Atomic Layer Etching

Moderator: Eric A. Hudson, Lam Research Corporation

8:00am PS+TF-WeM1 Selective Plasma Etching of Thin Films in Two Heating Way, Ion Bombardment and Infrared Irradiation, M. Izawa, Hitachi High-Technologies Corp., Japan; Kazunori Shinoda, N. Miyoshi, H. Kobayashi, Hitachi, Japan; N. Yasui, M. Tanaka, Y. Sonoda, K. Kuwahara, Hitachi High-Technologies Corp., Japan; K. Ishikawa, M. Hori, Nagoya University, Japan

With shrinking device size and introduction of 3D FinFET transistor structure, cyclic Atomic Layer Etching (ALE) becomes one of the key technologies in thin film etch. To achieve extreme high selectivity against mask and etch-stop layers, atomic level etching as a method to meet these etching requirements and eliminate physical damage has been investigated. Further, isotropic ALE will be required for use in nanoscale patterning for formation of more complex 3D structures. In cyclic ALE technology, a modification layer is formed on a thin film layer by supplying etching species. After that, the modification layer is removed by heating. We investigated two types of ALE tools; one is an anisotropic ALE tool based on Microwave ECR plasma and the other is a isotropic ALE based on ICP type down-flow plasma.

Recently, we have reported results of isotropic ALE of Silicon Nitride (SiN) film. [1] High-throughput and high-selectivity ALE of SiN using IR irradiation and down-flow plasma was also demonstrated [2]. Modification layer, ammonium hexafluorosilicate (NHF6SiF6), was synthesized by fluorocarbon plasma and nitrogen supplied from SiN film. Because the modification layer is formed only on SiN film, SiN film can be removed with high selectivity at IR radiation heating step. This technology can be also applicable to ALE of TiN.

Anisotropic ALE was also investigated by using Microwave ECR plasma [3]. In this study, Ar ion irradiation was utilized instead of heating. To achieve high selectivity, the ion energy lower than sputtering threshold is required. Because microwave ECR plasma has low plasma potential and is not fluctuated by wafer RF power, lower ion energy is available. In addition, it is known that excessive dissociation of gases and by-products causes reverse reaction and degradation of selectivity. We therefore used high gas flow rate and pulsed plasma to reduce dissociation. This ALE technology has been applied to high selective etching of Si, HfOx, and SiN film.


8:40am PS+TF-WeM3 Concurrent Engineering of Atomic Layer Etch Patterning Processes Involving Oxide and Nitride Materials, Mingmei Wang, P. Chen, TEL Technology Center, America, LLC; P. Ventzek, Tokyo Electron America; A. Ranjan, TEL Technology Center, America, LLC

Atomic layer etching (ALE) of Si has been the focus of extensive research and development for over two decades. [1] However, the precision etch of dielectric materials (SiO2, Si3N4) in patterning schemes employing self-aligned contacts (SACs) and self-aligned multiple patterning (SAMP) at the 10nm technology node and beyond are where ALE has significant potential. In both SAC and SAMP schemes, an oxide layer must be etched selective to a thin nitride layer with a corner with a thickness and radius of curvature of less than 10 nm. Fortunately precision etch using cyclic deposition/etch schemes have been proven effective at preserving the thin nitride corner. Unlike atomic layer etching of silicon using chlorine, fluorocarbon chemistry etching of nitride and oxide is not self-limiting process. The thin fluorocarbon polymer layers that protect the nitride layer corner deep in a feature are difficult to measure with common in-line metrology. Both these facts make trial-and-error development of processes for cyclic etch of oxide materials selective to nitride underlayers challenging. We have used concurrent engineering approaches including both modeling and experiment to bypass these difficulties. The core of the approach is a new integrated chamber (HPEM)-feature scale MCCFPM (Monte Carlo Feature Profile Model) model [2] for oxide nitride etch experiments conducted on a dual frequency plasma source using a benchmark Ar/ClF/CF4 chemistry. The concurrent engineering approach comprises stages of development and prediction tests using both blanket wafer and patterned coupon data and finally process parameter optimization. By using this approach, we have minimized nitride corner loss and optimized nitride/oxide etch selectivity with a minimum of engineering resources. The presentation will survey both experimental and computational results representing a case study in SAC process development. Furthermore, insights into the relationship between chamber function and critical surface processes will be discussed.

development of isotropic ALD for various materials will be important for existing and future 3D devices such as a 3D NAND, Fin FET, and GAA FET. Recently, the authors developed an isotropic ALD for SiN using formation and desorption of an ammonium hexafluorosilicate-based modified layer [1]. High-throughput high-selectivity ALD of SiN using IR irradiation was also demonstrated by the authors [2]. In this work, isotropic ALD of TiN using formation and desorption of an ammonium salt-based modified layer is developed.

The experimental apparatus used in this study is composed of a reaction chamber and an x-ray photoelectron spectroscopy (XPS). TiN deposited by atomic layer deposition was used as the sample material. Several samples were exposed to radicals that were generated in fluorocarbon-based gas mixtures. The samples were then annealed by using circulating fluid. The surface of the samples was analyzed by XPS. Photoemission spectra obtained after radical exposure and after thermal annealing of the TiN samples are compared. The etching depth was evaluated by ellipsometry. A nitrogen 1s peak (402 eV), which has been assigned as ammonium salt, was observed after radical exposure. Titanium 2p peaks (462 and 467 eV), which originate from a Ti-F bond, were observed simultaneously. These results imply that the surface of the radical exposed TiN consists mainly of ammonium salt such as ammonium fluorotitanate. After the samples were annealed on the wafer stage heated at 210°C, the nitrogen 1s peak at 402 eV, which is assigned as ammonium salt, disappeared. A nitrogen 1s peak at 396 eV, which is attributed to TiN, appeared after the ammonium salt-related peak disappeared. This phenomenon implies that the film of ammonium salt decomposed and desorbed from the TiN surfaces at elevated temperatures.

The preliminary tests of cyclic etching are carried out by repeating radical exposure and thermal annealing. For one cycle of etching, the etching depth increases with increasing radical exposure time and saturates at 0.7 nm. For multiple cycle etching, the etching depth increases with an increasing number of repetitions of the cycle. Tuning of the etched amount per cycle (EPC) in the range from 0.3 to 0.7 nm was demonstrated by changing the composition of gas mixtures. From these results, it is concluded that the ALD of TiN was successfully demonstrated.


Author Index

Bold page numbers indicate presenter

— A —
Altieri, N.D.: PS+TF-WeM11, 2

— C —
Chan, P.: PS+TF-WeM3, 1
Chang, J.P.: PS+TF-WeM11, 2
Chen, E.L.: PS+TF-WeM11, 2
Collins, K.S.: PS+TF-WeM5, 1

— D —
Dorf, L.: PS+TF-WeM5, 1

— G —
George, S.M.: PS+TF-WeM12, 2; PS+TF-WeM13, 2

— H —
Hori, M.: PS+TF-WeM1, 1; PS+TF-WeM10, 1
Huard, C.M.: PS+TF-WeM4, 1

— I —
Ishikawa, K.: PS+TF-WeM1, 1; PS+TF-WeM10, 1
Izawa, M.: PS+TF-WeM1, 1; PS+TF-WeM10, 1

— J —
Johnon, N.J.: PS+TF-WeM13, 2

— K —
Kenney, J.A.: PS+TF-WeM5, 1
Kobayashi, H.: PS+TF-WeM1, 1; PS+TF-WeM10, 1
Kurihara, M.: PS+TF-WeM10, 1
Kushner, M.J.: PS+TF-WeM4, 1
Kuwahara, K.: PS+TF-WeM1, 1

— M —
Marquardt, A.E.: PS+TF-WeM12, 2
Minardi, L.: PS+TF-WeM11, 2
Miyoshi, N.: PS+TF-WeM1, 1; PS+TF-WeM10, 1

— P —
Paterson, A.: PS+TF-WeM4, 1
Ranjan, A.: PS+TF-WeM3, 1
Rauf, S.: PS+TF-WeM5, 1

— S —
Sakai, S.: PS+TF-WeM10, 1
Sharma, K.: PS+TF-WeM13, 2
Shinoda, K.: PS+TF-WeM1, 1; PS+TF-WeM10, 1
Sonoda, Y.: PS+TF-WeM1, 1
Sriraman, S.: PS+TF-WeM4, 1
Sun, H.: PS+TF-WeM12, 2; PS+TF-WeM13, 2

— T —
Tanaka, M.: PS+TF-WeM1, 1

— V —
Ventzek, P.: PS+TF-WeM3, 1

— W —
Wang, J.C.: PS+TF-WeM3, 1
Wang, M.: PS+TF-WeM3, 1

— Y —
Yasui, N.: PS+TF-WeM1, 1

— Z —
Zhang, Y.: PS+TF-WeM4, 1