Studies on Sn Thin Film Decomposition Using VHF Hydrogen Plasmas

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https://hdl.handle.net/2324/4475167

出版情報：Kyushu University, 2020, 博士（工学）, 課程博士
バージョン：
権利関係：

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Name
論文名　: Studies on Sn Thin Film Decomposition Using VHF Hydrogen Plasmas
Title　（高周波水素プラズマを用いたスズ薄膜の分解に関する研究）
区　分　:　甲
Category

論 文 内 容 の 要 旨

Thesis Summary

Extreme ultraviolet (EUV) light with a wavelength of 13.5 nm has been expected as the cutting-edge light source for semiconductor lithography. Although, EUV light is an ideal lithography for more miniaturized and high-integrated semiconductor manufacturing, there are still many issues need to be settled before widely applied in production. One of the urgent issues of EUV lithography is the deterioration of the reflectivity of the condenser mirror. The EUV lithography utilizes EUV photons from high density and high temperature tin plasmas which are generated by the ionization of tin droplets by the irradiation of CO_2 laser beam. During this process, Sn debris adhere on the surface of condenser mirrors significantly decreasing their reflectivity. Because the reflectivity deterioration caused by deposition of Sn debris is reversible, efficient cleanings are supposed to be possible. The most common measure to remove Sn adhesion from condenser mirrors is introducing hydrogen plasma to react with Sn generating volatile gas SnH_4. In this process, hydrogen atoms and hydrogen ions can both react with Sn atoms. Therefore, to efficiently decompose the Sn debris the basic characteristics of hydrogen plasmas and ion energy dependence are needed to be investigated.

In this study, we proposed the possibility of removing Sn debris using VHF (very high frequency: 30-300 MHz) hydrogen plasma. This is because in the VHF frequency band, higher density plasma can be generated more efficiently than when using a lower frequency such as RF (radio frequency: 13.56 MHz). First, we generated VHF hydrogen plasma in a compact chamber and investigated the dependence of Sn removal on gas pressure, gas flow rate, and sample temperature. In addition, an intermediate layer was added to the chamber to generate hollow cathode plasma to investigate the effect of hollow cathode discharge on Sn debris removal. As a result, in VHF hydrogen plasma, an etching rate of 4.8 nm/min was achieved as a maximum value. The following conclusions were drawn from these basic data. (i) The higher the electron density, the more reactive ion etching can be promoted and the etching rate can be increased. (ii) If the gas pressure is high and SnH_4 is not sufficiently separated from the Sn sample surface, reattachment may occur. (iii) It is effective to increase the gas flow rate and lower the Sn sample temperature to prevent reattachment. Hollow cathode discharge was combined with VHF discharge to increase electron density. As a result, the electron density has more than doubled, and a maximum etching rate of 8.3 nm/min

has been obtained. However, the Sn yield value for assessing the efficiency of reactive ion etching was reduced to about 60% for VHF discharge alone. From the opposite point of view, it is suggested that the etching rate of Sn removal by VHF plasma when combined with the hollow cathode effect can be further improved.

So far, in the tin decomposition experiments using reactive ion etching, the dependence on hydrogen ion energy has not been clarified. Therefore, a negative DC bias voltage range of -50 to 7.5 V was applied to the Sn sample to investigate the dependence of Sn removal on hydrogen ion energy. A DC bias structure has been added to allow the sample to float from the ground. In addition, the middle layer divided the chamber into upper and lower spaces. VHF hydrogen plasma was generated in the upper space, and the plasma diffused into the lower space through an aperture in the middle layer. The sample was exposed to diffuse plasma in the lower space. The etched thickness of the Sn film was quantitatively analyzed using X-ray fluorescence. As a result, it was found that the threshold ion energy of Sn etching was less than 10 eV, and the peak of Sn yield appeared when the ion energy was about 10 to 14 eV. This means that it is efficient to use the floating voltage of the hydrogen plasma to remove the Sn film attached to the electrically insulating EUV mirror. This result is very beneficial for the actual decomposition of the Sn debris film from the EUV mirror.