Graded Etching of Thermal Oxide with Various Angles using Silicafilm

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Abstract — Reproducible tapered windows in thermal oxide have been produced by depositing a silicafilm on the thermal oxide before the chemical etching. As heat treatment temperatures of silicafilms are changed from 200°C to 1,000°C, graded angles are varied approximately from 3° to 28°.

Silicon dioxide layers are utilized as an insulating layer, a passivation and protection layer, and a substrate for metal in semiconductor applications. Specially, tapered windows in SiO₂ are useful for good step coverage in metallization. Graded steps have been produced with a single layer of SiO₂ [1], or a double layer of thin faster etching layer and SiO₂. According to the production methods, thin layers are classified into i) a doped oxide layer [2], ii) an ion implanted damaged layer [3], [4], [5], and iii) a deposited oxide layer [2].

In this paper, thin layers of silicafilm oxide have been formed on the thermal oxide having a lower etch rate. The silicafilm [6] consists of an alcohol solution to form a pure SiO₂ film when it is coated on a substrate. Characteristics of SiO₂ made through the silicafilm are similar to those of thermally grown oxide except the etch rate [6]. Since the silicafilm oxide layer is etched faster than the thick thermal oxide layer, tapered steps are formed in SiO₂. The angle θ which the taper forms with the original SiO₂ surface is given by [2]

\[ \sin \theta = \frac{E_t}{E_i} \]  

where \( E_t = \) etch rate of thick thermal oxide itself \( E_i = \) etch rate at the thin layer/thick oxide layer interface in the lateral direction.

Equation (1) shows that the tapered angle is a function of the ratio of the lateral etch rate of the interface and the bulk etch rate of thick oxide. The lateral etch rate cannot be precisely defined as a function of the etch rate of the thin layer, because it is not only dependent on the chemistry of the photoresist/thin deposited oxide interface and thin deposited oxide/thick thermal oxide interface, but also affected by the thickness of the thin layer. Also, these interface properties depend on the particular processing conditions used. Therefore, we investigated experimentally the relations between the tapered angle and processing conditions. The graded etch method used in this study is a new process which is relatively simple and easy to process. Also it is of low cost, and various tapered angles can be produced by simply varying the temperature of the heat treatment of the silicafilm.

In the experiment, polished (100) oriented n-type silicon wafers were oxidized at 1,150°C for 100 minutes by wet oxidation to grow a thermal oxide layer of about 1 μ in thickness. Silicafilm [6] was then deposited on the thermal oxide using a photosensor spinner for precise control in thickness. The thin layer formed on the SiO₂ was then subjected to a heat treatment at 200°C - 1,150°C in an air atmosphere. Windows were defined on the double layer using the conventional photolithographic processing. The oxide was etched at room temperature by dipping in buffered HF solution (40% NH₄F : 49% HF = 6:1). Resultant oxide step profiles were evaluated from the interference fringe pattern which results with an ordinary optical microscope.

Fig. 1 shows microphotographs of an interference fringe pattern for the case of a heat treatment at 200°C. Uniform widths between fringe lines indicate the good linearity of the tapered slope. As the heat treatment temperature becomes higher, the etch rate of the silicafilm oxide is reduced and a steeper tapered slope is obtained. These results are summarized in Fig. 2 which shows the graded angle as a function of the heat treatment temperature. For samples treated above 1,000°C, fringe lines are so crowded that it is difficult to distinguish optically the individual fringe lines.

Experiments were also carried out to find the dependence of the tapered angles on the spin speed of the silicafilm and/or on the mixture ratio of oxygen and nitrogen for the ambient gas during the heat treatment. The results, however, show that the tapered angles are nearly independent of the spin speed and/or of the mixture ratio of the ambient gas. The process described herein has produced a constant slope independent of the etch time, but small nonuniformities in flatness have been observed over the entire etched window wall. Similar results were obtained for other spin-on sources, such as boro-silicafilm or phosphoro-silicafilm containing impurities.

In conclusion, reproducible tapered windows in SiO₂ have been produced by depositing a layer of silicafilm on the thermally grown oxide. Controllable tapered angles have been obtained by changing the heat treatment temperature between 200°C and 1,000°C. Spin speed or
ambient gas did not affect the tapered angles. Steep tapers can be utilized to improve the step coverage of the metallization in integrated circuits and shallow tapers will find applications in integrated optical devices [7].

REFERENCES


Fig. 2. Tapered angle as a function of heat treatment temperature. ambient gas mixture: N₂ : O₂ = 4:1
spin speed of silicafilm: 3,000 rpm

Fig. 1. Microphotographs of interference fringe pattern for etched windows in SiO₂,
heat treatment temperature: 200°C
(a) magnification 50X
(b) magnified view of "box" in (a)
(c) cross-sectional view along the center line of the circle in (a)