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Chamber Walls Coatings During Patterning of Dielectric Damascene Structures With a Metal Hard Mask: Consequences on Cleaning Strategies

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The impact of a metal hard mask on the coating formed on the chamber walls during the dielectric etching process and reactor dry cleaning procedure has been investigated. We have used a technique based on X-ray photoelectron spectroscopy (XPS) to monitor the chemical composition of the layer deposited on an electrically floating sample placed on the top of a patterned wafer exposed to typical plasma processing conditions (coatings deposited on the floating sample are representative of those deposited on the chamber walls). We have patterned porous SiOCH damascene structures using a TiN hard mask. After hard mask opening and ashing in a silicon etcher using Cl₂ based plasmas, we have shown that the chamber walls are coated by a thin and mixed SiO-TiO deposit. During low-k etching in an oxide etcher with fluorocarbon based chemistries, the chamber walls are coated by a fluorocarbon layer containing a significant concentration of Ti. We have developed a two step cleaning procedure to remove the coating formed on the chamber walls of the silicon and oxide etchers.

Introduction

The coatings formed on the chamber walls originating from etch by-products deposition or from the feed gas stock condensation may generate difficulties in controlling plasma processes [1]. The empirical approach used in the industry has shown that the most effective way to maintain stable plasma processing conditions together with a large mean time between chamber wet cleans (MTBC) is to clean up the reactor walls after each wafer being etched. It is thus important to analyze the chemical nature of the layers coated on the reactor walls after an etching process in order to develop efficient cleaning processes of the plasma chamber [2]. We have developed a technique based on X-ray photoelectron spectroscopy (XPS) to monitor the chemical composition of the coatings deposited on a floating sample which are representative of those deposited on the chamber walls [3].

The recent introduction of metal hard masks such as TiN or TaN in dielectric stacks has a strong impact on the processes stability and reproducibility. Indeed, with these metal masks, a drift of the etching processes (etch rates, uniformity) and lower MTBC are observed when using the typical clean procedure (O₂ plasma). This study focuses on the determination of the chemical nature of the coatings formed on the chamber walls during the patterning of dielectric damascene

structures using a TiN metal hard mask and its effect on the dry cleaning procedure.

Experimental

The experimental work has been performed on a 200 mm etch platform. The etch experiments have been carried out in a silicon etcher and an oxide etcher. An XPS chamber is connected to the etch platform via a pumped transfer chamber allowing to perform quasi in situ surface diagnostics. The sample used to simulate the reactor walls is composed of a 15 nm thick Al₂O₃ layer deposited by Atomic Layer Deposition (ALD) on a 600 μm thick silicon wafer, which is then cut in square pieces of about 6 cm². The sample is then clamped onto a 200 mm diameter wafer using 4 cylindrical rolls made of adhesive KaptonTM placed under the sample leaving it in a slightly raised position above the wafer. Thus, the Al₂O₃ surface is separated from the wafer by an air gap and the thickness of the air gap is chosen to prevent the dc-biasing of the Al₂O₃ sample [3]. In such a configuration, we can form the same coatings on the sample and on the chamber walls and analyze their chemical composition by transferring the wafer carrying the electrically floating sample into the XPS analysis chamber. The Al₂O₃ sample is clamped on wafers used for the patterning of single damascene structures. The stack used is composed of a 300 nm thick SiOCH layer, a 40 nm thick SiO₂ capping layer and a 45 nm

thick TiN hard mask layer. These 200 mm wafers are then patterned with optical or e-beam lithography. The etch process steps to pattern such structures using the metal hard mask is as follows: (1) TiN opening in the silicon etcher using a Cl₂ based chemistry, (2) photoresist ashing in the silicon etcher and (3) dielectric etching in the oxide etcher using a fluorocarbon based chemistry.

Results and discussion

After TiN opening in the silicon etcher, XPS analyses indicate that the coating formed on the chamber walls is mainly a chlorine-rich SiO-TiO composite layer (figure 1). The material deposited on the chamber walls comes from the deposition of silicon and titanium etch by-products. After ashing of the remaining photoresist, XPS analyses show that the chlorine-rich composite SiO/TiO coating formed on the chamber walls after the TiN etching process is oxidized during the ashing step (figure 1). We have developed a cleaning strategy in two steps to clean up the chamber walls after the etching process (TiN etching + ashing): (1) a Cl₂ based plasma without bias (Ti removal) followed by (2) a SF₆/O₂ plasma (SiOCl species removal).

During the dielectric etching process, the XPS results show that the chamber walls are coated by a fluorocarbon layer containing a low concentration of Ti (figure 2). The introduction of a TiN metal hard mask leads therefore to the incorporation of Ti into the fluorocarbon coating formed on the chamber walls, which can explain the etch process drift and lower MTBC. We have developed a clean procedure strategy in two steps to clean up the chamber walls after the dielectric etch process: (1) SF₆ plasma removes the fluorocarbon layer and Ti based products and is followed by (2) an O₂ flash plasma (for a short time) to clean up the carbon left on the chamber walls.

Conclusions

In this work, we have investigated the coatings formed on the chamber walls during the patterning of dielectric damascene structures using a TiN metal hard mask. We have shown that Ti based etch by-product get deposited on the chamber walls. After TiN opening and ashing, the silicon etcher chamber walls are coated with a thin composite SiO/TiO layer and after dielectric etching, the oxide etcher chamber walls are coated by a fluorocarbon layer with a significant amount of Ti. We have developed specific cleaning procedures for both chambers to remove those titanium containing coatings. The cleaning

procedure after each wafer being etched should minimize the etch process drift and probably increase the mean time between wet clean.

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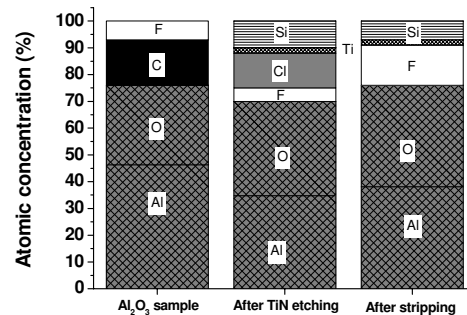


Figure 1: Chemical composition of the coating formed on the chamber walls (XPS analyses of the Al₂O₃ sample) during the TiN opening etch process: a) before plasma exposure, b) after TiN etching with a Cl₂ based plasma and c) after resist ashing with an O₂ plasma.

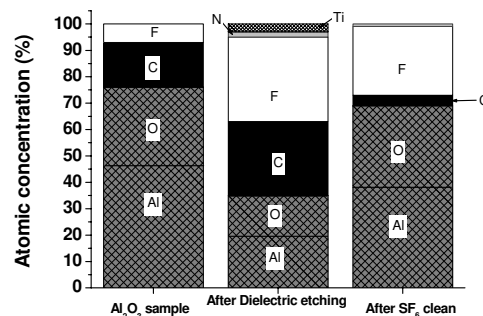


Figure 2: Chemical composition of the coating formed on the chamber walls (XPS analyses of the Al₂O₃ sample): a) before plasma exposure, b) after dielectric etching in a fluorocarbon based plasma and c) after cleaning with a SF₆ based plasma