Fabrication of slanted Si pillars for Antireflective surfaces using plasma etching

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Abstract: Slanted Si pillars for antireflective surfaces were fabricated by plasma etching. As the angle of the slanted Si pillars increased, the surface reflectance decreased. When the lengths of the slanted pillars were fixed and the diameters changed, the surface reflectance was affected by the filling-fraction of a pillar-formed surface. When the diameters of the slanted pillars were fixed and the lengths were changed, the weighted mean reflectance of the surface decreased as the aspect ratio of slanted Si pillars increased.

Keywords: Antireflective surface, plasma etching, slanted Si pillars, surface reflectance

1. Introduction

The anti-reflection techniques suppress light reflection on the surface and are one of the important research in applications such as solar cells, displays, optical lens systems, and so on [1-3]. The anti-reflection techniques can be implemented primarily with antireflective coatings or surface texturing [4-6]. The antireflective coating is the conventional method, but the use of a single dielectric coating is effective for only a relatively narrow wavelength range. Therefore, complex dielectric stacks or textured surfaces are required to produce broadband anti-reflection effects [7]. The surface texturing is well known for its ease and effectiveness in reducing surface reflectivity. Antireflective surfaces have been fabricated mostly by forming a fine uneven structure such as pyramids, vertical pillars, and conical shapes on various substrates [8-10]. The pyramid shape is mainly formed by wet etching, which is easy to manufacture, but the shape control is not uniform and is influenced by the crystal orientation of the substrate. The vertical pillar shape is made by dry etching, and uniformity is relatively good. Although the vertical pillars have been reported to have lower reflectivity as the aspect ratio increases, there has been no study of the reflectivity variation of the slanted pillars formed at various angles.

In this study, slanted Si pillars at various angles were fabricated by plasma etching, and the surface reflectance of the substrates with pillars were measured. Slanted Si pillars were fabricated using a Faraday cage, which can control the angle of ions incident on the substrate surface. The length and diameter of the slanted pillars were also changed to investigate the effect of the aspect ratio on the reflectance of the surfaces with slanted pillars.

2. Experiment

Plasma etching for the fabrication of the slanted Si pillars was conducted in an inductively coupled plasma (ICP) system. The slanted Si pillars were fabricated on a p-type Si (100) wafer that was cut into a 10 x 10 mm^2 rectangle. The Si substrate had a convex SiO_2-mask hole pattern. The diameter of the hole was 400 nm and the space between holes was 400 nm so that the pitch of etch pattern was 800 nm. The height of the hole pattern was 440 nm.

Etching was performed using a cyclic process consisting of alternating etching and deposition steps. SF_6 and C_4F_8 plasmas were used in the etching and deposition steps, respectively. The conditions for etching and deposition steps are given in Table 1.

Fig. 1 shows the schematic of plasma etching for the fabrication of slanted pillars. A Faraday cage was used to control the direction of ions incident on the substrate. In a conventional plasma etching, a sheath is formed along the surface of the substrate in contact with a plasma. Therefore, conventional plasma etching is not adequate for obtaining slanted etch profiles. A Faraday cage is a closed box of conductor and the top plane is replaced with a conductive grid. Since the sheath thickness was expected to be larger than the grid diameter, the presence of the grid did not disturb the plasma. In this case, the sheath was formed along the grid plane (in other words, top plane of the cage). The electric potential in the cage was uniform and unaffected by external electric fields. Therefore, ions entered the cage perpendicular to the sheath, while maintaining their initial direction within the cage. As the interior of the cage was free of electric fields, the angle of ions incident on the substrate could be accurately controlled by varying the angle of the sample holder.

Table 1. Cyclic process of etching and deposition

	Etching	Deposition
Discharge gases	SF_6	C_4F_8
Source Power (W)	400	400
Bias Voltage (V)	-100	0
Flow rate (sccm)	30	30
Pressure (mTorr)	10	30
Duration time (s)	21	5

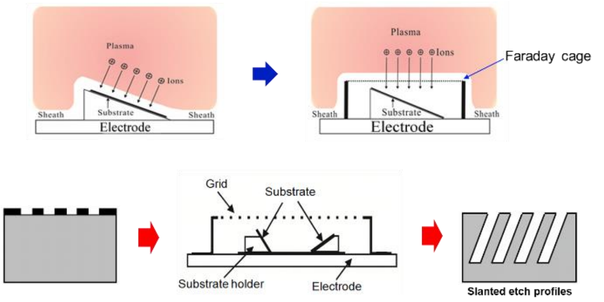

Fig. 1. Schematic of the concept of the Faraday cage (top) and plasma etching for the fabrication of slanted pillars (bottom).

3. Results

Fig. 2 shows cross-sectional images of the slanted Si pillars fabricated at various ion-incident angles from 0° to 60°. The ion-incident angle (θ) was defined as the angle between the ion-incident direction and the surface normal to the substrate. The length of the slanted Si pillars was about 1500 nm.

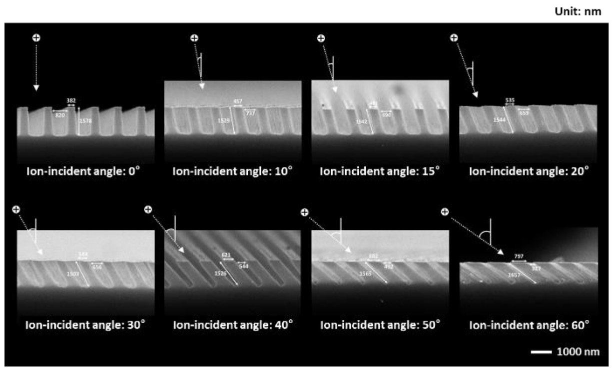

Fig. 2. Cross-sectional images of the slanted Si pillars

The weighted mean reflectance of surfaces decreased gradually as the angle of the slanted Si pillars increased as shown in Fig. 3.

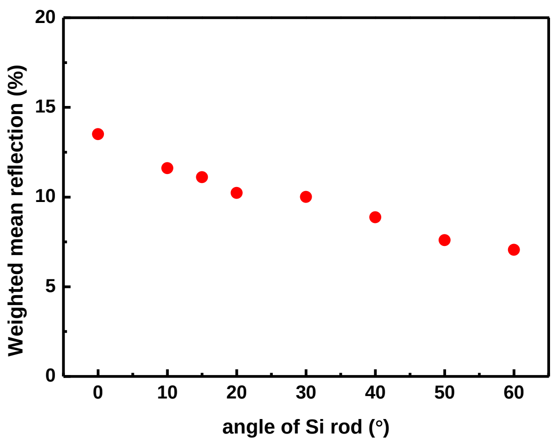

Fig. 3. Change in weighted mean reflectance with the angle of the slanted Si pillars.

In order to analyse the effect of the aspect ratio of the slanted pillars on the reflectance, the length and diameter of the slanted Si pillars fabricated at the ion-incident angles of 0° and 40° were changed.

When the lengths of the slanted Si pillars were fixed and the diameters were changed, the weighted mean reflectance of the surface was affected by the filling-fraction of a pillar-formed surface. The change in the weighted mean reflectance was similar to the refractive index change of the surface. The weighted mean reflectance was further reduced due to the large change in refractive index depending on filling-fraction of the slanted silicon pillar etched at 40° rather than 0°.

When the diameters of the slanted pillars were fixed and the lengths were changed, the weighted mean reflectance of the surface decreased as the aspect ratio of slanted Si pillars increased.

4. References

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