How etch-plasma researchers view plasma and how it can be applied to deposition

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Abstract: The dissociation of SiH_4 gas and its surface reaction during the plasma enhanced-chemical vapor deposition (PECVD) process are examined. Prior experimental studies on the deposition processes of a-Si:H and a-C:H are reviewed, drawing an analogy to dry etching. Furthermore, as latest application of numerical simulation to SiN-PECVD, Sony's deposition model and its use in analyzing film properties are presented.

1. Introduction

Advanced complementary metal-oxide-semiconductor (CMOS) technology has evolved, introducing more complex and vertical structures such as fin field-effect and gate-all-around transistors. Precise control of dry etching and deposition processes is essential to ensuring the high performance of the CMOS devices. Moreover, owing to the increasing demand for various devices requiring CMOS stacked with organic films, low temperature deposition processes, specifically plasma-enhanced chemical vapor deposition (PECVD) for amorphous (a)-Si, a-C, and SiN films.

2. PECVD process

PECVD is a deposition method that utilizes plasma to dissociate gases into reactive species. For example, SiH_4 is an essential gas for depositing Si and Si dielectric films. During the primary reaction, SiH_4 dissociates into SiH_x^+, SiH_x^-, SiH_x, Si, H, and H_2, depending on process parameters including radio frequency (RF) power, gas pressure, gas flow rate, wall-surface condition, and pump velocity [1]. These particles partially polymerized into clusters, which are subsequently transported to the wafer. Additionally, ions generated in the plasma are transported through the sheath region, with their energy and angular distribution function affected by the plasma potential. These processes are similar to gas phase reactions during plasma etching, where knowledge of etching is beneficial. The particles or clusters either adhere to or reflect off the pattern surface. When they adhere, surface migration occurs under surface conditions, eventually forming bonds influenced by ion irradiation. This cycle is repeated, leading to film deposition. The surface reaction is analogous to ion-assisted etching.

3. Experimental study on a-Si and a-C films

a-Si:H films exhibit excellent photoconductivity, making them ideal for solar cell applications. These films are formed using SiH_4 or SiH_4/H_2 plasm, with their properties controlled by RF power, residence time, and surface temperature. a-C:H films are used as mask materials in high aspect ratio contact etching due to their excellent resistance to plasma compared to conventional photoresists. These films are formed using CH_4 gas, with their plasma resistance influenced by the hydrogen content.

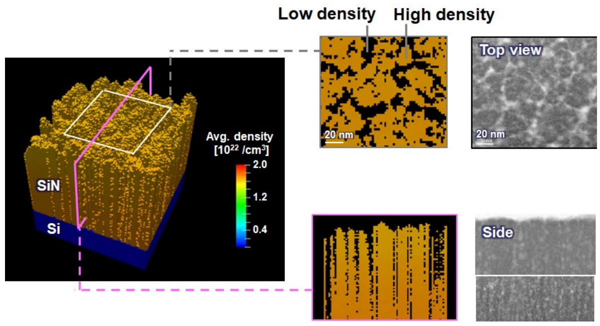

Fig. 1. Simulation of a columnar-deposited SiN film illustrating alternating low- and high-density regions on a Si substrate. TEM images for top and side views are shown.

4. Application of simulation to SiN-PECVD

The deposition model by Sony is presented as an example of numerical simulation applied to SiN-PECVD. This model draws an analogy with dry etching surface to predict coverage and film properties including density, permeability, and adhesion in large-scale (μm) pattern [2]. This model demonstrates that ion irradiation is essential for achieving desirable film properties in the PECVD process. Additionally, the model replicates columnar structure, consisting of alternating high- and low-density regions at low SiH_4 flow rates and a temperature of 120ºC. This is attributed to the deposition of large, heavy precursors transported to the surface, as shown in Fig. 1. The model reveals the achieving good coverage and film properties requires a short residence time during which smaller and lighter precursors are generated.

5. Conclusion

Deposition is a key process in advanced CMOS technology. PECVD for a-Si, a-C, and SiN films are presented herein, understanding its importance in deposition processes. Elucidating the mechanism of plasma chemistry during the process and quantitative control of coverage and film properties is essential.

References

[1] A. Matsuda, JJAP, **43**, 7909 (2004).
[2] N. Kuboi et al., JJAP, **62**, SI1006 (2023).