Electrical characteristics of crystalline HfO$_2$ high-$\kappa$ dielectric films deposited on crystalline $\gamma$-Al$_2$O$_3$ films

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1. Introduction

Numerous studies of high-$\kappa$ gate dielectrics have been carried out in order to improve the performance of future complementary metal-oxide-semiconductor (CMOS) devices [1]. However, there have been problems in applying these to conventional CMOS processes [2]. The most serious things of them are reaction between the high-$\kappa$ gate dielectrics and Si and un-uniform crystallization of the dielectric films during the device fabrication steps. And they cause some of the electrical properties to degrade. To overcome these problems, it has been proposed to insert oxide layer to the interface and to use silicates, aluminates or the accretion of nitrogen to the high-$\kappa$ films to the interface and to use silicates, aluminates or the accretion of nitrogen to the high-$\kappa$ films. We have studied single crystalline $\gamma$-Al$_2$O$_3$ films for use as high-$\kappa$ gate dielectrics and the dielectric properties and the metal-oxide-semiconductor field-effect-transistors (MOSFETs) characteristics have been reported [3][4]. In this paper, we propose the crystalline HfO$_2$/$\gamma$-Al$_2$O$_3$ stacks for use as high-$\kappa$ gate dielectrics to overcome the reaction and un-uniform crystallization problems mentioned above because the crystallinity provides the thermal stability.

2. Experiments

10nm-thick HfO$_2$ thin films were deposited on crystalline 3.5 nm-thick $\gamma$-Al$_2$O$_3$/p-Si(100), 3.5 nm-thick single -crystalline $\gamma$-Al$_2$O$_3$/p-Si(111) and HF-last p-Si(100) substrates. Then the e-beam deposition method was used under ultra high vacuum ambient using ceramics HfO$_2$ (99.9%) targets at a temperature of 500 ºC. Note that the crystalline $\gamma$-Al$_2$O$_3$ films were deposited by reported mixed-source molecular beam epitaxy at a temperature of 750 ºC. Then the chemical compositions, surface morphologies and crystallinities of the stack gates were analyzed using X-ray photoelectron spectroscopy (XPS), atomic force microscopy (AFM) and reflection high-energy electron diffraction (RHEED), respectively. To characterize electrically, the MOS capacitors with 4000 Å-thick Al films evaporated thermally were fabricated and current-voltage (I-V) and capacitance- voltage (C-V) measurements were carried out.

3. Results and discussions

Figure 1 shows RHEED patterns and AFM images of fabricated gate stacks. Only the HfO$_2$ deposited on $\gamma$-Al$_2$O$_3$ films showed spotty patterns, which indicate the films are crystalline. And smooth surfaces comparable with amorphous film deposited on HF last Si substrates were obtained. This indicates the crystalline $\gamma$-Al$_2$O$_3$ might relate to crystallization of HfO$_2$ films and the crystallizations do not affect to the surface morphology. Figure 2 shows the current-voltage (I-V) characteristics of the fabricated capacitors with stacked gate dielectrics. It was observed that leakage current densities of crystallized stacked gates are 10 times less than that of amorphous gate. That means the crystallization of the films do not affect to leakage characteristics. Figure 3 and figure 4 show normalized capacitance-voltage (C-V) characteristics and measurement frequency dependence on the flatband voltage shifts of the capacitors, respectively. It is observed that there is no significant frequency dependence on stacked capacitors compared with that of HfO$_2$/Si. This dependence is related to interface state, so this result indicates the $\gamma$-Al$_2$O$_3$ films between HfO$_2$ and Si provide considerable interface quality and are suitable as buffer layer for gate stacks.

4. Conclusions

We have proposed and fabricated crystalline HfO$_2$/$\gamma$-Al$_2$O$_3$ gate stacks, and the characterizations were carried out. The stability of the $\gamma$-Al$_2$O$_3$ films and the no-degradation of the crystalline gate stacks compared with amorphous one were...
demonstrated. These results indicate the crystalline gate stacks were suitable as future high-κ gate dielectrics.

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References

Fig. 1 Physical properties of the fabricated HfO2/γ-Al2O3 stacked dielectrics. RHEED patterns were observed along the [100] azimuth of the substrate. AFM images were obtained by 1 μm² area scan and the z-range are 10 nm. (a) HfO2 deposited on γ-Al2O3/Si(100) (b) HfO2 deposited on γ-Al2O3/Si(111) (c) HfO2 deposited on HF-last Si(100)

Fig. 2 A set of current-voltage characteristics of the fabricated stacked dielectrics

Fig. 3 A set of normalized capacitance-voltage characteristics of the fabricated stacked dielectrics measured at 1 MHz.

Fig. 4 Measurement frequency dependence on the flatband voltage shift of the fabricated gate stacks.