OUKA
The University of Osaka
Institutional Knowledge Archive

| | |
|---|---|
| Title | Plasma etching mechanisms in the fabrication of high-aspect-ratio microstructures in stacked layers of different materials |
| Author(s) | 岩瀬, 拓 |
| Citation | 大阪大学, 2019, 博士論文 |
| Version Type | VoR |
| URL | https://doi.org/10.18910/73566 |
| rights | |
| Note | |

*The University of Osaka Institutional Knowledge Archive : OUKA*

https://ir.library.osaka-u.ac.jp/

The University of Osaka

様式３

# 論　文　内　容　の　要　旨

| 氏　名　（　岩瀬　拓　） | |
|---|---|
| 論文題名 | Plasma etching mechanisms in the fabrication of high-aspect-ratio microstructures in stacked layers of different materials<br>（異種積層膜高アスペクト比微細構造プラズマエッチング機構の解明） |

論文内容の要旨

This thesis addressed the potential of stacked layer etching for fabricating high-aspect-ratio (HAR) holes by using a plasma containing nitrogen, hydrogen bromide, and fluorocarbon gas aimed at the development of a process for fabricating 3D NAND flash devices.

First, while the conventional process consists of multiple steps for each stacked layer, $HBr/CH_3F$-based gas chemistry was investigated to achieve a single-step etching process that reduces processing time. Analysis of the dependence of the surface composition on the wafer temperature led to improvement of both the etching profile and rate at low temperatures. The etching mechanism was examined considering the composition of the surface reaction layer. XPS analysis revealed that the adsorption of N-H and Br was enhanced at low temperatures, resulting in a reduced carbon-based-polymer thickness and enhanced Si etching. Finally, a vertical profile was obtained as a result of the formation of a thin surface reaction layer at a low wafer temperature.

Next, the effects of wafer temperature on the etching rate and surface composition were investigated to clarify the surface reaction mechanism under $HBr/N_2/CH_3F$-based gas plasma. The etching rates of both poly-Si and $SiO_2$ were found to increase at a wafer temperature of 20℃ as compared with those at 60℃. Comparison of the gas combinations of $CH_3F/N_2$ and $HBr/N_2$ mixtures indicated that the temperature dependence of the $SiO_2$ etching rate on the HBr to $CH_3F$ gas mixing ratio is relevant to the sticking probability of fluorocarbon polymers. To determine the cause of the temperature dependence, the surface composition was evaluated by thermal desorption spectroscopy and laser-sputtered-neutral-mass-spectrometry analyses. $NH_4Br$ was identified in the deposition film at a wafer temperature of 20℃. The observed increase in the poly-Si etching rate at lower temperatures was possibly caused by increased amounts of N, H, and Br fixed to the surface by the formation of $NH_4Br$.

Then, the reaction mechanism during etching to fabricate deep holes in $SiN/SiO_2$ stacks using an $HBr/N_2/CH_3F$-based gas plasma was investigated. To etch SiN and $SiO_2$ films simultaneously, the $HBr/CH_3F$ gas mixture ratio was controlled to achieve etching selectivity closest to one. Holes were formed in the $SiN/SiO_2$ stacks by one-step etching at several temperatures. The surface composition of a cross section of the holes was analyzed by ToF-SIMS. With low-temperature etching, Br ions (considered to be derived from $NH_4Br$) were detected throughout the holes. The dependence of the hole depth on the aspect ratio was found to decrease as the substrate temperature decreased, and it became significantly weaker at a temperature of 20℃. This indicates that the formation of $NH_4Br$ supplies $SiN/SiO_2$ etchant to the bottom of the holes. This finding will make it possible to alleviate the decrease in the etching rate due to a high aspect ratio.

Next, the deposition profile of $NH_4Br$ in $N_2/HBr$ plasmas was evaluated as a function of the depth in a macro-cavity structure for the HAR etching process. The macro-cavities reproduce deep holes in 3D NAND structures. The profile was compared with the calculated results for fluorocarbon in $CF_2$ radicals. The decay in the $NH_4Br$ deposition was smaller than that of fluorocarbon at depths greater than 50 mm in the cavity. A 50-mm depth corresponds to an aspect ratio of 60. To clarify the results, two models were investigated: $NH_4Br$ forms in the gas phase and on a solid surface. The latter model clarified the results reasonably compared with the former model. These results indicate that $NH_4Br$ sufficiently reaches the bottom of deep holes in HAR structures. While the major trend in the development of HAR etch technologies is ion-energy enhancement, etchant supply is also an important issue. Its importance will grow along with the development of 3D NAND technology. This thesis should contribute to the investigation of HAR etching.

様式７

# 論文審査の結果の要旨及び担当者

| 氏　名　（　岩瀬　拓　） | |
|---|---|
| | （職）　氏　名 |
| 論文審査担当者 | 主 査　教授　浜口　智志<br>副 査　教授　田中　学<br>副 査　教授　中谷　亮一 |

## 論文審査の結果の要旨

本論文は、不揮発性半導体メモリデバイスの一種である３次元NANDフラッシュメモリの製造工程に必要な、反応性プラズマによる異種積層膜・高アスペクト比孔エッチングプロセスに関するものである。

著者は、最初に、HBr/N2/CH3Fガスを用いたプラズマのポリシリコン・シリコン酸化膜の異種積層膜に関する低温にエッチングプロセスに関する表面温度依存性に関する研究を行った。その結果、材料表面温度が低くなるに従い、物質表面上に反応層が形成されることにより、エッチング特性（エッチング形状やエッチング速度等）が向上することを確認した。

次に、著者は、HBr/N2/CH3Fガスを用いたプラズマによる異種積層膜・高アスペクト比孔エッチングプロセスに対する各種表面解析により、この表面反応機構を詳細に解析した。この結果、エッチング対象膜の表面温度が下がるにつれ、臭化アンモニウム（NH4Br）が膜表面に形成され、表面の化学的エッチングが促進されることを明らかにした。

更に、窒化シリコンと酸化シリコンの異種積層膜に対する、HBr/N2/CH3Fガスを用いたプラズマエッチング機構の解析を行った。この場合も、窒化シリコンと酸化シリコンのエッチング速度の選択比を１に近づけ、両材料を同様にエッチングすることが求められるが、物質温度を20°C程度まで下げると、表面に吸着するBrの量が増え、窒化シリコンと酸化シリコンの両材料に対するエッチング速度が上がり、また、高アスペクト比の深い孔の底の部分においても、孔の深さに大きく依存しないエッチング速度が得られることを確認した。

最後に、マクロキャビティ構造と流体モデル計算を用いて、NH4Brがプラズマ中の気相反応で形成されるのかプラズマの生成するラジカルの表面反応により、NH4Brが形成されるかを調べた。その結果、上記のプラズマエッチングプロセスにおいては、吸着ラジカルの表面反応によりNH4Brが表面に形成されることを明らかにした。

このように、本論文において、著者は、HBr/N2/CH3Fガスを用いたプラズマによる異種積層膜・高アスペクト比孔エッチングプロセスの表面反応を明らかにし、今後の３次元NANDフラッシュメモリ製造プロセスの最適化に大きく貢献した。よって本論文は博士論文として価値あるものと認めるとの結論に至った。