Leakage current suppression by layered insertion of Y_2O_3 for ferroelectric HfO_2

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Abstract

The effect of the localized distribution of Y atoms in 7-nm-thick Y-doped HfO_2 films on the ferroelectric characteristics is investigated. Although a slight decrease in the remnant polarization (P_r) is observed, ferroelectric properties can be obtained with the localized distribution. Suppressed leakage current with better switching cycle endurance can be obtained with the localized distribution. Reduced generation of oxygen vacancy (V_O) might be the characteristic of the layered design.

1. Introduction

Ferroelectric HfO_2 films have been studied extensively for memory applications [1]. Among numbers of dopants to obtain ferroelectric HfO_2 films, the Y-atom-doping has been widely used as the antiferroelectric tetragonal phase can be suppressed [2]. The doping is performed by alternative injection of Hf and Y atom precursors in atomic-layer deposition followed by oxidation. Generally, the vapor pressure of the precursors of Y atoms is quite low; bubbling is commonly used to enhance gas delivery. The deposition rate should be precisely tuned so as not to change the composition of the Y-doped HfO_2 film. Meanwhile, ALD has the capability to deposit a monolayer (ML) or sub-ML by self-limit process [3]. Therefore, the controllability of the doping might be easy with localized Y_2O_3 insertion in the HfO_2. In this study, the advantage of localized Y_2O_3 layers in HfO_2 films is addressed. The localized insertion of the Y_2O_3 layer might be useful to prevent unintentional crystallization during the deposition process, as is used for localized Al_2O_3 layer for ZrO_2 film in DRAM applications [4].

2. Sample fabrication

Metal-insulator-metal (MIM) capacitors were fabricated on an n^+Si substrate with bottom and top W electrodes. About 7-nm-thick Y-doped HfO_2 films were deposited by ALD with 4 different Y_2O_3 and HfO_2 thickness combinations (Table 1). A Y-doped HfO_2 film (sample 1), with 13 sets of Y_2O_3/HfO_2= 0.03/0.5nm can be considered as a uniformly doped film (fig. 1(a)). On the other hand, sample 2 with Y_2O_3/HfO_2=0.2/2.7nm for 2 sets is the locally inserted film (fig. 1(b)). The localized presence of Y atoms can be confirmed by DF-TEM image. Note that the thickness of 0.2 nm is slightly less than 1 ML (0.23nm) of Y_2O_3. All the effective doping concentrations in the Y-doped HfO_2 layers are designed to be 5 mol%. Annealing was conducted at 600°C for 1 min in a forming gas (3%H_2+97%N_2) atmosphere. Capacitance-voltage (*CV*), polarization-voltage (*PV*) and leakage current (*JV*) measurements were performed to elucidate the advantage of the localized insertion process.

3. Results and Discussions

PV hysteresis curves on different voltage sweeps and *CV* characteristics of the samples are shown in fig. 2. Decent ferroelectric hysteresis loops were observed for all the samples when applied peak-to-peak voltage (V_{pp}) exceeds 4 V (about 2.7 MV/cm). The P_r obtained at 3 V_{pp} decreases from 20 to 15 μC/cm^2 by further localizing the Y_2O_3 position. The *CV* curves revealed that high dielectric constants of 34 and 32 could be obtained with uniform and localized doped films, respectively. A smaller dielectric constant is useful for memory applications.

The switching cycle test with a pulse height of V_{PP} of 4 V at 500 kHz shows a wake-up effect for all the samples (fig. 3) [5]. This fact indicates an incomplete transition of the ferroelectric phase during the annealing. A better endurance before dielectric breakdown by a factor of 5 in the switching cycles was obtained with localized Y_2O_3 films. *JV* characteristics revealed better insulation with the Y_2O_3 localized HfO_2 films (fig. 4). The evolution of leakage current measured at 1.5 V on the switching cycles indicates a gradual increase before the breakdown event. The behavior is a typical sign of defect-mediated formation of a conductive filament composed of oxygen vacancy (V_O) in HfO_2 films [6].

4. Conclusions

Ferroelectric characteristics were obtained with uniform and localized doped HfO_2 films. A slight decrease in the initial P_r from 20 to 15 μC/cm^2 indicates an incomplete transition to the ferroelectric phase in the HfO_2. However, suppression in the leakage current, as well as improvement in the switching cycle endurance, can be achieved with localized doped HfO_2.

Acknowledgment

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References

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Table1 Thicknesses design of the fabricated samples.

sample ID	1	2	3	4
HfO_2 (nm)	0.5	1.3	1.8	2.7
Y_2O_3 (nm)	0.03	0.09	0.15	0.20
# of set	13	4	3	2
total thickness (nm)	7.1	6.9	7.6	7.6

uniform ⟷ localized

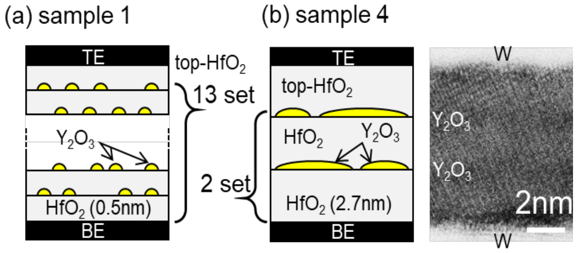

Fig. 1 (a) Uniform and (b) localized Y_2O_3 distribution in HfO_2 film. Localized Y atoms was observed even at 600°C annealing for 100 min.

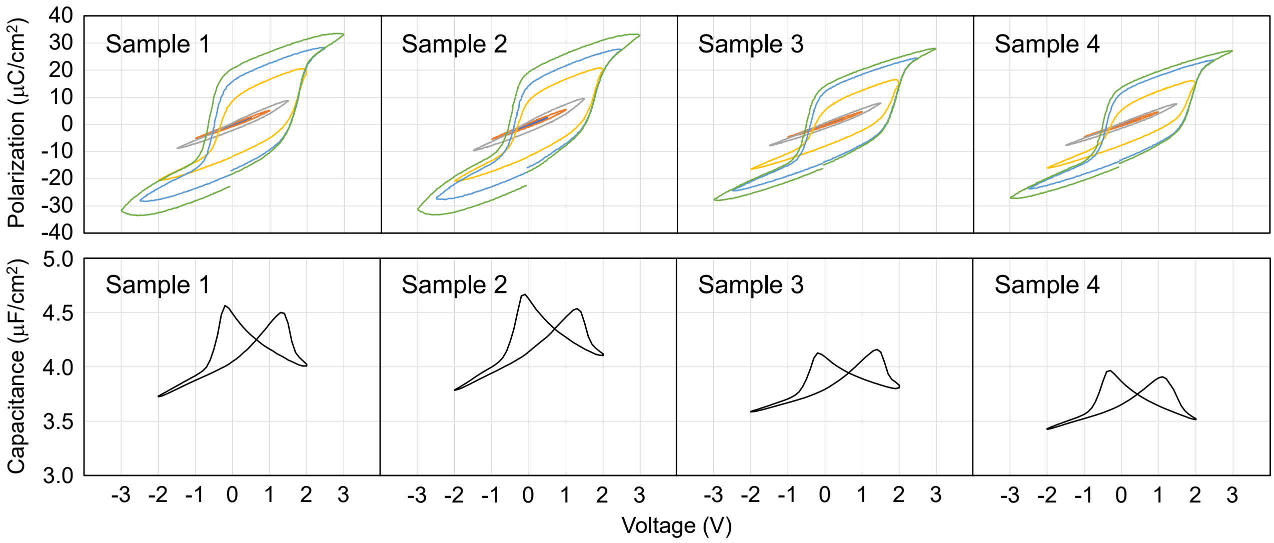

Figure 2 *PV* hysteresis loops and *CV* characteristics of the samples.

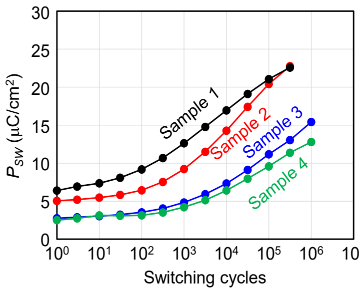

Figure 3 Switching cycle endurance of the samples. Wake-up effects were observed for all the samples. A better endurance can be obtained with Y_2O_3 localized HfO_2 films.

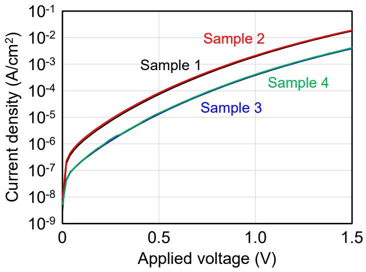

Figure 4 *JV* curves of before switching indicate better insulating properties with Y_2O_3 localized HfO_2 film.

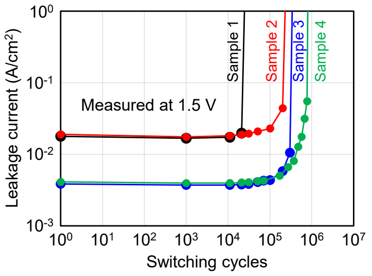

Figure 5 Leakage current of the samples at each switching cycles measured at 1.5 V. An early degradation is observed for uniformly doped HfO_2 films.