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Characterization of RF Voltage and Self-Bias under Power Variations in 13.56 MHz RF Sputtering System

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ABSTRACT

RF Sputtering has been widely used as a deposition system on thin films. This study examines the impact of input power on RF voltage and self-bias voltage in an RF Sputtering system operating at a frequency of 13.56 MHz. Power variations were carried out in the range of 50 to 150 Watts to observe the changes in voltage produced during the plasma formation process. The experimental results indicate a linear dependency between power and both voltages, with a coefficient of determination (R^2) above 0.9 and slope values of 2.86 and 0.96 for the RF voltage and self-bias voltage, respectively. The observed linear correlation indicates that adjusting power regulation can be utilized as an effective control parameter for both voltages, enabling the production of uniform and high-quality thin film deposition.

1. INTRODUCTION

One common method used for thin film synthesis is sputtering. This technique utilizes the principle of coating high-energy ions on a substrate placed in a vacuum. This method has several variations, including Direct Current (DC) Sputtering and Radio Frequency (RF) Sputtering (Nursanti A. M. Syafira A., 2022). RF sputtering can be used on conductors, semiconductors, and insulators due to its ability to produce more stable plasma. Several studies have reported that RF sputtering produces better results in thin film coatings compared to DC sputtering (Ardiyanti, 2021).

RF sputtering works by using radio frequency (RF) energy from a generator as the primary power source to generate plasma. RF sputtering is supported by several other components, including a vacuum pump to create a vacuum environment, a matching box to adjust the impedance between the generator and the plasma, a cooler to maintain the system temperature, and a reaction chamber where the sputtering process occurs. This series of tools will be used to generate plasma, which can then be used to transfer target atoms to the substrate surface in the thin-film deposition process (Bussell et al., 2022).

Several experiments have shown that the quality of thin films produced by the deposition process is significantly influenced by certain process parameters, including input power, RF voltage, and self-bias voltage (Tchenka et al., 2021). RF voltage is a high-frequency alternating current (AC) voltage used to generate and maintain plasma in an RF sputtering system. Meanwhile, self-bias voltage is a direct current (DC) voltage that forms naturally in the reaction chamber due to the charge in the plasma, which functions to accelerate ions towards the target for the sputtering process (Masheyeva, Dzhumagulova, Myrzaly, Schulze, & Donkó, 2021). Previous research indicates that power, RF voltage and Self-Bias voltage play a crucial role in determining the optical properties, morphological properties, degree of crystallinity, and number of defects in the resulting material (Mahjabin et al., 2022) (Astuti et al., 2022). Therefore, a study that provides a deeper understanding of the electrical behavior in RF sputtering systems is essential for advancing process control and system optimization.

This study will present results on the power changes in response to RF voltage and self-bias voltage. Analyzing the dynamics of these three parameters will reveal new ways to understand and manage input power more efficiently. The results can serve as a basis for improving the efficiency and performance of RF sputtering processes, both in further research and industrial applications.

2. METHOD

This research was conducted to analyze the relationship between input power and RF voltage, as well as self-bias voltage, in an RF Sputtering system. The experimental process utilized an RF generator with a frequency of 13.56 MHz, type Huttinger 600 PFG, and a matchbox PFM 1500 A. The input gas pressure was kept constant at 5×10^3 mbar using argon gas. Figure 1 illustrates the thin film deposition process, where the anode serves as the glass substrate, acting as the deposition medium, and the cathode is the target material, specifically copper (Cu).

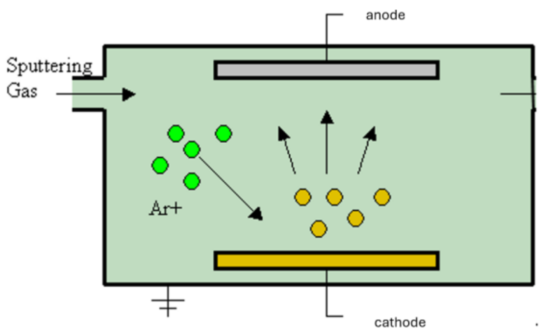


Figure 1. Illustration of the deposition process

The research was conducted by applying variations in power input to the RF generator, which served as the source of RF Sputtering energy, as shown in Figure 2. The applied input power variations ranged from 50 W to 150 W, with a 20 W increment. At each power value, measurements were taken of the RF voltage and self-bias voltage using a digital oscilloscope and voltmeter, which were connected directly to the matching box and target electrode. The data obtained were then analyzed to identify the trend of voltage changes against power, which was used to investigate the relationship between these parameters in the plasma generation process and the stability of thin film deposition.

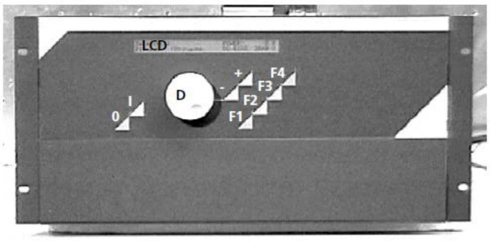


Figure 2. RF Generator

3. RESULTS AND DISCUSSION

Experiments on power variations from 50 to 150 Watts produced a graph as shown in Figure 3. The resulting RF voltage ranged from 400 to 600 volts, while the self-bias voltage was recorded between 210 and 340 volts. This difference is caused by the RF voltage being the main voltage that fluctuates along with changes in input power, while the self-bias voltage is a natural voltage that appears due to the presence of plasma, so that the output voltage does not reach the highest peak like the RF voltage (Vassallo et al., 2023)(Acuña et al., 2021).

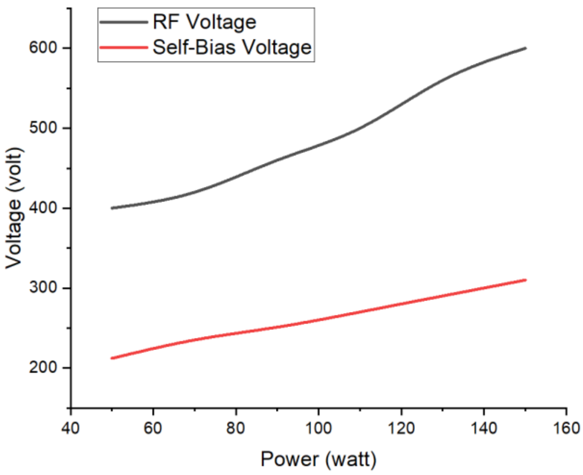
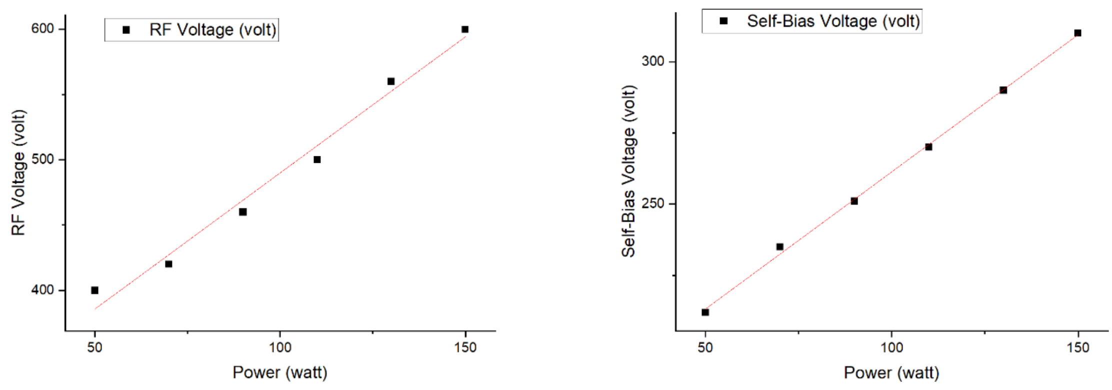


Figure 3. Plot illustrating the dependence of RF Voltage and Self-Bias Voltage on Power

The graph then analyzed using a linear regression, and a plot is formed in Figure 4. Both plots in Figure 4 show a positive linear relationship between the variables, as indicated by the red trend line, which closely follows the pattern of the data points. The results of the graph pattern indicate that the greater the input power, the higher the RF voltage and the resulting self-bias voltage. The increase in RF voltage is caused by the increase in input energy to the system, thereby strengthening the electric current at the electrodes. This will increase the rate of gas ionization in the reaction chamber. Then, naturally, the self-bias voltage due to gas ionization, namely plasma, is formed and increases with the increase in RF voltage (Orlac'H, Novikova, Giovangigli, Johnson, & Cabarrocas, 2019).



(a) (b)

Figure 4. (a) Variation of RF Voltage with Power (b) Variation of Self-Bias Voltage with Power

The fitting results of the linear regressions show a slope coefficient of RF Voltage and Self-Bias Voltage about 2.86 and 0.96 as in Table 1. The data show that a 1 Watt increase in power will increase the RF voltage by 2.86 Volts and the self-bias voltage by 0.96 Volts. The Pearson correlation coefficient (*r*) and the coefficient of determination (R^2) for both graphs are recorded as more than 0.9, indicating a very strong correlation between the input power and the two voltages.

Table 1. Linear Regression Analysis Results

Plot	RF Voltage	Self-Bias Voltage
Equality	y=a+b*x	y=a+b*x
Intercept	281.43 ± 14.79	165.05 ± 1.96
Slope	2.86	0.96
Pearson Correlation (*r*)	0.991	0.999
Coefficient of Determination (R^2)	0.982	0.998

In linear regression analysis, obtaining the coefficient of determination close to 1 indicates that the variance of dependent variable is highly influenced by the variance of independent variable. Conversely, the coefficient of determination close to 0 suggest that there is no relationship between the two variables. This analysis provides a quantitative basis for concluding that variations of input power are strongly related to dependent variables of RF Voltage and Self-Bias Voltage (Jones, Barnett, & Vagenas, 2025). These results indicate that in the sputtering system, the RF voltage and the self-bias voltage can be controlled effectively by adjusting the input power on the RF generator.

The data indicate a pronounced linear trend with increasing input power and the RF voltage, as well as the self-bias voltage, demonstrates significant control over key parameters in the RF sputtering process. The ability to regulate voltage by varying input power enables the optimization of plasma formation conditions, which is essential to ensure uniformity and functional integrity of the deposited films. These results underscore the importance of understanding the power and voltage dynamics in sputtering systems, laying the foundation for enhancing the efficiency and quality of material coating processes across various technological and industrial fields.

4. CONCLUSION

Research on the relationship between input power and RF voltage, as well as self-bias voltage, has been successfully carried out using a 13.56 MHz RF Sputtering device. The results show a strong linear relationship between the three parameters, where an increase in input power corresponds to an increase in both RF voltage and self-bias voltage. The results of the linear regression analysis on the data indicate that the Pearson correlation value (r) and the coefficient of determination (R^2) are both above 0.9 in both datasets. This finding confirms that both voltages can be controlled effectively through power regulation, indicating that they have the potential to be used as control parameters in the thin film deposition process to achieve optimal coating quality.

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