Extended Abstracts of the 18th (1986 International) Conference on Solid State Devices and Materials, Tokyo, 1986, pp. 201-204

A-4-2

Excimer Laser Etching of Si and SiN

T.FUJII,R.KAWABATA,H.KOMIYA, AND H.SHIMIZU

VLSI DEVELOPMENT LABOLATORIES, SHARP CORPORATION

2613-1 ICHINOMOTO, TENRI, NARA 632 JAPAN PHONE:07436-5-1321

Laser etching characteristics of Si and Plasma-SiN are investigated. The difference of etching threshold powers is explained by the surface heating efficiencies. To reduce threshold power of Si etching, quarz cover and SiN precoating are effective. Submicron projection etching is performed using this system.

1.INTRODUCTION

In recent years, new etching technologies have been proposed to satisfy the requirements of the future VLSI fabrication processes. Photo-enhanced etching is one of the promising techniques to realize damageless projection etching(1). We have already reported a Si etching technique using ArF excimer laser and SF6 gas(2). In that paper, the nonlinear power dependence of the etch rate was observed and Si surface seemed to be heated up to a melting point above the threshold laser power.

To apply this technique to the VLSI fabrication process, there are three technical problems to be solved. The first is reduction of laser power. The second is increasing etch rate. The third is improvement of the spatial resolution.

In this work, SiN etching is examined in low power region, and the method to reduce the laser power of Si etching is developed. The example of fine patterning using this technique is also shown.

2.EXPERIMENTAL

The schematic diagram of the experimental apparatus is shown Fig.1. The excimer laser beam was focused on the substrate perpendicularly through the suprasil window. The patterning was carried out by putting the projection mask near the wafer surface. The reaction chamber was filled with SF6 gas. All the experiment was performed at room temperature. The repetition rate and duration time of the laser pulse were 50 Hz and 13nsec respectively. The peak power of the laser was varied from 5 to 40 MW/cm2. The laser was operated at 193nm(ArF) and 248nm(KrF).

p(100) single Si ,poly-Si ,and plasma-SiN were used. The Si sample was cleaned by the diluted HF solution before the experiment.

Etched depth was measured by the mechanical stylus or SEM photograph.

3.RESULTS AND DISCUSSION

3.1 Etching charateristics of Si and SiN

Optical and thermal properties of Si and SiN are listed in the table 1. Plasma-SiN has little reflectivity and large thermal resistivity that is feasible for the low laser power etching.

Fig.2 shows the laser peak power dependence of the etch rate. Threshold laser peak power for the etching reaction is observed in both poly-Si and plasma-SiN etching. respectively . In the case of SiN etching, the different laser threshold power of 6MW/cm2(ArF) and 16MW/cm2(KrF) are observed. In the poly-Si case, the threshold power(24MW/cm2) does not depend on the laser wavelength. The etch rate depends nonlinearly on the laser peak in both cases. The high etch rate of 80 Å/pulse is achieved at the 20MW/cm2 in plasma-SiN etching.

These effects can be explained by the thermal and optical properties of Si and SiN which are shown in table 1. If the thermal dissociation of SF6 near the surface is dominant in this etching reaction, the surface temperature of the sample has to correspond to the dissociation temperature of SF6 at the threshold laser peak power. The surface heating efficiency is estimated by the following fomula.

$$\text{SURFACE HEATING EFFICIENCY} = \alpha * (1-R) * \text{THERMAL RESISTIVITY}$$

α : Absorption coefficeint

R : Reflectivity

The surface heating efficiency should meet with the inverse of etching threshold laser peak power. Both values shows good agreement as listed in table.1. Thermal dissociation SF6 is considered to play an important role in this reaction.

The high etch rate(80A/pulse) of SiN is due to the high thermal resistivity that holds the high temperature state much longer than Si.

The SF6 gas pressure dependence of the etch rate is shown in Fig.3. The etch rate of plasma-SiN is propotional to the SF6 gas pressure. On the other hand, Si etch rate seems to be saturated in the high pressure region. The gas dissociation and etching reaction occurs simultaneously on SiN surface, but in the case of Si etching another mechanism should be proposed. For example, the sticking effect of reaction product can be taken into account.

3.2 Si etching at low laser power region

It is supposed that etch rate can be increased by concentrating reactive product. Three types of configuration are tested. In the case of (A), p-type single Si cleaned by diluted HF is etched in usual configuration. In the case of (B), the same sample as (A) is used, and quarz plate is put on above the substrate surface. The gap between quarz plate and substrate is about 25 µm. In the case of (C) plasma-SiN(3000A) coated Si is etched with the same configuration as (B). In this case etch rate is estimated by subtracting the coated SiN etch time from the total etching time.

The laser peak power dependence of etch rate in these three experiments are shown in Fig.4. The calculated surface temperature is also shown. The non-equilibrium heat propagation equation is solved numerically by the finite difference scheme(3,4). The threshold laser peak power are reduced in the cofiguration (B) and (C). The surface temperature at the etching threshold laser peak power is 1600°C for (A) ,1200°C for (B), and 800°C for (C), respectively.

The etched depth is propotional to the deposited laser pulse at (A) and (C). On the other hand, in the case of (B) the etching delay time is observed near the threshold power. The laser peak power dependence of this delay time is shown in Fig.5.

We consider that these phenomena may be explained by the formation of the surface deposited film that supplies the etching species for Si etching. In configuration (B) the low conductance of the gas is effective to form the surface deposited film which supplies reactive products and promotes etching reaction. The delay time seems to correspond to the initial growth time of the deposited film. In the configuration (C), the initial growth of the deposited film may be completed before the Si etching ,because the etch rate of SiN is higher than Si. The activation energy for this etching reaction is calculated to be 0.49 eV at (C).

3.3 Projection patterning

The proximity projection etching was performed in this etching system. The examples are shown in Photo.1 for poly-Si, Photo.2 for plasma-SiN, and Photo.3 for single Si. The 0.5 µm space patterning of plasma-SiN is well achieved. The reason for these high spatial resolution is due to the nonlinear etch rate dependence of the laser peak power.

4.SUMMARY AND CONCLUSIONS

The excimer laser etching characteristics of Si and SiN are compared. In SiN case, the threshold power depends on laser wavelength(6 MW/cm2 for ArF, 16 MW/cm2 for KrF). On the other hand, the same threshold power (24MW/cm2) is observed in Si. This is explained by means of surface heating efficiencies calculated by optical and thermal constant of Si and SiN.

The etching threshold laser power of the single Si is reduced by the combination of quarz plate cover and the plasma-SiN precoating. The reason for this reduction of etching threshold laser power is not clear, but these condition may enhance suface sticking of the film that supplies the etching species. This effect increases etching rate in the low power region.

The application of this etching reaction to plasma-SiN , poly-Si, and single Si patterning were performed. The submicron pattern of the plasma-SiN is obtained by the proximity projection.

We think this laser etching technique is one of the candidates to realize submicron patterning.

5.REFERENCES

1. N.Hayasaka et al., Proceesings of 7th Dry Process Symp(Tokyo),p34,(1985).
2. T.Fujii et al.,Extended Abstracts of 17th Conference on Solid State Device and Materials,Tokyo,(1985),p177.
3. R.F.Wood et al., Phys. Rev. B , 23, 2923(1981).
4. L.D.Merkle et al.,J.Appl.Phy , 55, 772(1984)

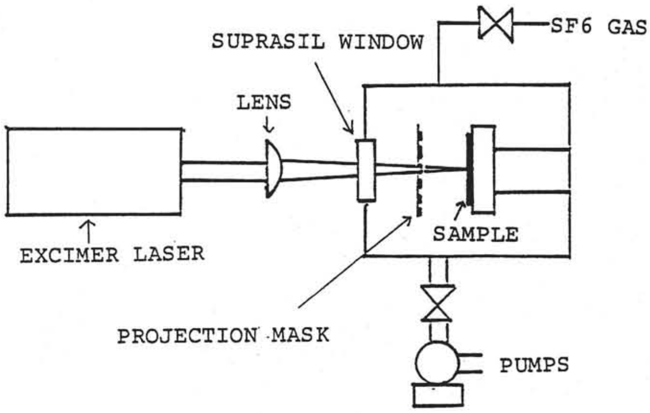

Fig.1 Schematic diagram of the experimental apparatus.

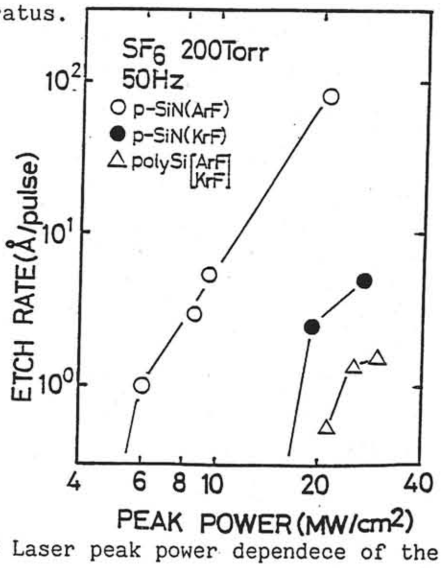

Fig.2 Laser peak power dependece of the Si and SiN etch rate.

		Absorption coefficient	1−R	Thermal resistivity	Heating efficiency	Experiment
SiN	ArF	1	1	1	1	1
	KrF	0.44	1.1	1	0.48	0.33
Si	ArF KrF	5.1	0.42	0.2	0.42	0.30

Table.1 Optical and thermal properties of Si and SiN.
The experimental value is the inverse of the threshold laser power.

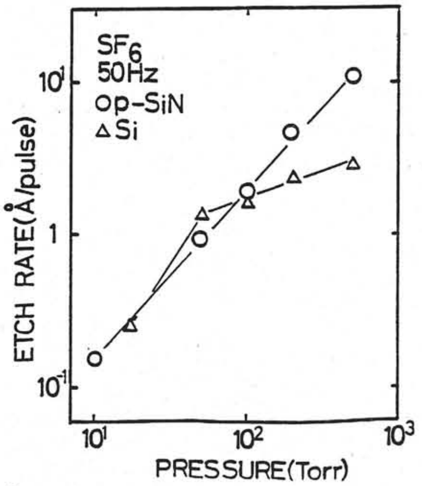

Fig.3 SF6 gas pressure dependence of the Si and SiN etch rate.

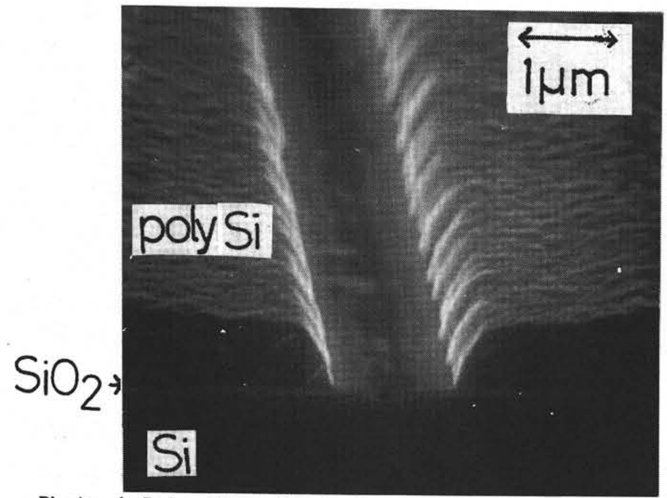

Photo.1 Poly-Si pattern formed by the projection etching.

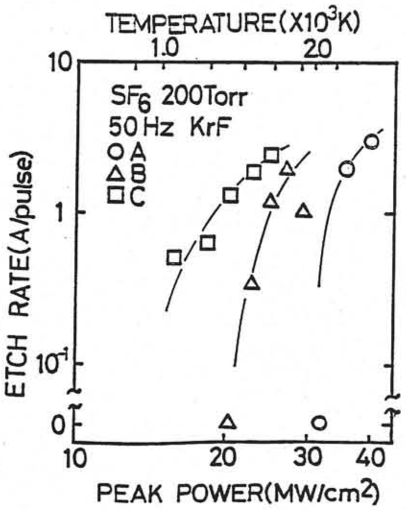

Fig.4 Laser peak power dependence of the single Si etch rate. The difference between three types of the etching configuration can be seen.

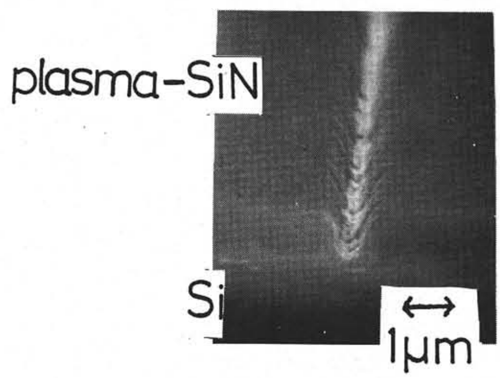

Photo.2 Plasma-SiN pattern obtained by the projection etching. 0.5 μm space pattern is formed.

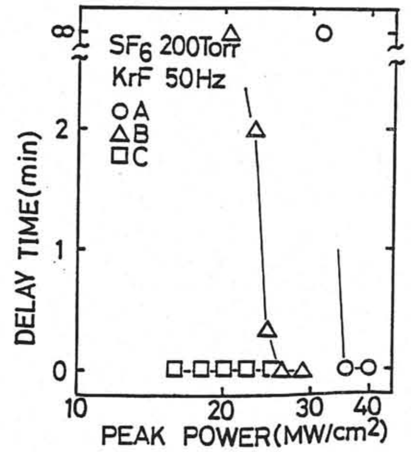

Fig.5 Plot of etching delay time as a function of the laser peak power. The infinity indicates the sample being not etched at that laser peak power.

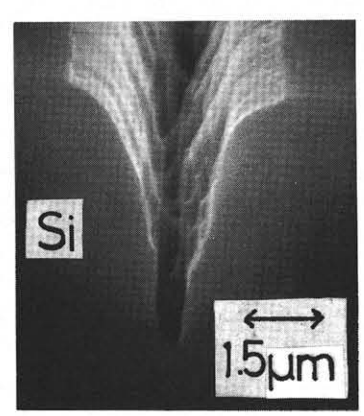

Photo.3 Single Si pattern obtained by the projection etching.