 1** and the k-value is 23 for $LaLuO_3$. The experiment was performed on Si with relatively thick $LaLuO_3$ film to extract the intrinsic dielectric properties of $LaLuO_3$. The other important requirement for the gate dielectric film is the energy band-gap. **Fig. 2** shows that $LaLuO_3$ satisfies the requirements for the energy band-gap of dielectric films (5.5~5.8 eV, measured by the spectroscopic ellipsometry).

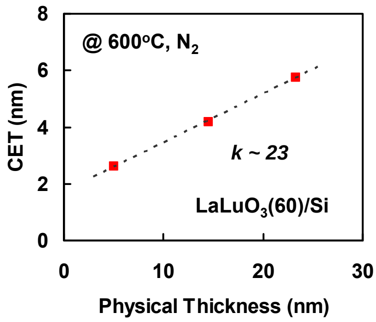

Fig. 1. The relationships between CET and film thickness (determined by GIXR) for 60% La-$LaLuO_3$, annealed at 600°C in N_2 ambient. The dielectric constant is estimated from the slope (~23).

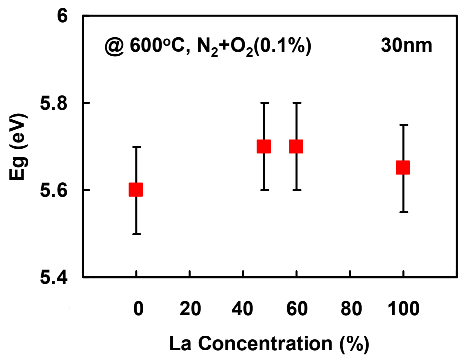

Fig. 2. La concentration dependence of optical band gaps of $LaLuO_3$ determined by spectroscopic ellipsometry measurements.

Amorphous structure of $LaLuO_3$ film is really maintained after annealing at 600°C in N_2+0.1%O_2 ambient as shown in **Fig. 3**, though both La_2O_3 and Lu_2O_3 are easily crystallized into hexagonal and cubic phase, respectively. The crystallization temperature was above 850˚C. A X-TEM image of **Fig. 4** also shows amorphous $LaLuO_3$ film throughout the film. Here it should be noted that there is no interface layer between Ge and $LaLuO_3$ film even after annealing in O_2 ambient. No interface layer such as GeO_x is also shown in FT-IR measurement, as shown in **Fig. 5**. The interface GeO_x absorption peak is only observed for the sample annealed in 100%O_2 at 600°C. This will be a significant benefit in terms of the EOT reduction but it gives us a concern about the interface quality.

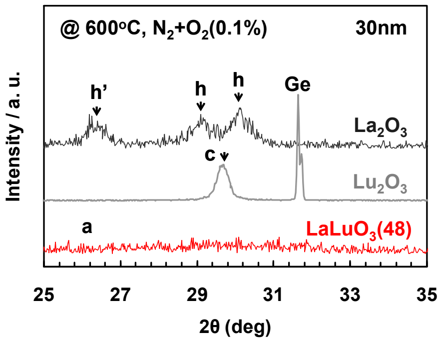

Fig. 3. XRD spectra of 30nm thick 48% La-$LaLuO_3$, La_2O_3, and Lu_2O_3 on Ge annealed at 600°C in N_2+0.1%O_2 ambient (a: amorphous, c: cubic, h: hexagonal, h': hexagonal of $La(OH)_3$).

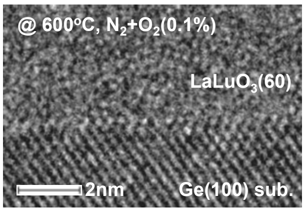

Fig. 4. A X-TEM picture of 60% La-$LaLuO_3$/Ge annealed at 600°C in N_2+0.1%O_2 ambient.

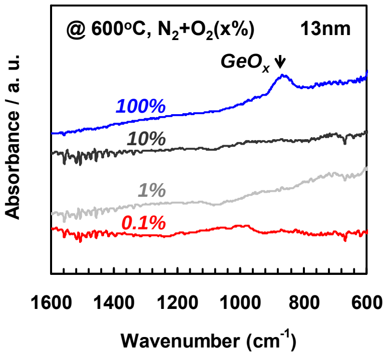

Fig. 5. Fourier transform infrared absorption spectra of 48% La-$LaLuO_3$/Ge annealed at 600°C in N_2+O_2 ambient with various O_2 concentrations from 0.1% to 100%.

Next, we discuss MIS characteristics of Au/$LaLuO_3$/Ge capacitors. **Fig. 6** shows C-V curves at 1MHz of $LaLuO_3$/Ge MIS capacitors annealed at 600°C in N_2 and N_2+0.1%O_2 ambient. The C-V curves are quite good after 600°C annealing and show no difference of saturated capacitance between N_2 and 0.1%O_2 annealed samples thanks to no interface layer Furthermore, a small amount of O_2 significantly improves the interface quality as compared to N_2 annealing. It is really advantageous for the Ge gate stack that the O_2-introduced annealing can dramatically decrease the interface states on Ge without any cost of the saturated capacitance (EOT). It is noted that a hysteresis (V_{hys}) is not improved in Fig.6 even by O_2-introduced annealing. We studied the V_{hys} by changing annealing temperature and oxygen concentration, as shown in **Fig. 7**. The results clearly indicate that the hysteresis is not originated from oxygen vacancies but from strongly temperature dependent phenomena, and we are optimistic for optimizing the annealing condition from results in Fig. 7.

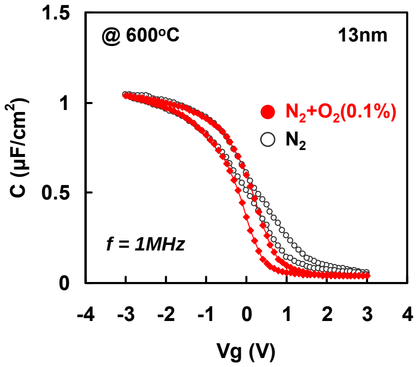

Fig. 6. C-V characteristics of Au/48% La-$LaLuO_3$/Ge MIS capacitors annealed at 600°C. The hysteresis is as the counter clockwise, and its window is about 300mV.

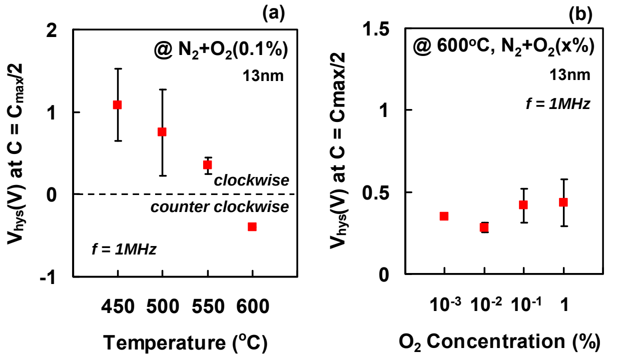

Fig. 7. **(a)** V_{hys} vs. annealing temperature at $C=C_{acc}/2$ of Au/48% La-$LaLuO_3$/Ge MIS capacitors annealed at various temperatures in N_2+0.1%O_2 ambient. **(b)** V_{hys} vs. O_2 concentration at $C=C_{acc}/2$ of Au/48% La-$LaLuO_3$/Ge MIS capacitors annealed at 600˚C with various O_2 concentrations.

4. Conclusions

We have investigated dielectric properties of $LaLuO_3$ for Ge MIS gate stack. $LaLuO_3$ has a high dielectric constant (k~23) and amorphous structure after annealed at 600°C. Its energy band-gap is reasonably large (5.5~5.8 eV). The C-V curves annealed in O_2 ambient are quite good and show a high saturated capacitance thanks to no interface layer. It is suggested that the hysteresis in C-V curves can be reduced by optimizing annealing temperature rather than ambient. $LaLuO_3$ will be a very promising candidate for the high-k dielectric film on Ge.

Acknowledgements

This work was partly supported by a Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology in Japan and partly performed in collaboration with STARC.

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