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Plasma Etching of Copper Films Using Ultra Violet Radiation

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1. Introduction

Recently, copper(Cu) is one of the most attractive materials for the interconnection lines of next generation LSIs because it has lower electrical resistivity and stronger resistance to electromigration.[1] However, due to the low volatility of copper halides (CuClx), its plasma etching at low temperature is very difficult. It has been known that process temperature more than 200℃ is required to etch copper film [2]-[4]. As a result, conventional photoresist can not be used as an etch mask.

On the other hand, some of studies reported that copper can be rapidly etched in a chlorine atmosphere with ultra violet (UV) lasers even at room temperature [5]. However, it is considered that UV laser has limitation on large area etching.

Inductively coupled plasma (ICP) has properties of high plasma density in low pressure, good uniformity in large area, low plasma density[6].Therefore, ICP is a suitable plasma source for semiconductor fabrication, mainly for plasma etching.

In this work, we report low temperature etching of copper using ICP etcher with a UV lamp and discuss the effects of UV radiation.

2. Experiments

A schematic of an inductively coupled plasma (ICP) etcher with a focused UV lamp is shown in Fig.1. The UV light irradiated the sample on the substrate through the quartz window. Spectra of UV lamp(200W) have some peaks in the wavelength region of 350 to 400nm. A RF wave of 13.56MHz is excited by 1-turn antenna. The substrate temperature was measured using the thermocouple attached directly to a Si wafer. 500nm-thick Cu films were deposited by DC magnetron sputtering on Si wafer having about 50nm TiN/100nm thermal SiO_2/Si substrate structure. A 20nm-thick SiO_2 was deposited by RF sputtering as the hard mask or photoresist were used as the etch mask. The etch rate was calculated from the time taken to etch fixed-thickness Cu films completely. A mixture of Cl_2/N_2 or Cl_2/Ar was used as the etching gas.

3. Results and Discussion

Fig. 2 shows the thickness of CuCl formed on copper during plasma etching with and without UV irradiation. The thickness of CuCl without UV irradiation increases with process time. However, the thickness of CuCl decreases with process time under UV irradiation; this reveals the etching of copper film. Thus, we believe that the irradiation of UV plays a key role in etching the copper film.

To understand the effects of UV irradiation on etching mechanism, the dependence of the etch rate on process temperature is investigated. Fig. 3(a) shows that etch rate increases with process temperature. Fig. 3(b) shows the Arrhenius plot derived from Fig. 3(a). The activation energy of 0.12eV is an order of magnitude smaller than the heat of sublimation of 1.6eV which is required to sublime Cu_3Cl_3 from CuCl [7]. Thus, we infer that UV irradiation enhances CuCl desorption by the selective heating of CuCl and non-thermal photodesorption[6]; this is consistent with the previous results on the etching of Cu films with UV lasers [6]. It should be noted that etch rate is high considerably even at low temperature by UV irradiation.

Fig. 4 shows the dependence of etch rate on UV intensity at a process temperature of 60℃. Etch rate monotonously increases with UV intensity, which is attributed to the enhanced volatility of CuCl.

Fig. 5(a) and 5(b) shows the SEM photographs of the sample after etching without and with UV irradiation, respectively. Without UV irradiation, we can see the formation of CuCl reaction product as expected in Fig. 2. Under UV irradiation, however, we could not observe any Cu or Cl peaks from our AES measurement on the surface of a barrier metal.

4. Conclusions

An ICP etching of copper under UV irradiation is suggested using Cl_2/N_2 or Cl_2/Ar gas mixture. UV light irradiation decreases the activation energy for Cu etching from 1.6eV to 0.12eV due to the enhancement of the CuCl desorption, which makes it possible to etch Cu films at a low temperature of 60℃. Etch rate monotonously increases with UV intensity.

We will present more etch characteristics at SSDM'97.

References

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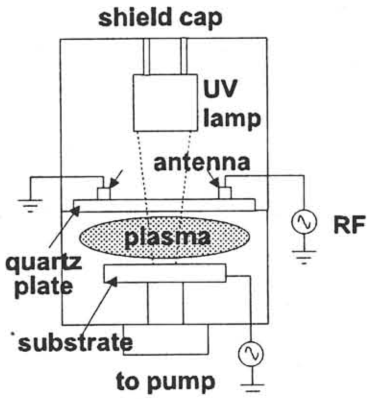


Fig. 1 A schematic of an inductively coupled plasma (ICP) etcher with a focused UV lamp

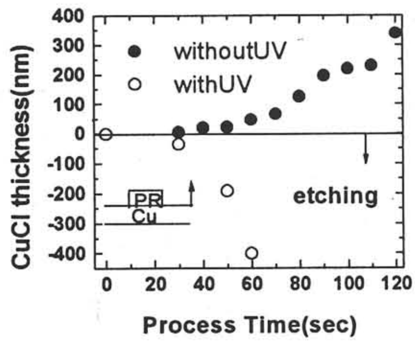
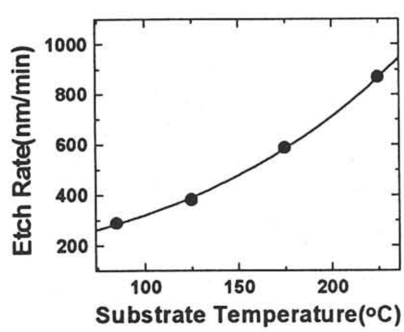
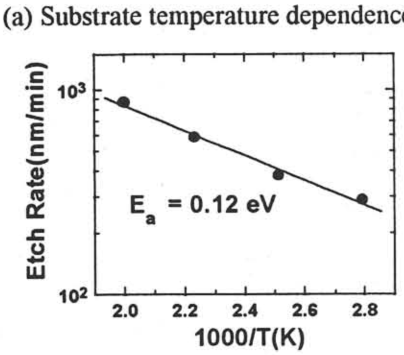


Fig. 2 The thickness of CuCl formed on copper .vs. plasma etching time under a condition ; N_2/Cl_2 = 0.5, 5mTorr, 500W, room temperature



(a) Substrate temperature dependence



(b) Arrhenius plot

Fig. 3 The etching rate .vs. the substrate temperature under a condition ; Ar/Cl_2 = 0.5, 5mTorr, 300W, with UV irradiation

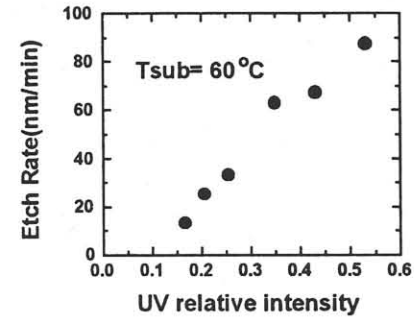
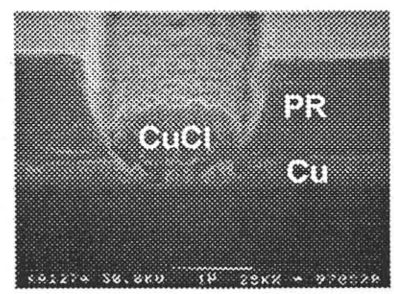
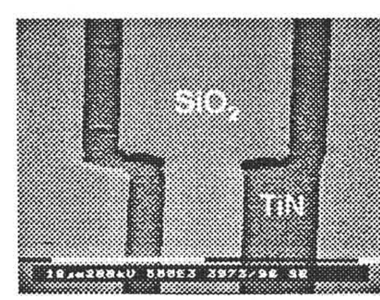


Fig. 4 The etching rate .vs. UV intensity under a condition; Ar/Cl_2 = 0.5, 5mTorr, 500W, Tsub = 60℃



(a) Without UV irradiation



(b) With UV irradiation

Fig. 5 SEM overview of the sample after the etching of copper films under a condition ; Ar/Cl_2 = 0.5, 5mTorr, 300W, 100W bias