Development of Yttrium Oxide Film Deposition using Microwave Excited Atmospheric Pressure Plasma Jet with a Mist Addition

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Abstract: A method for depositing Y_2O_3 films using a MW-APPJ with a precursor solution mist addition was studied. Y_2O_3 formation in the deposited film was confirmed by XPS, SEM, and film profile analysis when the deposition rate of Y_2O_3 films was 0.8 μm/min using the MW-APPJ with CVD mist addition. The study highlights the potential of MW-APPJ to be able to use as a plasma enhanced chemical vapor deposition system with high-deposition rate to from Y_2O_3 film at low substrate temperature condition.

Keywords: Microwave-Atmospheric Pressure Plasma Jet, Thin-film, Y_2O_3, Yttrium oxide.

1. Introduction

As integrated circuits continue to miniaturize, several challenges must be addressed, including the corrosive gas plasma for high-speed and vertical etching process of wafers. The high-density corrosive plasma source can potentially damage components such as chamber wall, monitor windows, and holders during the etching process [1].

To address corrosion issues, silicon-based ceramics have been widely utilized as plasma-facing materials due to their high resistance and chemical stability. These materials are often used as a protective shield to protect ceramic components inside etchers or chemical vapor deposition reactor chambers from corrosion caused by fluorocarbon corrosive gases such as CF_4, CHF_3, C_4F_6, and C_2F_6 [2].

However, it is also possible for contaminated particles to be generated from these plasma resistant ceramics through particle detachment [3]. The interaction of these materials with plasma can result in erosion and the production of contaminant particles on the wafer, leading to significant issues such as short current in integrated circuits [4].

To address the new challenges, yttrium oxide (Y_2O_3) is used as a plasma-resistant material in chamber environments. This material exhibits thermodynamic stability and a high melting point compared to traditional ceramics like alumina, making it a promising choice for use plasma processing equipment [5], [6]. It is necessary to utilize a Y_2O_3 film with a thick and high density in order to meet the requirements of the complex structure inside the chamber for this application.

Atmospheric pressure plasma jet (APPJ) has attracted significantly as to be able to use a film deposition tool because films can be deposited at low substrate temperature without requiring a vacuum chamber [7]. In plasma enhanced chemical vapor deposition (PECVD), the assistance of the plasma reactive media for the dissociation of the precursor allows the process to proceed at much lower temperatures compared to conventional CVD.

In this study, we have developed a high-speed Y_2O_3 film formation method using a Microwave excited Atmospheric Pressure Plasma Jet (MW-APPJ), introducing a precursor into the reaction region as gaseous state. Deposited films were investigated to clarify film characteristics, varying MW-APPJ working gas flow rate.

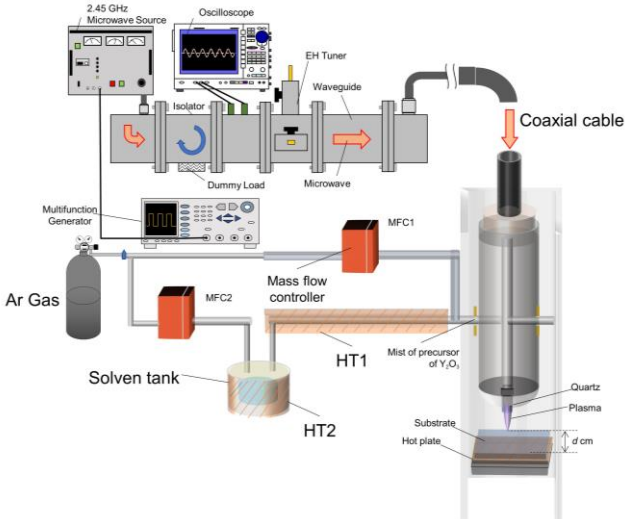

Figure 1. Experimental setup of MW-APPJ with a mist system.

2. Experimental procedure

The experimental setup of MW-APPJ with a mist system is shown in Fig. 1. Microwave of 2.45 GHz was modulated using a 10 kHz square wave. The net power was 70 W with an on-time duty factor of 30%. The APPJ reactor consisted of a cylindrical container with a gas inlet port and a quartz nozzle placed at the lower end of the central axis. Argon was used as a working gas at a flow rate between 278 to 338 sccm, and an organic Y_2O_3 precursor solution was introduced into the reactor via a solvent tank at a flow rate between 133 to 223 sccm. The solvent tank and stainless-steel tube were wrapped with heaters (HT1 and HT2) set at temperatures of 100°C and 130°C, respectively. A hot plate machine was placed under the quartz nozzle at a temperature of 100° C.

An organic Y_2O_3 precursor solution was prepared individually in the solvent tank to investigate vapor introduction to the carrier gas. $Y(CH_3COO)_3 \cdot 4H_2O$ was used as a base material for Y_2O_3 precursor solution. The film thickness was measured using a step-profiler (Surfcoder ET200). The chemical composition of the deposited film is analyzed by X-ray photoelectron spectroscopy (XPS). The deposited film surface and its cross section was observed by Scanning Electron Microscopy (SEM).

3. Results and Discussions

Quartz glass substrate (25×25 mm^2) was located under the quartz nozzle. The distance between the quartz nozzle and the substrate was 5.5 mm. Deposition time was fixed at 20 min.

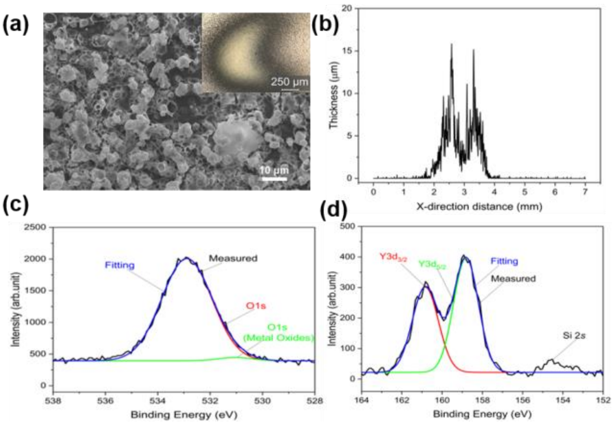

Figure 2. Y_2O_3 film of (a) Inset shows microscopy image, (a) Top-view SEM image, (b) Thickness profile on quartz substrate, (c) XP spectra of O1s, (d) $Y3d_{3/2}$ and $Y3d_{5/2}$.

The microscope image was shown in Fig. 2 (a). The clear white colored film was deposited on the substrate. The films were observed to have a crescent shape and were observed to be shifted towards one side. The deposited film width was approximately 2 mm in Fig. 2 (b). In Figure 2 (c) illustrates the O1s spectrum, which can be deconvoluted into two oxygen peaks with binding energies of approximately 530.7 eV and 532.9 eV. These peaks are attributed to O-H surface bonds and to oxygen trapping within the material during oxide growth. Figure 2 (d) displays the Y $3d_{3/2}$ and Y $3d_{5/2}$ spectra, respectively. The Y $3d_{5/2}$ spectrum reveals that the main component consists of yttrium hydroxide species, indicating that the precursor solution of Y_2O_3 is decomposed and deposited components are partially present in the deposited film.

In addition, the Si 2s spectra in Fig. 2 (d) indicate the presence of a quartz substrate. As previously confirmed in Fig. 2 (b), the deposited film width was approximately 2 mm. Due to the limited area of the deposited films, the Si 2s spectra were observed in close proximity to the Y $3d_{3/2}$ and Y $3d_{5/2}$ spectra. Figure 2 (a) presents the surface SEM image of the film after deposition. As previously confirmed through XPS analysis in Fig. 2, the observed area shows that all the quartz substrate area were fully covered with deposited Y_2O_3. The obtained film appears as a mostly continuous, reasonably smooth layer with formed on top.

Even tough large-sized cracks were observed on the deposited film. This study demonstrates that Y_2O_3 films deposited onto a quartz substrate at a rate of 0.8 μm/min using the MW-APPJ with CVD mist addition. XPS measurements reveal the formation of Y_2O_3 film in the deposited film. The influence of operating parameters on the deposited film characteristics, and deposition rate and will be discussed in the conference.

4. Conclusions

This study aimed to develop a Y_2O_3 film formation method using a Microwave excited Atmospheric Pressure Plasma Jet (MW-APPJ) with a precursor solution mist system and investigate deposited film characteristics. Results showed that Y_2O_3 films can be deposited onto a quartz glass substrate at a rate of 0.8 μm/min using the MW-APPJ with CVD system. The analysis of the deposited film via XPS revealed the formation of Y_2O_3 in the film. These findings indicate that the developed MW-APPJ system could be applied as a local method for Y_2O_3 film deposition.

Additionally, this study highlights the potential for Y_2O_3 as a promising plasma-resistant material due to its thermodynamic stability and high melting point compared to conventional ceramics like alumina. In future research, it will be explored the suitability of this method for industrial applications, as well as investigate the properties and performance of the deposited films under different conditions.

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