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Young's modulus and residual stress extraction of TaN ultrathin film

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Abstract

The mechanical properties extraction of the ultrathin film is a big challenge to be determined and controlled. In this study, we select a non-contact method [1][2][3]to conduct the measurement of the TaN ultrathin film, which can effectively prevent to damage the TaN film at the same time. Firstly, we exploit the PVD process with various gas ratios to deposit the TaN thin film on the SiO_2 cantilevers. Then, we analyze the mechanical properties of the TaN thin film to extract the major characteristics. The frequency and geometry would dominate the performance of Young's modulus.

On the other hand, residual stress is accumulated by all the random stress induced during the process. Especially, uniform stress has a major impact on residual stress. Therefore, the uniform stress can be simplified as the residual stress and also can be expressed by the Stoney equation [4][5]. According to our experimental results, the N_2 gas ratios-dependent Young's modulus of TaN thin film is located at approximately 247.55±6.11GPa and 249.61±16.48GPa for 120μm and 140 μm cantilevers, respectively. In addition, the residual stress is reduced from -1.02GPa to -0.74GPa as the N_2 flow increases. Consequently, we provide an efficient approach to the bilayer microcantilevers [3][4]to modifying the mechanical properties of ultrathin TaN film and the N_2 gas ratios can validate its mechanical properties during the deposition process.

Introduction

TaN is one of the critical materials in semiconductors and MEMS developments which is exploited to be the barrier and diffusion layer to prevent Cu diffusion due to its good adhesion, correction, and hardness. To satisfy the requirements of small form factor and miniaturization of ICs, there are many issues that need to be overcome such as thin film cracks, enhanced failure, and process induced residual stress. In addition, measuring and determining the mechanical properties of TaN thin film is quite difficult. In this study, we used the simple cantilever beams array fabricated by the MEMS process to be the platform for the mechanical properties extraction, then deposited the TaN thin film with the different gas ratios on the cantilevers by PVD process. The gas ratio dependency of Young's modulus and residual stress are explored and tuned.

Experimental

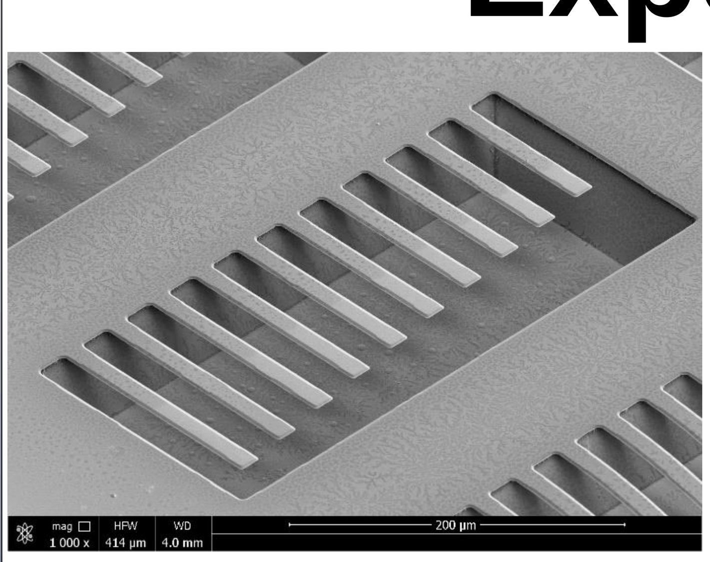

Fig1. The cantilever beams array and deposited with R_N=0.3

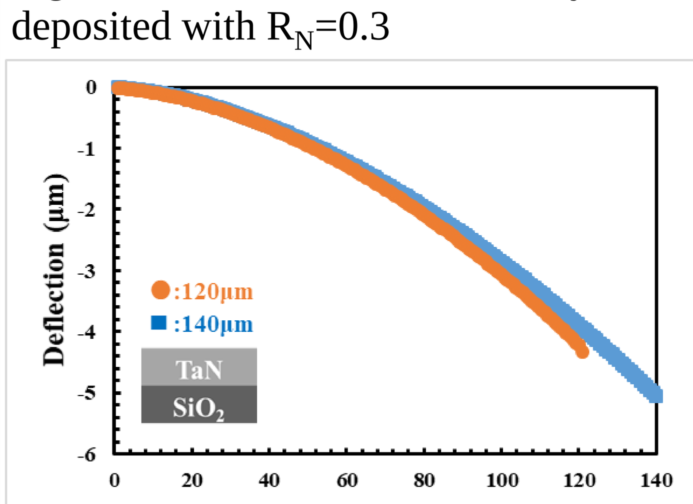

Fig2. The deflection of 120 μm and 140 μm cantilevers deposited with R_N=0.3

The platform of the cantilever beams array is shown in Fig1. We deposited 1μm thermal oxide on the blanket single crystal wafer by Furnace, patterned the different length cantilever beams array by the lithography process, and used the reactive etching and buffered oxide etch solution to remove the oxide layer. Cantilever beams will be suspended after the wet etching process. There are different lengths of cantilever beams patterned in the target wafer. The length of 120 μm and 140 μm cantilevers were chosen in this experiments, following deposited 10nm thickness of TaN ultra-thin film with various gas ratios R_N=0.3, 0.4, and 0.5. The gas ratio can be expressed as $\frac{N_2}{Ar+N_2}$. Fig2. shows the deflection results of 120 μm and 140 μm cantilever beams deposited with R_N=0.3.

Frequency and the geometry of the cantilever beams play significant factors in determining and extracting Young's modulus of TaN thin film. The Laser Doppler Vibrometer (LDV) is mainly for frequency determining. The geometry of the cantilever beams were measured by the Scanning Electron Microscope (SEM). Fig3. and Fig4. show the frequency before and after the TaN thin film deposition. In contrast of SiO_2 , the thickness of TaN is much thinner than SiO_2. The uniform stress can be regarded as the residuals stress and is determined by the Stoney equation.

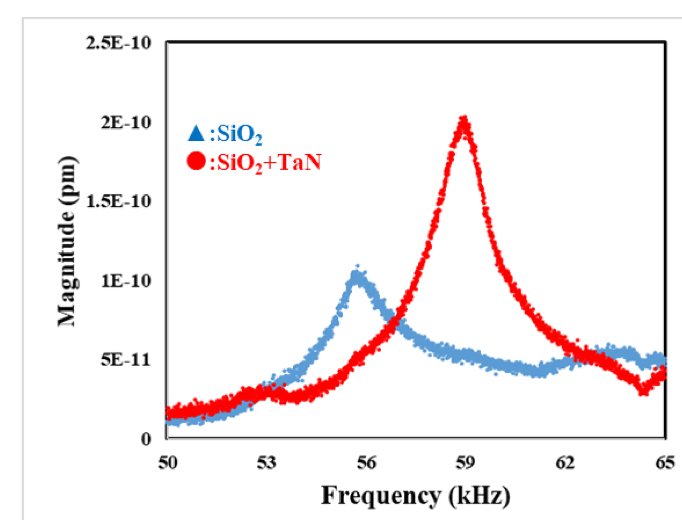

Fig3. The frequency determined results before and after the TaN thin film deposit on 120μm cantilevers.

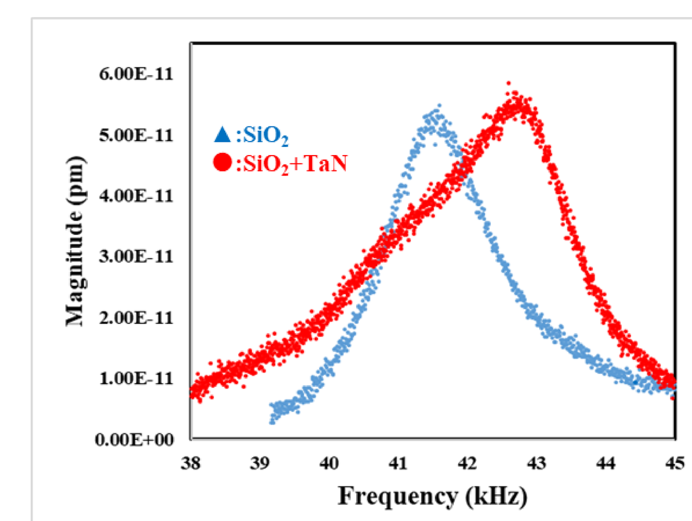

Fig4. The frequency determined results before and after the TaN thin film deposit on 140μm cantilevers.

Results and Discussion

As can be seen in Fig5., Young's modulus can be extracted by the difference gas ratio, in which the average of the results is approximately 246.631GPa. It has no significant changes for Young's modulus by tuning the N_2 flow. On the other hand, Fig 6. shows the extraction results of residual stress from R_N=0.3 to 0.5. The residual stress are reduced from -1.02GPa to –0.74GPa and -0.95GPa to -0.67GPa for 120 μm and 140μm cantilever beams, respectively. The residual stress is reduced as the N_2 flow increases.

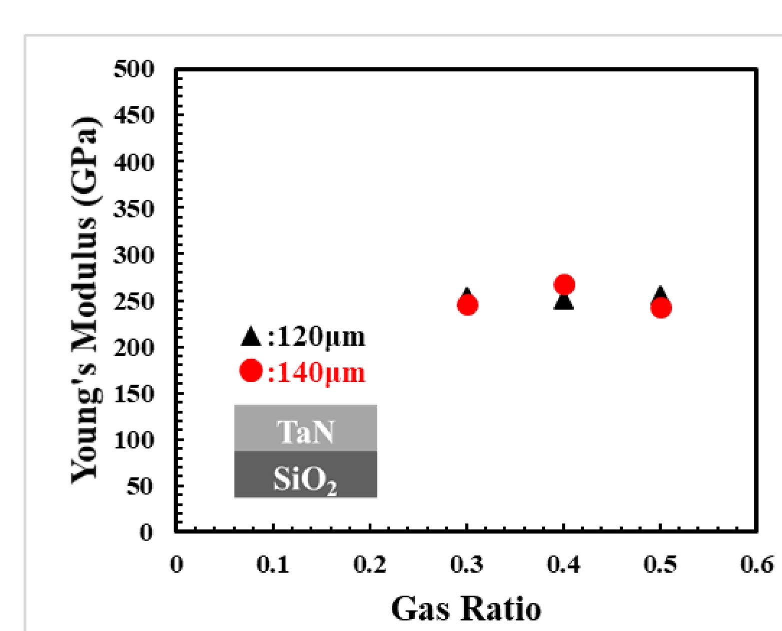

Fig5. The results of Young's modulus extraction deposit with R_N=0.3-0.5 on 120μm and 140μm.

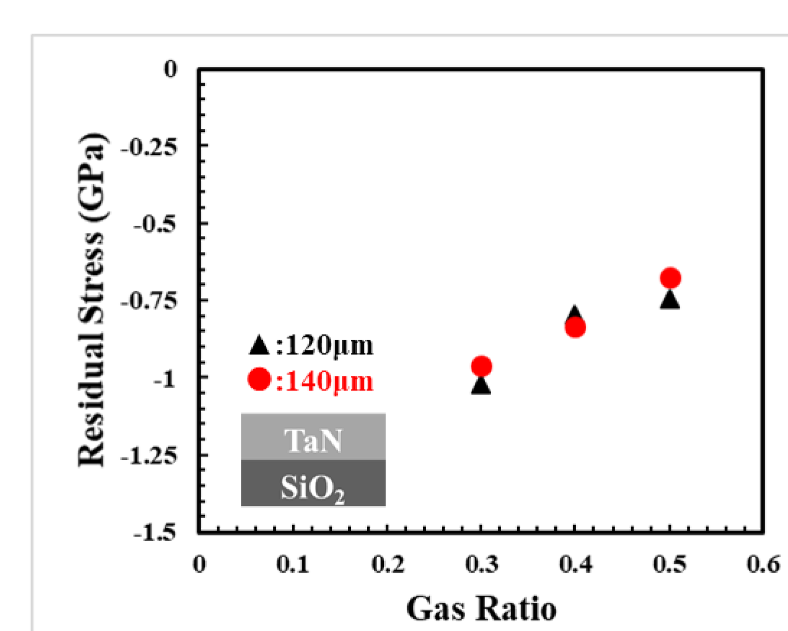

Fig6. The results of residual stress extraction deposit with R_N=0.3-0.5 on 120μm and 140μm.

Conclusion

Young's modulus and residual stress of TaN ultrathin film can be success extracted by the bilayer method. Tuning the N_2 flow had a significant influence on reducing the residual stress after depositing the TaN thin film. It can prevent the ultrathin film crack or failure and also reduce the risk of Cu diffusion.

References

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