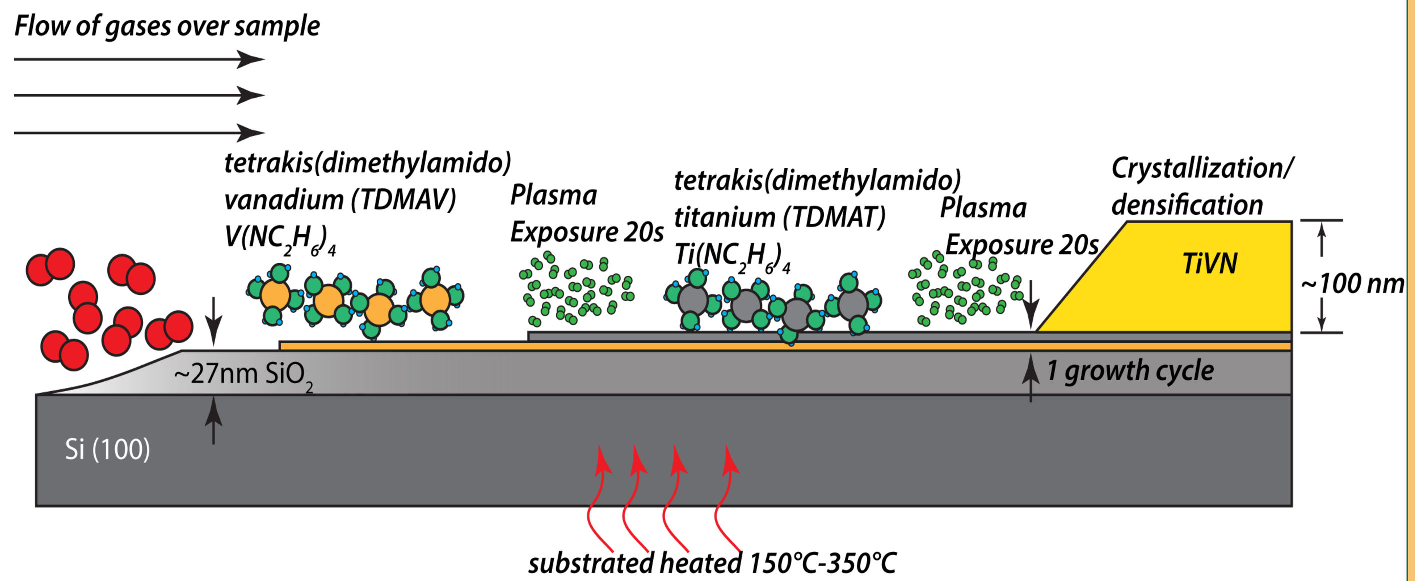
The Effects of Substrate Bias Voltage on the Tribological Properties of Plasma-Enhanced Atomic Layer-Deposited Nitride Thin Films

Thomas Lockhart, Kylie E. Van Meter, Prof. Brandon A. Krick
Department of Mechanical Engineering, FAMU-FSU College of Engineering, Tallahassee, Florida

Definitions

- Thin Films- a layer of material up to a few micrometers in thickness and contains certain material properties
- Plasma-Enhanced Atomic Layer Deposition (PE-ALD)- Method of depositing gases via self-limiting chemical surface reactions that can be enhanced with radiofrequency voltage

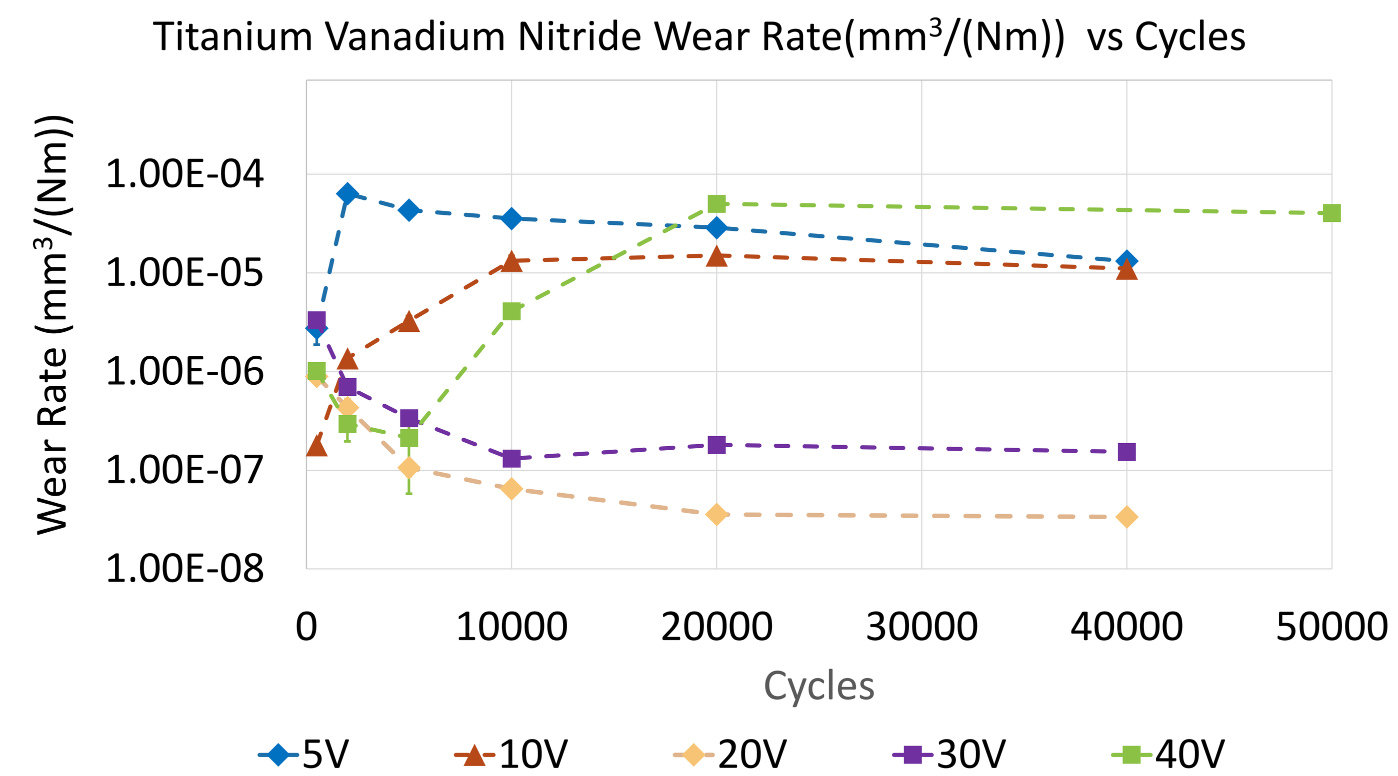


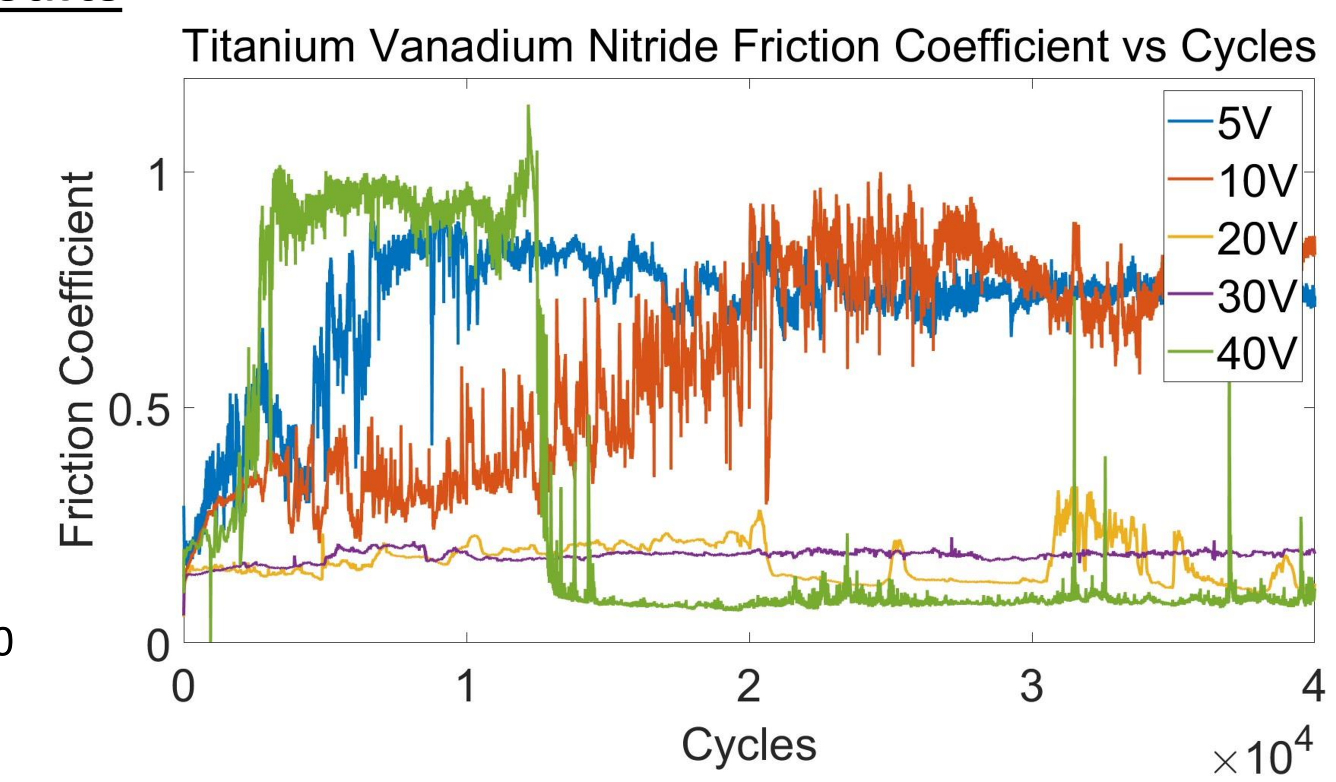
a.) Thermal growth of SiO_2 layer 1000 °C for 10 min in O_2 b.) TDMAV pulse for 0.5 s c.) Plasma Exposure d.) TDMAT pulse for 0.25 s e.) Plasma Exposure

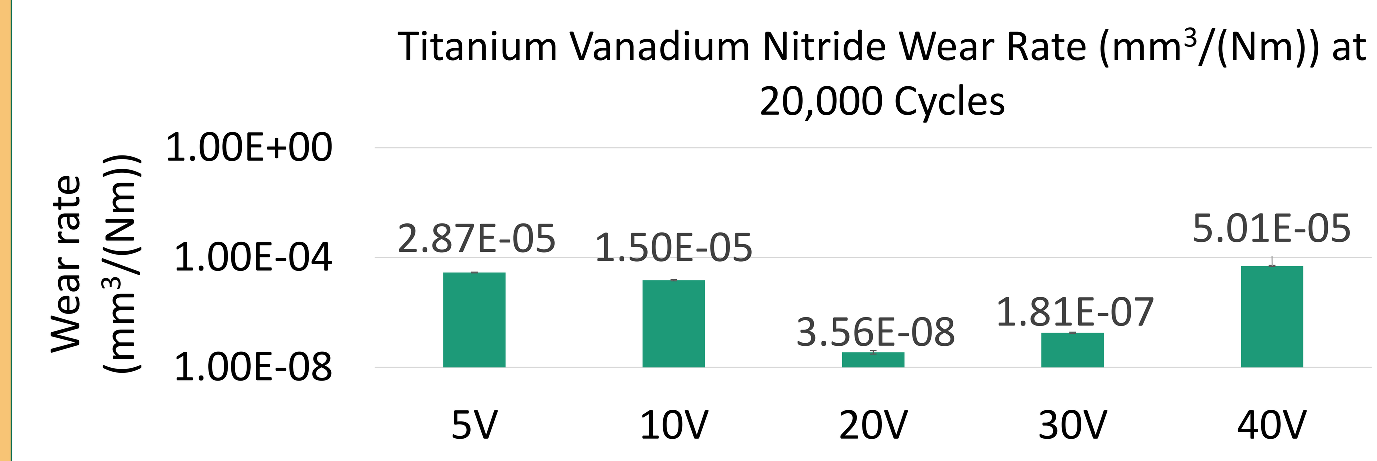
Introduction

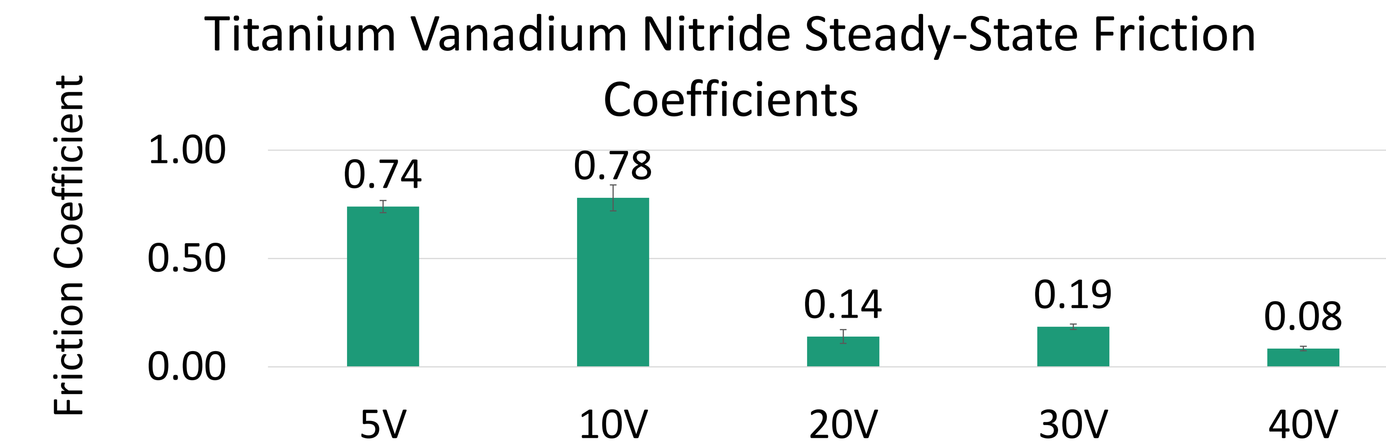
- PE-ALD is a deposition process that can make uniform thin films that take place at low temperatures making it advantageous to other methods
- Parameters within the deposition process such as radiofrequency voltage can be changed to affect the films material properties
- PE-ALD thin film's wear and friction properties make it advantageous for certain biomedical and micro-electronic applications
- While research had been done on PE-ALD there has been little on the effect of radiofrequency plasma voltage bias for TiVN thin films on material properties like wear rate and friction coefficient
- It was predicted that the higher the voltage used the smaller the wear rate and friction coefficient
- The samples were tested in a Nitrogen gas environment to limit any potential chemical reactions with the atmosphere during each experiment

Results





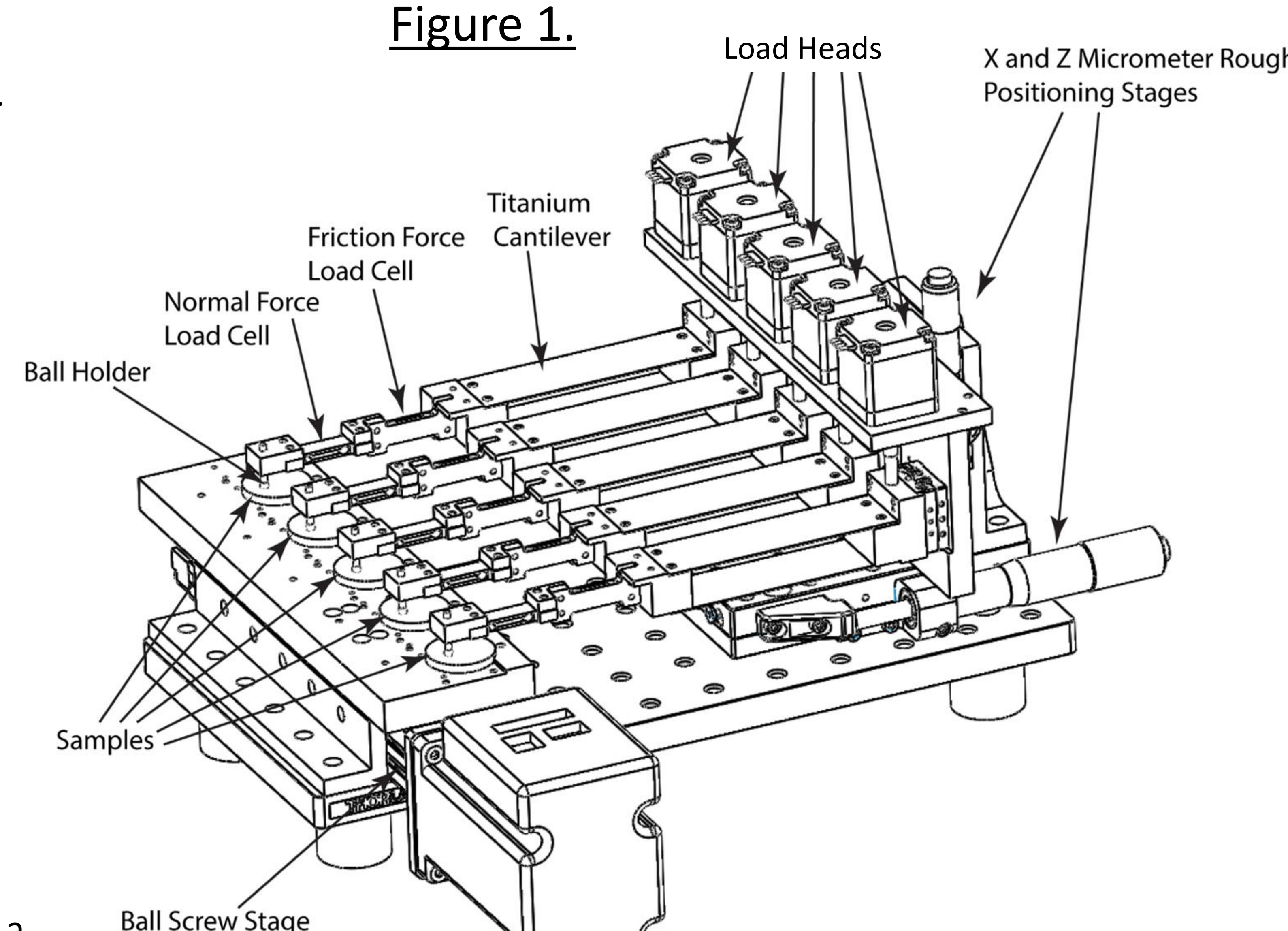




Methods

- TiVN thin film samples created at 5, 10, 20, 30, and 40 V were provided by Veeco.
- Samples were loaded onto the tribometer in Figure 1.
- To determine the wear rate and friction coefficients of each sample at different magnitudes of movement cycles, a stripe test was utilized in 1mm increments from 6mm to 1mm, an example of a stripe test is shown in Figure 2
- The stripe test created six 1mm long wear scar sections with 0.5K, 2K, 5K, 10K, 20K, and 40K/50K movement cycles using the tribometer in Figure 1.
- A 3 mm Diameter Sapphire Ruby Ball was the countersurface used during each experiment
- The countersurface load was 100mN at a speed of 1mm/s
- The Nitrogen gas environment created the following conditions to limit unwanted chemical reactions with the environment during the experiment
  - <0.1ppm O_2
  - <0.1ppm H_2O

Figure 1.



Data Processing

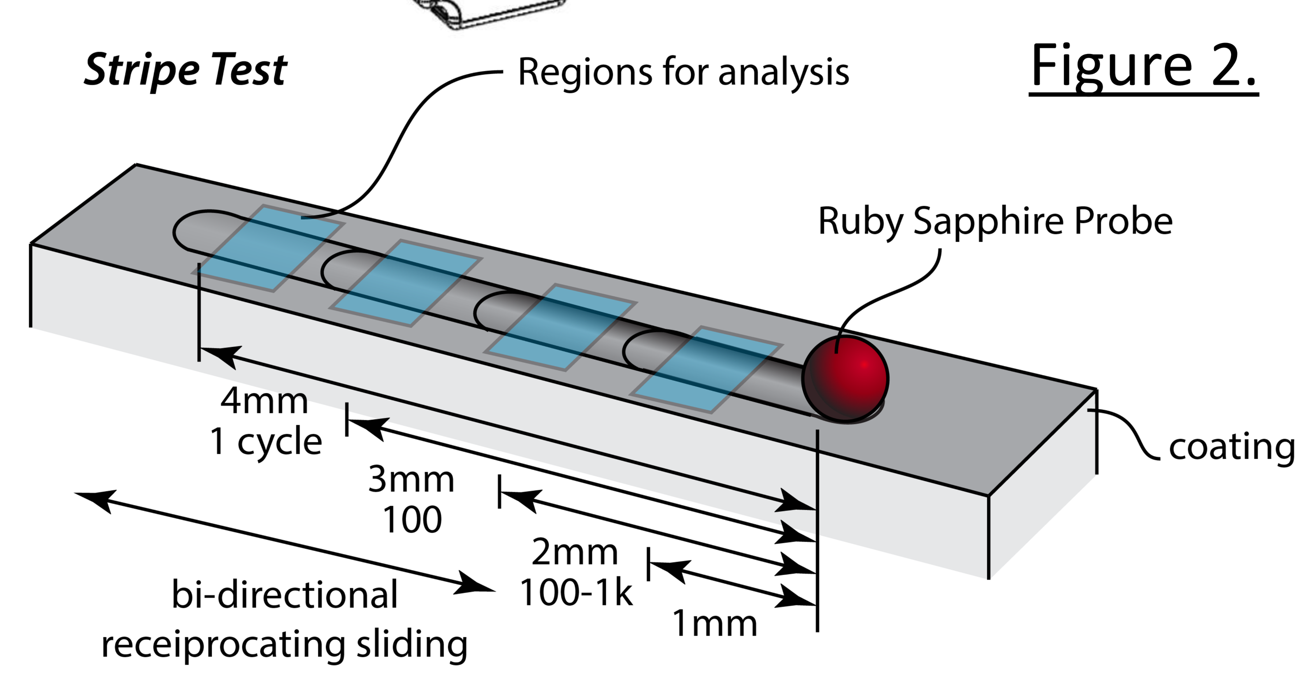
- Friction coefficient data was recorded by the tribometer in Figure 1.
- The wear scars created by each section of the stripe test were then scanned using a Scanning White Light Interferometer
- Four cross-sections of each cycle section were used to calculate the average wear rate and standard deviation using the following equation

$$\left[\frac{mm^3}{Nm}\right] = \frac{V}{F_N \cdot d} = \frac{1000 \cdot A}{2 \cdot F_N \cdot C}\left[\frac{mm^3}{Nm}\right]$$

A=Area mm^2 F_N=Load N C=Cycles

- Steady-state wear rates and friction coefficients were then graphed against the number of cycles for an accurate comparison of wear rate and friction coefficient across different voltage samples

Figure 2.



Conclusion

- The 5 and 10 V samples both have high wear rates between 10^{-4} and 10^{-5} $mm^3/(Nm)$ and high friction coefficients between 0.7 and 0.85
- The 20 and 30V samples have low wear rates between 10^{-7} and 10^{-8} $mm^3/(Nm)$ with low friction coefficients between 0.15 to 0.19
- The 40V sample exhibits a high wear rate of 5.01×10^{-5} $mm^3/(Nm)$ and the lowest friction coefficient of 0.08
- When comparing the material properties of 5V and 10V samples to the 20V and 30V samples, there is an indication that at low voltages the deposition process may be interrupted by unwanted chemical reactions resulting in a thin film with higher wear rates and friction coefficients, but chemical analysis is required to confirm this determination
- The 20V sample however exhibits material properties that make it the most ideal sample for industrial applications based on the data presented
- Since the 40V sample exhibited the lowest friction coefficient yet one of the highest wear rates it could be an indication that the sample failed during testing due to delamination of the thin film, but this requires further research

Acknowledgments and References

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Chowdhury, M. I., Sowa, M., Van Meter, K. E., Babuska, T. F., Grejtak, T., Kozen, A. C., Krick, B. A., & Strandwitz, N. C. (2021). Plasma-enhanced atomic layer deposition of titanium molybdenum nitride: Influence of RF bias and substrate structure. *Journal of Vacuum Science & Technology A*, *39*(5), 053408–1-053408–12. https://doi.org/10.1116/6.0001175

Faraz, T., Arts, K., Karwal, S., Knoops, H. C. M., & Kessels, W. M. M. (2019). Energetic Ions during plasma enhanced atomic layer deposition and their role in tailoring material properties. Plasma Sources Science and Technology, 28(2), [024002]. https://doi.org/10.1088/1361-6595/aaf2c7

Sowa, M. J., Ju, L., Kozen, A. C., Strandwitz, N. C., Zeng, G., Babuska, T. F., Hsain, Z., & Krick, B. A. (2018). Plasma-enhanced atomic layer deposition of titanium vanadium nitride. *Journal of Vacuum Science & Technology A*, *36*(6), 1–7. https://doi.org/10.1116/1.5037463