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Improvement of SiO_2 pattern profiles etched in CF_4 and SF_6 plasmas by using a Faraday cage and neutral beams

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Abstract

This study reports on a new plasma etching technique, using a Faraday cage and neutral beams, that improves the etch profile of an SiO_2 trench in CF_4 and SF_6 plasmas. A Faraday cage, with a top plane made of conductive grids, was placed on the cathode of a transformer-coupled plasma etcher such that the initial direction of ions passing through the grids traveling inside the cage is maintained. Neutral beams were generated by reflecting the ions on the surfaces of 5°-slanted conductive reflectors located under the top grid of the Faraday cage. Three sets of etch experiments were conducted to observe the individual effects of the Faraday cage and neutral beams on the etch profiles: conventional plasma etching (case I), etching using a Faraday cage (case II), and etching using a Faraday cage and neutral beams (case III). For case II, faceting of the mask and substrate and narrowing of the line spacing were drastically suppressed. This is because the electric potential in the Faraday cage is uniform, and, therefore, the distortion of the electric field near the convex corner of a microfeature is eliminated. For case III, faceting and narrowing were further reduced because the direction of neutral beams is unaffected by negative charges accumulated on the sidewall during this process. The increase in the neutral to ion flux ratio via the use of a Faraday cage contributes to the evolution of different etching profiles depending on CF_4 and SF_6 plasmas. This can be attributed to differences in the angular dependence of the etch yield for the two plasmas.

Keywords: Plasma etching; Faraday cage; Neutral beam; Faceting

1. Introduction

Plasma etching is widely used for the patterning of thin solid films due to its anisotropic etching capability. However, there are two factors in plasma etching which contribute to the evolution of a nonvertical etch profile. One is the local distortion of electric fields at the convex corners of the microfeatures [1,2]. This field distortion enhances the ion flux at the corner to produce faceting of the mask and substrate, and narrowing of the line spacing [3,4]. The other is the accumulation of negative charges on the surface of insulating sidewalls due to the combination of less-anisotropic electron flux and highly anisotropic positive ion flux [4,5]. This localized charging of the sidewall surface additionally bends the trajectory of the ions, leading to bowing, microtrenching, an RIE lag, and to electrical damage.

The above two factors cannot be overcome by simply adjusting process variables including the source power, bias voltage, pressure, substrate temperature, and others. In this study, a new etching technique using a Faraday cage and neutral beams was used to minimize or avoid faceting of the mask and substrate and narrowing of the trench line spacing. For conventional neutral beam etching (NBE) [6], a neutral beam is generated from an ion beam by charge exchange reactions in the gas phase and residual ions are eliminated by a retarding grid. This process has the disadvantage of low etch rates and is affected by gas chemistry to a significantly different extent from that of conventional plasma etching. In comparison with the conventional NBE, the plasma etching

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technique employed here, using a Faraday cage and neutral beams, has the advantage of showing relatively high etch rates because radicals in the plasma also contribute to the etching. Another advantage is that the energy of neutral beams and the density of reactive radicals can be independently controlled by adjusting the bias voltage and the source power in a transformer-coupled plasma (TCP) etcher.

2. Experiment

Etching experiments were carried out using a TCP etcher, as shown in Fig. 1(a). The etching system has been described in detail in our previous paper [7]. Therefore, only the most important dimensions will be presented in this paper: (i) the inner diameter of the reaction chamber was 30 cm, (ii) the cathode diameter was 12.5 cm, and (iii) the spacing between the 0.8-cm-thick dielectric window under the coil and the cathode was 3.5 cm.

The substrate for the etching was a 2-μm-thick SiO_2 film thermally grown on a P-type Si wafer. The film was masked with a 1500-Å-thick Al line. The line width and line space of the Al mask were 0.6 m and 1 μm, respectively. Three samples of the substrate, cut into a 5×5 mm^2 square, were placed on the cathode and were etched under three different conditions, i.e., cases I, II, and III, as shown in Fig. 1(b). In case I, the substrate is exposed directly to the plasma. This corresponds to the conventional plasma etching process, which is subject to the electric field distortion at the convex corners of microfeatures and charging of the sidewalls.

In case II, the substrate is placed in a Faraday cage. A Faraday cage is simply a closed box consisting of a conductor. The cage with copper sidewalls and a roof made of a brass wire grid was bolted to the stainless-steel cathode to make an enclosed Faraday cage. When the substrate is located in the cage, the electric field near the convex corners of the microfeatures is not distorted by the external field because the electric potential in the cage is unaffected by outside voltages and is uniform in the cage [8–14]. Therefore, ions enter perpendicular to the sheath formed along the top grid plane of the cage and reach the substrate with their initial direction maintained. However, even when the Faraday cage is used, the problem of local electric fields caused by negative charges accumulating on the surface of insulating sidewalls continues to exist.

In case III, the substrate is placed in a Faraday cage with specially-designed neutralizing reflectors. The grid plane of the Faraday cage is slanted at a 10° angle with respect to the horizontal cathode, and the neutralizing reflectors (arranged in parallel to one another) are slanted at an angle of 5° with respect to the grid plane. Ions passing through the grid of the Faraday cage are neutralized by the grazing angle collision of ions with the reflector surface. As a result, neutralized ions or neutral beams, which impinge perpendicular to the substrate surface, are obtained.

CF_4 and SF_6 were separately used as discharge gases in experiments concerning the above three cases. The process conditions were as follows: the pressure was 5 mTorr, the gas flow rate 4 sccm, the source power 300 W, the bias voltage -400 V, and the substrate temperature was 15 °C. The high bias voltage (-400 V) was selected to effectively observe faceting. Because the etch rates were different for the above three cases, the etch time was selected such that an etch depth of 1 μm was obtained for all cases. In another set of experiments using a CF_4 plasma, an extended etch time, corresponding to 150% of the above cases, was used to observe changes in the etch profile with time.

The etch rates of blank SiO_2 substrates were determined by optically measuring changes in the thickness after etching (SpectraThick 2000-Deluxe). The etch profiles of substrates patterned with Al lines were obtained by scanning electron microscopy (SEM).

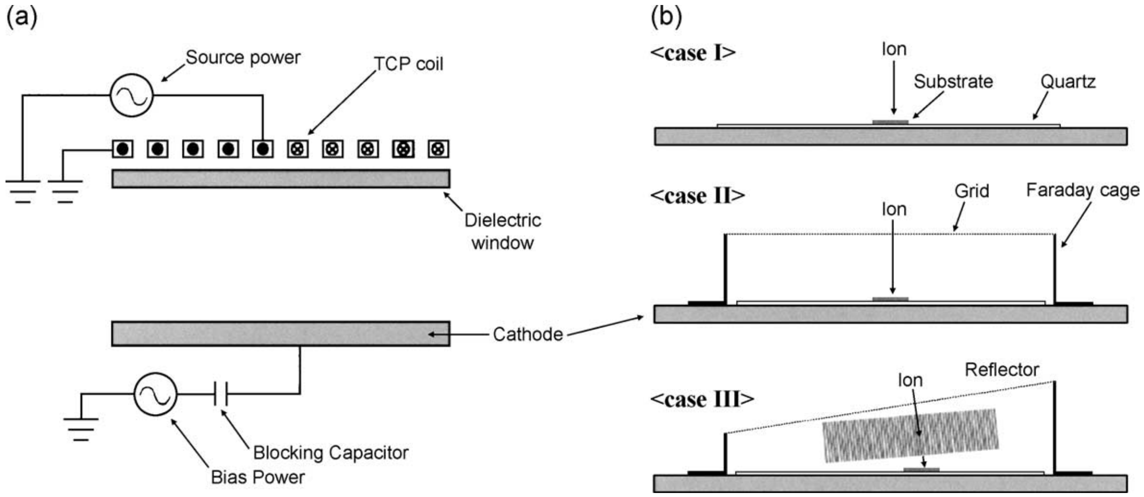

Fig. 1. Schematic diagrams of the system used in this study. (a) A transformer-coupled plasma (TCP) etcher. (b) Three cases of etch experiments: conventional plasma etching (case I), etching using a Faraday cage (case II), and etching using a Faraday cage and neutral beams (case III).