強誘電体 Y-doped HfO_2 の薄膜化に伴う残留分極量および信頼性の向上

Improvements of Remanent Polarization and Endurance Characteristics in Thin Ferroelectric Y-doped HfO_2

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1. Introduction

One of the most exciting properties in ferroelectric HfO_2 is that very thin ferroelectric film is available, while cycling properties of ferroelectric films are critically important in terms of ferroelectric applications.

In this work, we show thickness dependence of P_{sw} ($P_{sw}=P_r^{+}+P_r^{-}$) in ferroelectric HfO_2 down to 3 nm. Although P_{sw} is sharply reduced below 8 nm with post deposition anneal (PDA), a large P_{sw} enhancement is achieved by post metallization anneal (PMA) down to 5 nm. Furthermore, a highly reliable cycling performance is reported in 5 nm ferroelectric HfO_2 with neither wake-up nor obvious fatigue to 10^8 cycles.

2. Results and Discussion

Y_2O_3-doped HfO_2 film was prepared on p^+-Ge substrate, and followed by PDA. Y doping concentration was optimized at 30-nm-thick HfO_2[1]. A sharp drop of P_{sw} is observed below 8 nm, as shown by the black curve in **Fig. 1(a)**. When the thermal treatment was changed from PDA to PMA, a TiN top layer was deposited on HfO_2 before annealing. PMA hugely enhances P_{sw} in the ultrathin region down to 5 nm, as shown by the red curve in **Fig. 1(a)**. Comparing to 30 nm film, 5-nm-thick Y-HfO_2 exhibits a monotonic increase of P_{sw}, which enables to lower the operating voltage, as shown in **Fig. 1(b)**.

Next, two thicknesses of ferroelectric HfO_2 films with PMA in **Fig. 1(b)** were cycled at 3 MV/cm by a square pulse at 100 kHz. **Fig. 2** shows the cycling number dependence of $\pm P_r$ for 5 and 30 nm thick HfO_2 with PMA. Both wake-up and fatigue of polarization are observed in 30 nm film for 10^6 cycles, while no visible wake-up and very slight fatigue in 10^8 cycles under 3 MV/cm are demonstrated in 5-nm-thick film. It is surprising to see that Y-doped HfO_2 with good ferroelectricity is maintained down to 5 nm. Although the origin of the higher reliability in thinner films is not so clear, it is inferred that the grain size can be comparable to the film thickness in ultrathin HfO_2[2], therefore, there may be only a single domain connecting two electrodes[3] and no internal freedom of domain switching in the film. This view may explain significant improvements of the wake-up and fatigue in thinner ferroelectric HfO_2 film.

3. Conclusion

P_{sw} in ferroelectric HfO_2 was simply enhanced down to 5 nm by employing PMA. A highly reliable cycling performance was also demonstrated in 5-nm-thick HfO_2 ferroelectric film with no wake-up, almost no fatigue to 10^8 cycles. Good cycling performance in 5-nm-thick HfO_2 is promising for low power applications.

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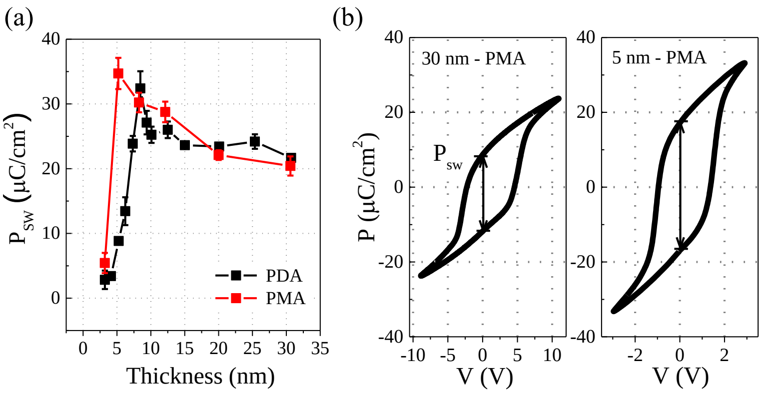

Fig. 1 (a) The thickness dependence of P_{sw} in ferroelectric HfO_2 from 30 to 3 nm with PDA and PMA. **(b)** P-V hysteresis in 30 and 5 nm Y-doped HfO_2 with PMA.

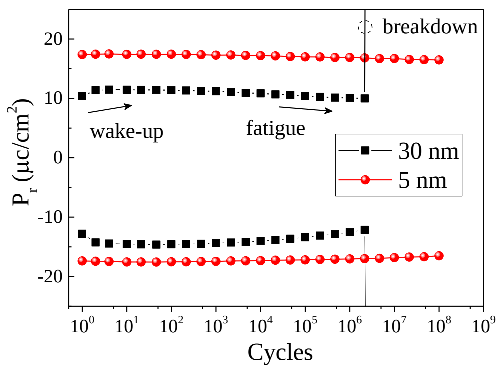

Fig. 2 Cycling characteristics of P_r of ferroelectric Y-doped HfO_2 with 30 and 5 nm. The devices were stressed by square pulses with 3 MV/cm at 100 kHz.