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Strain-Enhanced Ferroelectric Aluminum-Doped Hafnium Oxides for Volatile and Nonvolatile Memories Applications

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Abstract

In this work, we investigate the mechanical strain effect of TaN on ferroelectric HfAlO capacitors. The experimental results confirm that the work function tuning of strained TaN electrodes by N_2 doping can improve the ferroelectric polarization and also enhance the anti-ferroelectric state. The strain-enhanced ferroelectric HfAlO capacitor with the modification of FE and AFE states shows the potential for volatile and nonvolatile memories applications.

1. Introduction

The studies of new ferroelectric materials and devices [1]-[5] attract more attention due to the etching friendly hafnium-oxide-based dielectrics and highly scalable process that are important for volatile and nonvolatile memory applications. Recently, the ferroelectricity of hafnium oxide with aluminum doping (HfAlO) has been demonstrated [5]. Recently, we have demonstrated that the gate strains by tuning nitrogen contents of TaN (work function tuning) can enhance the crystallization of ferroelectric orthorhombic phase in HfZrO films [2]-[3]. Furthermore, the results of recent research also proposed that work function difference of electrodes can form a built-in bias to create a bi-stable anti-ferroelectric operation [6]. In this work, we further investigate metal-gate strain effect on ferroelectric HfAlO devices based on experimental results and pulse IV measurement. Our experimental results find that the metal-strain not only improves the ferroelectric polarization effect of HfAlO but also enhances the anti-ferroelectric property, which is beneficial for volatile and nonvolatile memory applications.

2. Device Fabrication

First of all, a 3-nm-thick dry oxide was grown on a highly doped n+ substrate as a buffer layer. Then a stable 10-nm-thick HfAlO film with an Al/Hf ratio of ~4% was deposited by atomic layer deposition. A TaN electrode of 200 nm thickness with different N_2/Ar ratios for 2%, 6%, 10% and 14% was then deposited on the top of HfAlO film to form ferroelectric capacitors. After gate patterning, the TaN/HfAlO/SiO_2/n^+ MIM capacitors were exposed to rapid thermal annealing (RTA) of 700°C and 800°C. The ferroelectric hysteresis property were measured by RT66B ferroelectric tester. The ferroelectric dipole switching was measured by pulse I-V measurement (Agilent B1530A).

3. Results and Discussion

Fig. 1 shows the P-E hysteresis loop of ferroelectric HfAlO MIM capacitors with 10% N_2 doped TaN gate and 800C RTA. It is clearly observing that the HfAlO film has strong field dependence of polarization effect. The saturated ferroelectric responses including remnant polarizations of around 11.6μC/cm^2 and coercive fields of approximately 2.65 MV/cm can be measured. The fast ferroelectric domain switching can be used for the application of high speed memory.

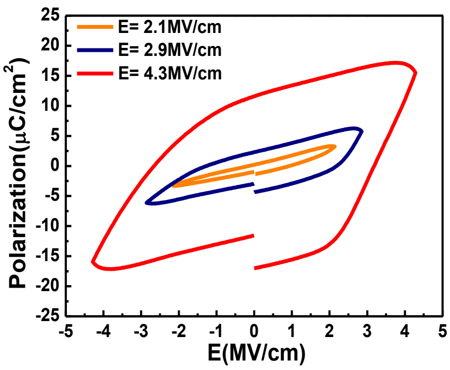
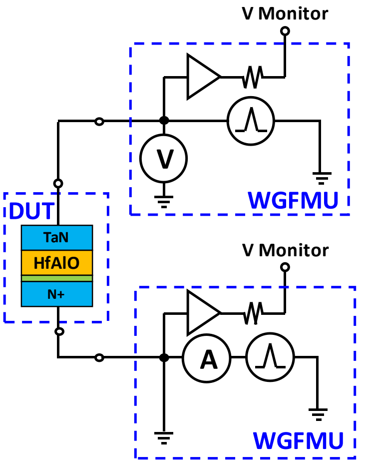


Fig. 1 Ferroelectric hysteresis loop of polarization–electric field (P–E) of ferroelectric HfAlO MIM capacitors.

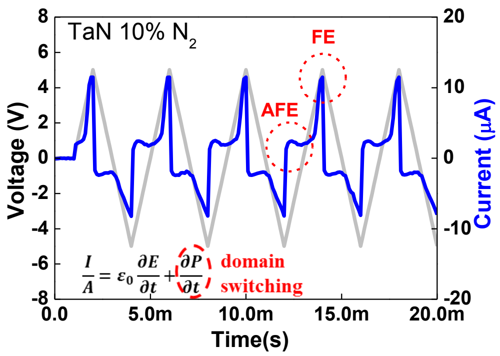
To further investigate the transition of ferroelectric and anti-ferroelectric properties, the transient current response of ferroelectric domains was performed by pulse IV measurement, as shown in Fig. 2(a). The response current of ferroelectric domain switching can be expressed as the following [7].

$$i(t) = A(\varepsilon_0 \frac{\partial E(x,t)}{\partial t} + \frac{\partial P(x,t)}{\partial t})$$

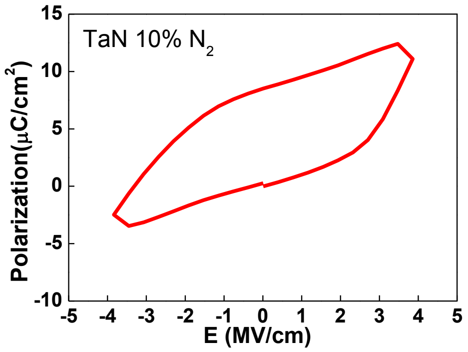
where P is the ferroelectric dipole polarization, E is the applied electric field, and ε_0 is dielectric constant of the ferroelectric HfAlO dielectric. In Fig. 2(b), the transient current responses is clearly measured under ±5V triangular voltages. The two peaks corresponds to the ferroelectric (FE) and anti-ferroelectric (AFE) domains, respectively. As seen in Fig. 2(c), the ferroelectric polarization hysteresis loop can be deduced from current response equation described above, which supports the ferroelectric polarization property of HfAlO MIM capacitor.



(a)



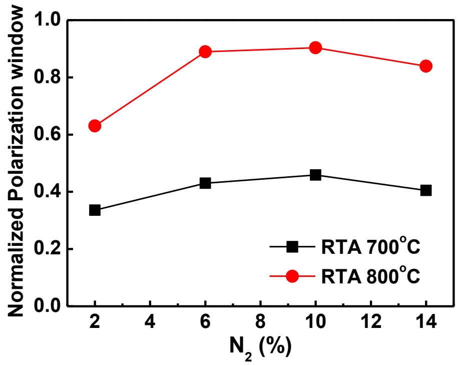
(b)



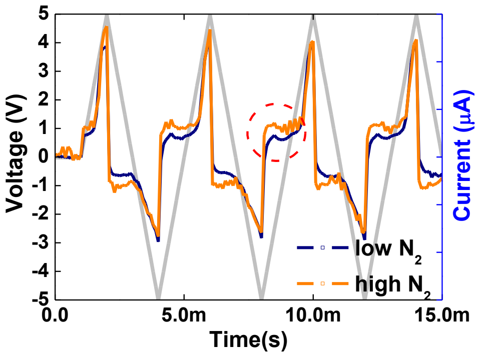
(c)

Fig. 2 (a) Pulse IV measurement setup, (b) triangular wave form with applied ±5V voltages, and (c) extracted polarization loop as a function of electric field.

Fig. 3(a) shows the comparison of ferroelectric polarization effect. The results reveal that the metal-gate strain enhances the ferroelectric polarization effect, which has the same trend as metal-gate strained HfZrO film [3]. The experimental results also confirmed that the 10%-N_2-doped TaN is the appropriate recipe to optimize the polarization of HfAlO for both 700C and 800C RTA conditions. The high-N_2 doping into TaN not only improves the ferroelectric polarization effect, but also enhances the AFE, as shown in Fig. 3(b). The recent researches have demonstrated that the AFE state is highly correlated with the negative capacitance effect and nonvolatile property of ferroelectric memory [3],[6].



(a)



(b)

Fig. 3 (a) Relative polarization comparison under various nitrogen contents of TaN electrodes, and (b) output characteristics of triangular pulse IV for low- and high-N_2 TaN cases.

4. Conclusions

According to our study, the nitrogen doping of TaN electrode can improve ferroelectric polarization due to strain effect. The deduced polarization loop by transient IV also supports the measured results. The enhanced AFE accompanied by mechanical strain is favorable for the application of ultralow-power nonvolatile memory with the requirement of negative capacitance effect.

Acknowledgements

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