for fabricating complementary metal oxide semiconductor (CMOS) devices. Damage on Si substrates is caused during etching of the transistor side-wall and the contact through the drain region [1], and this can greatly affect performance. It is important to control the etching process quantitatively along with the mechanism of the SiN surface reaction.

We propose a surface reaction model for the SiN etching process by fluorocarbon ($C_F/Ar$) and hydrofluorocarbon ($C_F_{2}/O_{2}/Ar$) plasma based on the slab model of SiO$_2$ [2]. The surface layer is assumed to consist of two layers: a reactive layer divided by several thin slabs and a deposited C-F polymer layer on the reactive layer. We considered the chemical reactions in detail including reactivity of radicals (C, F, O, and H), dangling bonds ratio, outflux of N, and generation of by-products (HCN, C-N, CH, CF$_2$, SiF$_2$, and SiF$_4$) as ion assist, which depend on process parameters. We confirmed that absolute values and trends of SiN etch rate, polymer thickness, damage thickness, and selectivity of Si/SiO$_2$ and Si/Si along with gas flow rates of C$_F$ and CF$_2$ were consistent with experimental data of conventionally produced plasma.

Furthermore, to analyze 3D damage distribution affected by the etched profile, we developed a new 3D simulation technique using an extended voxel model (called “smart voxel”) also including the above slab model. By using gas fluxes with local pattern effect, the slab model is solved at each voxel. Then, the etch rate and thicknesses of polymer and damage are derived. Smart voxel has details of the history of the etching situation and gives them around existing voxels when etch front is evolved in the next calculation time step. By repeating these procedures, 3D damage distribution considering a time-dependent etched profile can be realized. In addition to this new concept, modeling of gas transportation in the pattern treated as fluid is adopted without interaction between voxels, which is different from a Monte Carlo (MC) method. Hereby, 3D damage for multi-layer (Si/SiO$_2$/Si) can be predicted much faster and more accurately than the conventional MC model and can be utilized to design the etch process.

In summary, we will show a 3D etched profile and damage distribution for SiN side-wall etching and discuss how to control etching parameters to achieve low damage.

Acknowledgements: We thank Prof. S. Hamaguchi for stimulating discussion.

of magnetic tunnel junctions (MTJ) and CMOS devices. One of the issues concerning MRAM fabrication is the development of a nano-scale anisotropic etch technology for MTJ. In this work, an MTJ is considered as the memory component of an MRAM device and high integration of MTJs is required for commercially competitive MRAM chips. One approach to MTJ etching is to use CO\textsubscript{2}NH\textsubscript{2} plasma with Ta hard masks. With this process, vertical etching profiles with a taper angle of 80\textdegree\ have been achieved with high etching selectivity of magnetic materials over Ta [1].

In previous research [2], etching yields of Ta and N\textsubscript{i} films were evaluated with a mass-selected ion beam system with incident ions of Ar\textsuperscript{+}, N\textsuperscript{2+}, O\textsuperscript{2+}, and CO\textsuperscript{2+}. The film thickness was determined from X-ray reflectivity data of incident CO\textsuperscript{2+}. It is found that the Ta film surface was oxidized while the Ni film surface was not oxidized by the same CO\textsuperscript{+} ion irradiation. Therefore, it was concluded that the oxidized layer of Ta, which was formed by CO\textsuperscript{+} irradiation, suppressed the Ta etching yield.

In this study, Ta etching yields by CO\textsuperscript{+} ions were compared with corresponding theoretical values of physical sputtering of Ta to understand why the Ta etching yield by CO\textsuperscript{+} ion irradiation was typically very low. The experimentally obtained sputtering yield is typically about 1 % of the theoretical yield of physical sputtering by non-reactive incident species of the same mass. Our XPS analysis of Ta after CO\textsuperscript{+} ion irradiation indicates that the Ta film is highly oxidized (i.e., to the equivalent degree of Ta\textsubscript{2}O\textsubscript{5}) by CO\textsuperscript{+} ion irradiation while Ar\textsuperscript{+} ion irradiation of a Ta oxide film reduces its oxidation degree. Therefore, the low Ta etching yield by CO\textsuperscript{+} ion irradiation is caused by the formation of a larger amount of oxygen supply by incident CO\textsuperscript{+} ions with less oxygen sputtering. The dependence of the Ta sputtering yield by CO\textsuperscript{+} ions on the ion incident angle will be also discussed in terms of the angle dependence of the surface oxidation level.

In this study, sputtering yields and surface reaction characteristics of ITO and ZnO by energetic chemically reactive CH\textsubscript{x} ions (CH\textsuperscript{+} and CH\textsubscript{3}\textsuperscript{+}) as well as inert-gas ions (Ar\textsuperscript{+}, Ne\textsuperscript{+} and He\textsuperscript{+}) were examined with the use of a mass-selected ion beam system. It has been found that, for physical sputtering, sputtering yields of ZnO are much higher than those of ITO. For ZnO, etching by CH\textsubscript{3}\textsuperscript{+} proceeds faster than Ar\textsuperscript{+} physical sputtering, which indicates that the etching yield is enhanced by chemical reactions of CH\textsubscript{3} with ZnO. The chemical effect is more pronounced at a lower incident energy. With a fewer hydrogen atoms in the incident ion (i.e., in the case of CH\textsuperscript{+} ion incidence), however, carbon deposition tends to take place on the ZnO surface. Similar beam-surface interactions of ITO with CH\textsuperscript{+} ions as well as inert-gas ions were also examined and compared with those of ZnO. Mechanisms of chemical reactions of CH\textsubscript{+} ions with ZnO and ITO will be discussed in the presentation.

11:00am PS-TuM10 Study of Hydrofluorocarbon Precursor Parameters for Plasma Etching of ULK Dielectric, Chen Li, G.S. Oehrlein, University of Maryland, College Park, R. Gupta, V. Pallem, Air Liquide

Plasma etching of ultra-low k (ULK) dielectrics requires gas precursors that enable very high etching selectivity of ULK over the mask and underlayer. With the increasing demand for high-resolution optoelectronic devices and micro-pattern formation of transparent conducting oxides (TCOs), especially that of tin-doped indium oxide (ITO), it has been required more frequently than before in the development of such devices. Since ITO contains indium, which is one of minor metals whose global production is typically small and are generally traded at high prices, less expensive alternative materials for TCOs are highly sought after. Zinc oxide (ZnO) is a possible candidate for such TCOs alternative to ITO.

Micro-pattern formation of thin film materials may be achieved by reactive ion etching (RIE), which uses chemically reactive plasmas that typically allow high selectivity of etching of specific materials over others and high controllability of micro/nano-scale structure formation. RIE has been widely used in fabrication processes of semiconductors. For high-resolution optoelectronic devices, there has been a considerable demand for RIE processes of ZnO with CH\textsubscript{4} based plasmas, which is a non-corrosive gas and expected to yield high etching rates for ZnO. The RIE process of ZnO with CH\textsubscript{4} based plasmas, however, has also various problems such as carbon deposition during the etching processes. To further develop RIE technologies of ZnO by CH\textsubscript{4} based plasmas, a better understanding of elemental processes of plasma-surface interactions of CH\textsubscript{4} based plasmas with ZnO.

In this study, sputtering yields and surface reaction characteristics of ITO and ZnO by energetic chemically reactive CH\textsubscript{4} ions (CH\textsubscript{2} and CH\textsubscript{3}) as well as inert-gas ions (Ar\textsuperscript{+}, Ne\textsuperscript{+} and He\textsuperscript{+}) were examined with the use of a mass-selected ion beam system. It has been found that, for physical sputtering, sputtering yields of ZnO are much higher than those of ITO. For ZnO, etching by CH\textsubscript{3}\textsuperscript{+} proceeds faster than Ar\textsuperscript{+} physical sputtering, which indicates that the etching yield is enhanced by chemical reactions of CH\textsubscript{3} with ZnO. The chemical effect is more pronounced at a lower incident energy. With a fewer hydrogen atoms in the incident ion (i.e., in the case of CH\textsuperscript{+} ion incidence), however, carbon deposition tends to take place on the ZnO surface. Similar beam-surface interactions of ITO with CH\textsuperscript{+} ions as well as inert-gas ions were also examined and compared with those of ZnO. Mechanisms of chemical reactions of CH\textsubscript{+} ions with ZnO and ITO will be discussed in the presentation.

11:40am PS-TuM12 Selective Etch and Functionalization of Coblock Polymers, Evgeniya Lock, S.G. Walton, Naval Research Laboratory Coblock polymers have been applied as nanotemplates for production of nanocomposites and biomolecules nanoarrays due to their ability to spontaneously form dense periodic spherical, cylindrical, and lamellar domains. The nanostructure is typically produced after chemical etch or electron beam-based etch in fluorine containing gas environment. However, systematic studies of the effects of plasma etching of coblock polymers in different gas environments are limited. Furthermore, selective chemical functionalization of one of the blocks, while the other one is etched will enable more robust biomolecules/nanoparticles integration and is of critical importance. In order to achieve nanoscale high resolution etch, a precise control of the plasma/surface interactions is needed.

We have already shown that electron beam-generated plasmas can introduce large range of chemical functionalities in a polymer layer by layer etch with low etch rates [1, 2]. In this work, we will show the ability of these plasmas to achieve nanoscale etch of PS-b-PDMA in different gas environments. In addition, the effect of ion energy (1 to 100 eV) on features definition and etch depth will be evaluated. This work was supported by the Naval Research Laboratory Base Program.

References:

12:00pm PS-TuM13 Dry Etch Process Development for PMMA Removal Selectively to PS for sub-10nm Patterning, Aurelien Sarrazin, P. Pimenta-Barros, N. Poxsemme, S. Barnola, A. Gharbi, R. Tiron, CEA, LETI, MINATEC in- fonus, France, C. Cardinaud, CNRS-IMN, France

For sub-10nm patterns, the semiconductor industry is facing the limits of conventional lithography to achieve narrow dimensions. Presently, extreme ultraviolet lithography (EUV) is under development but this technology is not mature. On another hand, multiple patterning, which benefits from a tremendous technological knowledge in conventional lithography, deposition and etching processes, could be an alternative technique but its major drawback is the complexity of integration generating wafer cost increases. These issues encourage the development of limitless resolution and low cost techniques such as Directed Self Assembly (DSA). Indeed, DSA is one of the promising solutions to reach sub-10nm patterns with a high selectivity.
One challenge of DSA integration is the PMMA removal selectively to PS. Using dry etch for this step is mandatory for line application since wet cleaning is prohibited with the risk of pattern collapse. In this work we propose to study PMMA block plasma etching with a high selectivity over PS using oxidizing and reducing chemistries. All experiments have been carried out in a CCP etching chamber.

First a screening of these chemistries has been performed on PS and PMMA films showing that CO based chemistry is the most interesting process providing infinite selectivity to PS. To achieve this result, studies have been performed with different gases to evaluate the evolution of etch rate with the process time. Complementary analyses using X-ray Photoelectron Spectroscopy (XPS), Fourier Transform Infrared Spectroscopy (FTIR) will also be presented for understanding volume and surface etch mechanisms. These blanket results will be tested on lamellar block copolymers. The compatibility of these chemistries will be validated in term of etch rate, CD control using Scanning Electron Microscopy (SEM) and roughness using Atomic Force Microscopy (AFM). We will demonstrate that a trade-off is needed between high selectivity to PS and high etch rate to remove the PMMA.
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