Thin Solid Films 579 (2015) 127–130

Contents lists available at ScienceDirect

Thin Solid Films

journal homepage: www.elsevier.com/locate/tsf

Etching characteristics of hydrogenated amorphous silicon and poly crystalline silicon by hydrogen hyperthermal neutral beam

Seung Pyo Hong, Jongsik Kim, Jong-Bae Park, Kyoung Suk Oh, Young-Woo Kim, Suk Jae Yoo, Dae Chul Kim *

Plasma Technology Research Center, National Fusion Research Institute, 37 Dongjangsan-ro, Gunsan-si, Jeollabuk-do, 573-540, Republic of Korea

ARTICLE INFO

Article history:
Received 6 August 2014
Received in revised form 26 February 2015
Accepted 27 February 2015
Available online 6 March 2015

Keywords:
Microwave plasma source
Hydrogen plasma
Plasma etching
Hyperthermal neutral beam energy
Neutralizer
Etching selectivity

ABSTRACT

A hydrogen hyperthermal neutral beam (HNB) generated by an inclined slot-excited antenna electron cyclotron resonance plasma source has been used to etch hydrogenated amorphous silicon (a-Si:H) and polycrystalline silicon (poly-Si) films. In this work, we present selective etching of a-Si:H with respect to poly-Si by hydrogen plasma and hydrogen HNB under various substrate temperatures, gas pressures, and bias voltages of the neutralizer. We have observed that the etch rate of a-Si:H is considerably higher than that of poly-Si. The etch rate is largely dependent upon the substrate temperature. In this experiment, the optimal substrate temperature for improving the etch rate is approximately at 150 °C. The root mean square surface roughness of the etched material reaches a maximum at 150 °C and decreases rapidly. The etch rate of poly-Si is not sensitive to changes in the experimental condition, such as the substrate temperatures and gas pressures. However, as the hydrogen HNB energy is increased, the etch rate of poly-Si also increases gradually. The hydrogen HNB energy contributes in improving the etch rate of a-Si:H and poly-Si films.

1. Introduction

In the semiconductor and flat panel display industry, plasma etching is one of the most important processing techniques applied. Most of all, for etching materials such as semiconductors, metals, and insulators widely use gases contain halogen, in which their compounds are highly reactive. Plasma etching techniques using these conventional reactive gases have created contamination on the etched surface with halogen compounds and caused damage to the surface with the bombardment of charged particles [1,2]. In addition, these gases are toxic and have difficulties of disposing. However, the etching processes by hydrogen plasmas are eco-friendly due to hydrogen being nontoxic itself. Although the use of hydrogen etching is applied to a narrow range of materials, it has been investigated as a useful alternative for several plasma etching processes.

Chang et al. have used hydrogen plasmas to etch surfaces of semiconducting materials (e.g., GaAs, GaSb, InP, Si), including its oxides, and Si nitride [3]. Their results show that hydrogen plasmas could be used to etch most material that forms volatile species at operating temperatures. Occasionally when the selective etching of silicon is required, hydrogen ions and radicals have been used. Nozaki et al. have shown that the hydrogenated amorphous silicon (a-Si:H) etched by hydrogen radicals is approximately two times faster than that of crystalline silicon (c-Si) [4]. Subsequently, the etching selectivity between a-Si:H and c-Si was investigated more systematically by M. Otobe et al. [5].

In this paper, we have additionally used the hydrogen hyperthermal neutral beam (HNB) energy to improve the etching efficiency of silicon films. The etching method using the hydrogen HNB can provide additional reaction energy for etching process. We introduce etching characteristics of a-Si:H and poly-Si with hydrogen plasmas & hydrogen HNB energy. We have used the inclined slot-excited antenna (ISLAN) electron cyclotron resonance (ECR) microwave plasma-source system to generate the hydrogen HNB energy. A layout of the ISLAN plasma source system is shown in Fig. 1 [6].

2. Experimental details

Etching of silicon has been performed using hydrogen plasma and HNB generated by the ISLAN plasma source system. The generation system of HNB consists of the neutralizer, source chamber, limiter, and a process chamber. The neutralizer is installed on top of the source to generate HNB. The source chamber, shaped as a cylinder, is made of quartz having an inner diameter of 170 mm. The inside wall of the source chamber is deposited with silicon films to prevent sputtering of elements from the quartz cylinder, which can redeposit on the silicon surface and limit etching. The limiter consists of an array of permanent magnets, which prevents charged particles in the plasma from flowing down onto the substrate. The process chamber is made of aluminum alloy with an inner diameter of 250 mm and designed to process the 200 mm wafer.

Prior to the etching process, the chamber reaches a vacuum pressure of 4.0×10^{-4} Pa with a turbo molecular pump. The gas pressure is around 0.05–0.27 Pa (0.4–2 mTorr) with H_2 gas flow rate of

* Corresponding author.
E-mail address: dchcharm@nfri.re.kr (D.C. Kim).

http://dx.doi.org/10.1016/j.tsf.2015.02.073
0040-6090/

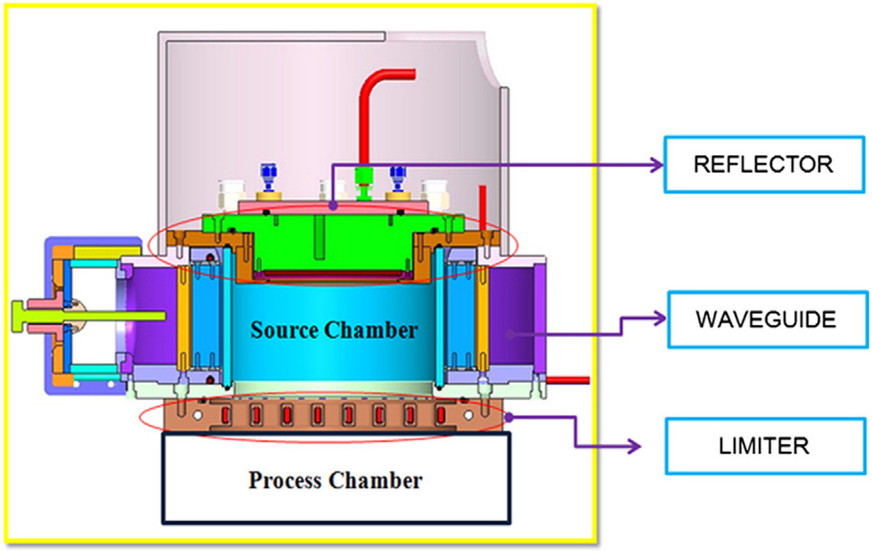

Fig. 1. Schematic of the inclined slot-excited antenna (ISLAN) system.

30–70 sccm. The applied microwave power is 1000 W at a frequency of 2.45 GHz. Etching experiments are performed at various substrate temperatures and the bias voltage of the neutralizer (hydrogen HNB energy) is in the range of 0 V to −40 V. The a-Si:H and poly-Si thin films were deposited on the Si(100) wafer with low pressure chemical vapor deposition. The a-Si:H and poly-Si films were deposited respectively at temperatures of 530 and 620 °C, at the operating pressures of 46.7 and 20 Pa (350 and 150 mTorr) by using the SiH_4 60 sccm precursor gas. The a-Si:H and poly-Si films are concurrently etched under the same conditions. The etched depth is measured by a field-emission scanning-electron microscope (FE-SEM, Sigma, Zeiss) to accurately estimate the etch rate. The FE-SEM acceleration voltage of 5 kV is used. Atomic force microscopy (AFM, NX10, Park systems) is used for analyzing the etched surface morphology, and also to observe the surface roughness.

3. Results and discussion

3.1. Changes of the etch rate by varying the substrate temperature for different operating pressures

Previous to the etching process, the native surface oxide layer of the sample is removed by dipping into a diluted hydrofluoric acid. Since the native oxide acts as an effective blocking layer, without undergoing this process, etching of the a-Si:H and poly-Si is not nearly completed [4].

Fig. 2 shows the measured etch rate of a-Si:H and poly-Si as a function of the substrate temperature for different operating pressures. The etch rate is defined as etched depth per processing time. The processing time is constantly kept for 5 min. The etch rate for a-Si:H is the highest at the substrate temperature of approximately 150 °C regardless of changing the operating pressure. By increasing the substrate temperature higher than 150 °C, the etch rate of a-Si:H decreases drastically. Such a decrease in the etch rate has been reported [7,8]. This has been explained in terms of a decrease in the surface coverage of chemisorbed hydrogen or the diffusion of hydrogen into the silicon surface.

The substrate temperature for hydrogen plasma etching of a-Si:H films is very important, because the etch rate is largely dependent upon temperature. In the case of poly-Si, however, there are no significant differences in the etch rate. The etch rate increases with higher operating pressures, which shows a dissimilarity to the paper quoted in this study [5]. In the case of using a capacitive coupled plasma (CCP) etching system, the etch depth increases with decreased pressure. This could be explained by the mean free path of hydrogen radicals for being too short to react with Si atoms, since the CCP plasma system is utilized at high pressure ranges. On the other hand, the etch rate is shown to increase with higher operating pressures because the hydrogen flux also increases gradually as pressure is changed from 0.05 Pa to 0.27 Pa.

3.2. AFM measurements of the etched surfaces

Fig. 3 shows the surface morphology of the etched a-Si:H films at various substrate temperatures measured by AFM in non-contact mode with an area of 2×2 μm^2. In the case of a-Si:H, the surface morphology of the reference sample and that of the etched sample at a substrate temperature of 500 °C is almost identical. Although, AFM images are not shown, there appears to be no significant change on the surface morphology for poly-Si at various substrate temperatures.

The resulting root mean square (rms) roughness for each individual substrate temperature is plotted in Fig. 4. The maximum value of the rms roughness is 4.738 nm for the a-Si:H film with substrate temperature at 150 °C. The rms roughness at the substrate temperature of 500 °C is 0.384 nm, which is similar to the reference sample: 0.377 nm. The rms roughness of a-Si:H films increases until the substrate temperature reaches at around 150 °C and decreases sharply.

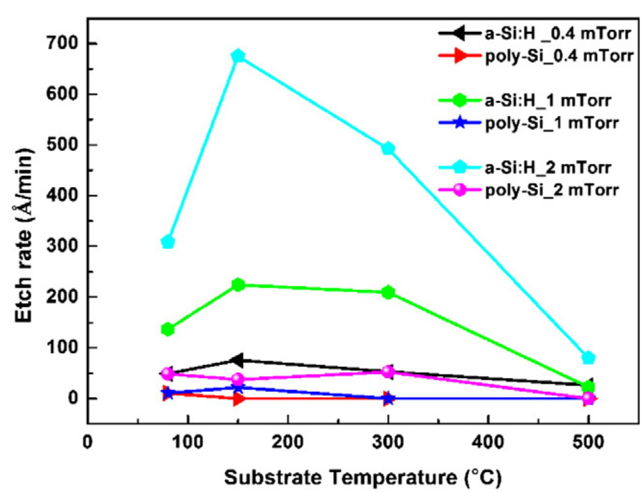

Fig. 2. The etch rate of a-Si:H and poly-Si as a function of the substrate temperature for different operating pressures.