Electrical characteristics of crystalline HfO₂ high-κ dielectric films deposited on crystalline γ-Al₂O₃ films

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1. Introduction

Numerous studies of high-k 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- κ 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- κ films. We have studied single crystalline γ -Al₂O₃ films for use as high κ gate dielectrics and the dielectric properties and the metal-oxide-semiconductor field-effecttransistors (MOSFETs) characteristics have been reported [3][4]. In this paper, we propose the crystalline HfO₂/γ-Al₂O₃ stacks for use as high-κ gate dielectrics to overcome the reaction and un-uniform crystallization problems mentioned above because the crystallinity provides the thermal stability.

2. Experiments

10nm-thick HfO₂ thin films were deposited on crystalline 3.5 nm-thick γ -Al₂O₃/p-Si(100), 3.5 nm-thick single -crystalline γ -Al₂O₃/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 HfO₂ (99.9%) targets at a temperature of 500 °C. Note that the crystalline γ -Al₂O₃ films were deposited by reported mixed-source molecular beam epitaxy at a temperature of 750 °C. 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 HfO₂ deposited on γ -Al₂O₃ 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 γ -Al₂O₃ might relate to crystallization of HfO2 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 HfO₂/Si. This dependence is related to interface state, so this result indicates the γ -Al₂O₃ films between HfO₂ 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/γ - Al_2O_3 gate stacks, and the characterizations were carried out. The stability of the γ - Al_2O_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

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Fig.1 Physical properties of the fabricated HfO_2/γ -Al₂O₃ stacked dielectrics. RHEED patterns were observed along the [100] azimuth of the substrate. AFM images were obtained by 1 μ m² area scan and the z-range are 10 nm. (a) HfO_2 deposited on γ -Al₂O₃/Si(100) (b) HfO_2 deposited on γ -Al₂O₃/Si(100) (b) HfO_2 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 1MHz.

 $HfO_{2}/\gamma - Al_{2}O_{3}/Si(100) \quad HfO_{2}/\gamma - Al_{2}O_{3}/Si(111) \quad HfO_{2}/Si(100)$

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