# Effect of Plasma Treatment on Performance of AlScN-Based Ferroelectric Tunnel Junctions

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## 1. Introduction

Recent advances in artificial intelligence (AI) and machine learning have increased the demand for high-speed, low-power processing technologies. Computing-in-memory (CiM) devices based on aluminum scandium nitride (AlScN) ferroelectric tunnel junctions (FTJ) offer integrated memory and computation in a cross-point structure, enabling in-situ multiply–accumulate operations for efficient parallel computing [1,2]. However, the reduction of the voltage for polarization switching still poses as a significant challenge for practical use. While thinning the film effectively lowers the polarization switching voltage, it also increases leakage current and tends to degrade the $I_{on}/I_{off}$ ratio. Previous studies have reported that plasma nitridation and plasma oxidation treatments can suppress leakage current in AlScN films and improve the $I_{on}/I_{off}$ ratio [3,4]. The objective of this study is to reduce the switching voltage while maintaining a high Ion/Ioff ratio by combining the plasma treatment with film thinning of the ferroelectric AlScN.

## 2. Experimental Procedure

FTJ devices using AlScN were fabricated based on the process flow shown in Fig. 1. First, a 10 nm thick TiN bottom electrode was deposited on an $n^+$-Si substrate using RF sputtering. Then, AlScN thin films with 30% scandium concentration were deposited by DC sputtering at a substrate temperature of 400 °C, with an Ar:$N_2$ gas flow ratio of 5:10. The film thicknesses were set to 20 nm, 35 nm and 50 nm. After AlScN deposition, some samples were subjected to plasma nitridation and plasma oxidation for 1 minute each (hereafter referred to as "plasma treatment"). Subsequently, an Al top electrode was deposited on the TiN layer by RF sputtering, followed by photolithography and dry etching to pattern the electrodes. Finally, Al was deposited on the backside of the substrate to form a back contact, completing the two-terminal FTJ memory cell structure.

## 3. Results and Discussion

Figure 2 shows the typical capacitance–voltage (C–V) characteristics with and without plasma treatment, while Figure 3 presents the relationship between film thickness and coercive voltage. As film thickness decreases, the capacitance peak shifts towards lower voltages, indicating that film thinning is effective for a reduction in operation voltage. It has been demonstrated that, as a result of plasma treatment, the capacitances decrease and the coercive voltages increase for each film thickness of AlScN.

Figure 4 shows the current density-voltage (J–V) characteristics. As film thickness decreases, the leakage current increases and the $I_{on}/I_{off}$ ratio decreases, as shown in Fig. 4(a). However, the leakage current can be improved by plasma treatment as shown in Fig. 4(b). Figure 5 shows the $I_{on}/I_{off}$ ratio at 5V for the different AlScN thickness. In the absence of plasma treatment, the $I_{on}/I_{off}$ ratio decreases monotonously as the thickness of the AlScN film is reduced. On the other hand, in the case with plasma treatment, the $I_{on}/I_{off}$ ratio increases regardless of the AlScN thickness. Especially, the plasma-treated sample with 35 nm AlScN exhibits the higher $I_{on}/I_{off}$ ratio. These results suggest that the optimum plasma treatment condition depends on the film thickness. The plasma nitridation reduces nitrogen vacancies in the AlScN film, thereby suppressing leakage current. Concurrently, the plasma oxidation forms an interfacial oxide layer, thereby enhancing the $I_{on}/I_{off}$ ratio [3,4]. That is, in the case of the 50nm AlScN film, the plasma treatment is insufficient, and consequently the modified region could be small as shown in Fig. 6(a). In contrast, in the case of 20nm AlScN film, the excessive nitrogen incorporation likely inhibits polarization switching, leading to a decreased $I_{on}/I_{off}$ ratio. These interpretations are consistent with angle-resolved hard X-ray photoelectron spectroscopy (AR-HAXPES) results, showing that 1 min plasma nitridation/oxidation treatments influence the AlScN film up to ~20 nm from the surface [5].

## 4. Conclusions

In this study, we investigated the effects of plasma nitridation/oxidation treatments with film thinning on the performance of AlScN FTJ devices. As a result, for thinner AlScN FTJ devices, the optimal plasma treatment conditions depending on film thickness are crucial for realizing high-performance FTJ devices.

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## References

[1] M. Kimura *et al*, IEEE Transactions on Neural Networks and Learning Systems Volume: **34** 2366-2373(2023).
[2] S. -L. Tsai *et al*, Jpn. J. Appl. Phys. **61** SJ1005 (2022).
[3] T. Okazaki *et al*, Proc. in Workshop on ElectronDevice Interface Technology (EDIT)(2023).
[4] K. Goshima *et al*, P-21International Workshop on DIELECTRIC THIN FILMS FOR FUTRURE ELECTRON DEVICES (IWDTF) (2023).
[5] T. Tsutsumi *et al*, Jpn. J. Appl. Phys. **63** 04SP66 (2024).

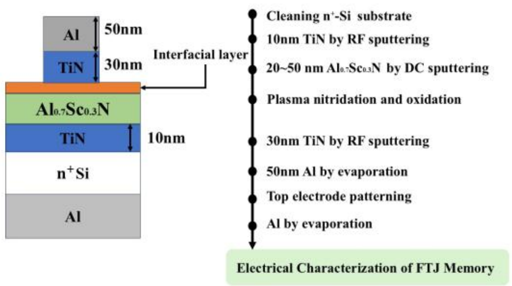


Fig. 1 AlScN FTJ memory structure used in this work

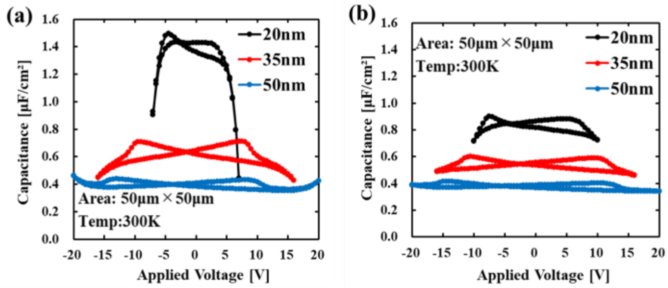


Fig. 2 Capacitance–voltage (C–V) characteristics of AlScN-based FTJ devices: (a) as-deposited, (b) plasma nitridation (60 s) + plasma oxidation (60 s).

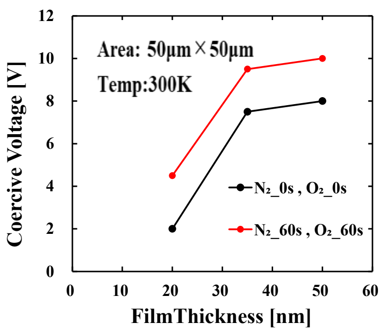


Fig. 3 Relationship between thickness and coercive voltage.

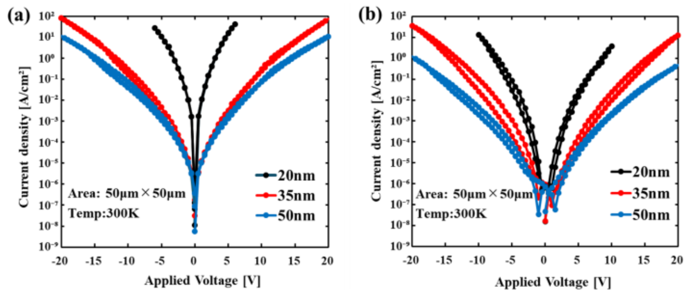


Fig. 4 The current density-voltage (J–V) characteristics of AlScN-based FTJ devices: (a) as-deposited, (b) plasma nitridation (60 s) + plasma oxidation (60 s).

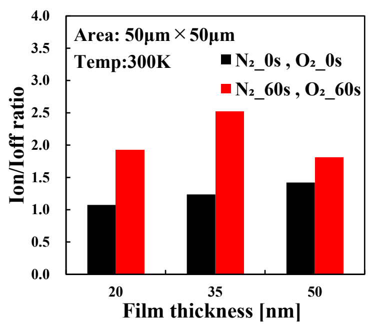


Fig. 5 The $I_{on}/I_{off}$ ratio at 5V for each film thickness.

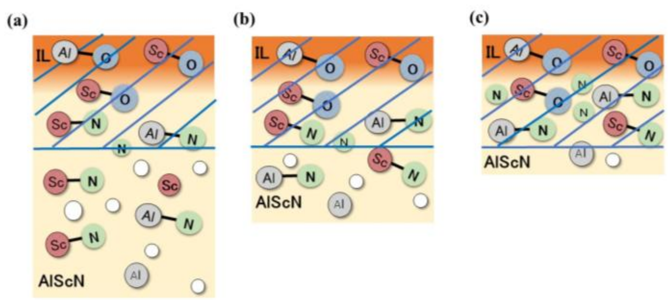


Fig. 6 Schematic illustration of AlScN films after nitridation and oxidation treatment: (a) 50 nm, (b) 35 nm, (c) 20 nm.