Tuning of Effective work function in Cl free TiAlN ALD through fine Al doping process for Gate electrode application

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Abstract text

In the advancement of semiconductor device fabrication, integrating high-κ dielectrics and metal electrodes is essential to overcome the limitations of traditional silicon-based MOSFETs. Titanium nitride (TiN) is a pivotal material, effectively mitigating diffusion-induced oxidation at polycrystalline silicon electrode interfaces. TiN have metallic properties like low resistivity and exceptional physical and chemical stability, render it indispensable in applications such as electrodes, surface coatings, and diffusion barriers. Work function of metal electrodes critically influences MOSFET electrical characteristics, including threshold voltage and leakage current. However, Fermi-level pinning in high-κ materials leads to deviations from intrinsic work function values, necessitating the consideration of effective work function values. For TiN, the effective work function typically ranges between 4.6 and 4.8 eV, aligning well with p-MOSFET. In contrast, n-MOSFET require lower work function values, prompting extensive research into methods for reducing TiN's work function to meet these requirements. Atomic layer deposition (ALD) has emerged as a cornerstone technique in semiconductor shrinking, offering unparalleled control over film thickness and composition. TiN thin films are commonly deposited via thermal ALD processes utilizing precursors such as titanium tetrachloride ($TiCl_4$) and ammonia (NH_3). This approach reliably yields high-quality films with low resistivity. However, the incorporation of chlorine residues necessitates post-deposition at temperatures exceeding 400 °C. Alternatively, metal-organic precursors like tetrakis(dimethylamido)titanium (TDMAT) can be employed; nevertheless, achieving low resistivity with TDMAT often requires plasma-enhanced processes or subsequent high-temperature annealing. In this study, we developed a thermal ALD process using TDMAT and NH_3 as precursors, incorporating trimethylaluminum (TMA) cycles to deposit TiAlCN thin films at a relatively low temperature of 300 °C. This method achieved films with a resistivity of approximately 5000 μΩ·cm, lower than previously reported values for thermal ALD TiN films deposited from TDMAT without post-deposition annealing. Furthermore, by doping aluminum concentrations below 10%, we successfully tuned the work function from 4.9 eV to 4.5 eV. Compared to conventional $TiCl_4$-based processes, our method offers advantages including reduced carbon contamination and lower deposition temperatures, thereby minimizing potential adverse effects on adjacent thin films. This makes the process particularly suitable for the fabrication of MOSFETs with increasingly complex architectures.

Reference

[1] Moon, Jungmin, et al. "The work function behavior of aluminum-doped titanium carbide grown by atomic layer deposition." *IEEE Transactions on Electron Devices* 63.4 (2016): 1423-1427.

Supplemental Document

Figure 1 a,b illustrate the present schematics of the thermal atomic layer deposition (ALD) process for titanium aluminum nitride (TiAlN), detailing the process variations and corresponding aluminum (Al) doping concentrations. The incorporation of Al cycles does not significantly affect the overall film thickness.

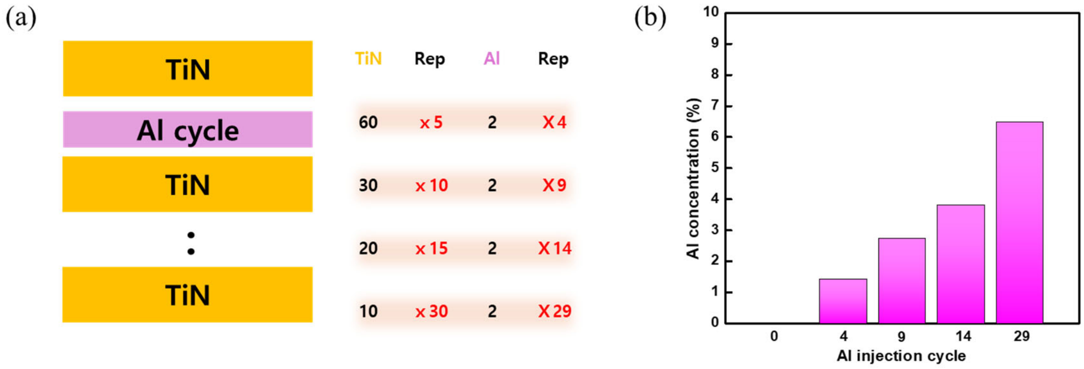

Figure 1. (a) design of Al doping process of Thermal ALD TiAiN. (b) Aluminum amount in TiAlN film according to the doping cycle.

Figure 2 a,b depict the electrical properties, specifically resistivity and effective work function, of titanium aluminum nitride (TiAlN) films. The effective work function was measured on hafnium dioxide (HfO_2) insulators of varying thicknesses.

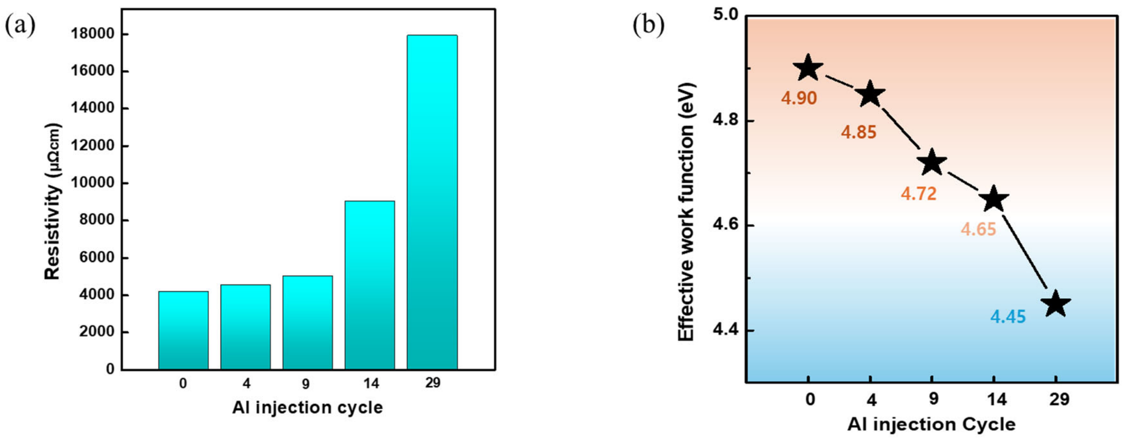

Figure 2. (a) Resistivity of Thermal ALD TiAlN Flim. (b) Effective work function difference according to the Al doping cycle.