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Nanometer-Sized Patterning of Polysilicon Thin Films by High Density Plasma Etching Using Cl_2 and HBr Gases

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Abstract−High density plasma etching of polysilicon thin films was carried out in an inductively coupled plasma (ICP) for the formation of nanometer-sized patterns. The etch rate and etch selectivity of polysilicon films were investigated as a function of the concentration of Cl_2 and HBr etch gases. The fast etch rate of polysilicon films was obtained in Cl_2/Ar gas, and the high selectivity of polysilicon to photoresist was found in HBr/Ar gas. Finally, the etching of polysilicon films masked with photoresists was attempted in HBr/Ar and Cl_2/Ar gases. The good pattern profile of polysilicon films with 60 nm lines was achieved in an HBr/Ar plasma.

Key words: Polysilicon, Nanometer Pattern, High Density Plasma Etching, Cl_2, HBr

INTRODUCTION

The new memory devices, which can be applied to the smart phone, new personal computer with fast booting speed and various mobile devices, should be nonvolatile and low in cost. They should also have low power consumption and be easily integrated for high density levels. Recently, nonvolatile semiconductor memories (NVSM) have been extensively studied for the development of next generation memory devices. In the NVSM, there are two major technologies such as the floating-gate structure and the SONOS (polysilicon-blocking oxide-silicon nitride-tunnel oxide-silicon) structure. The principal and structural differences between two types of devices are the nature of the storage medium and the thickness of the tunnel oxide. As the process technology for the deposition of ultra thin silicon oxide film (1-5 nm) for SONOS structure has been developed, the SONOS structure has become a viable candidate for the scaled NVSM technology [French et al., 1995; Su et al., 1994].

The SONOS structure is composed of polysilicon thin film and ultra thin layers of silicon oxide and silicon nitride. Besides the deposition of ultra thin layers of silicon oxide and nitride, the etching of ONO (blocking oxide/silicon nitride/tunnel oxide) dielectric stack and the etching of gate polysilicon films with nanometer-sized patterns are regarded as the key process technology in the fabrication of SONOS structure. Since the thickness of ONO dielectric stack (5-10 nm) is so thin, the etching of the ONO stack is greatly affected by the etching of the polysilicon gate with nanometer-size patterns. In addition, the channel formation of the nanometer size by etching on an SOI (silicon on insulator) wafer is also important. The structure of the SONOS device is shown in Fig. 1. As the critical dimension of polysilicon gate for the SONOS structure diminishes down to the nanometer size, the use of a hard mask over a photoresist may be desirable in the etching of polysilicon thin films with nanometer-sized patterns. However, the etching process using a hard mask requires the additional processes containing the deposition and etching of a hard mask material [Yost et al., 2002; Desvoivres et al., 2000].

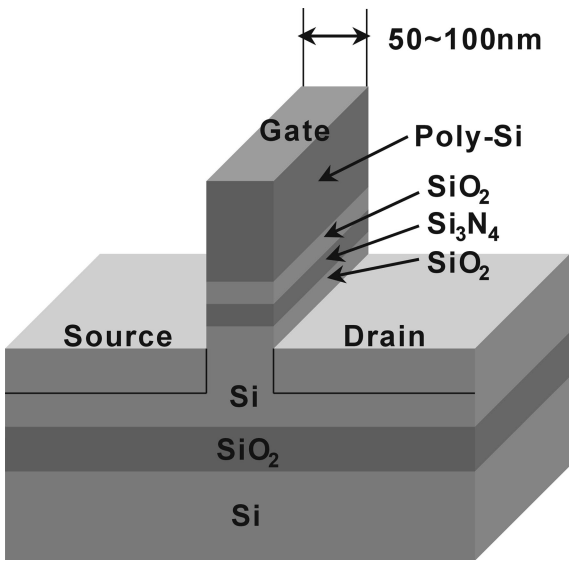

Fig. 1. The schematic of the SONOS structure in the nonvolatile memory device.

In this study, Cl_2 [Gadgil et al., 1992; Yi, 2001] and HBr [Xu et al., 2001; Vyvoda et al., 1998; Tuda et al., 2001] gases which have been known to show fast etch rate and good etch profile for polysilicon films were employed. The possibility of using a photoresist mask for the etching of polysilicon films with nanometer-sized patterns was explored in a high density plasma of Cl_2 and HBr gases. The effect of the etch gas on the etch characteristics of polysilicon films was examined and then the etch profiles of polysilicon films with the nanometer-sized pattern were compared.

EXPERIMENTAL

The polysilicon thin films were deposited on SiO_2/Si substrates by low pressure chemical vapor deposition (LPCVD) and silicon

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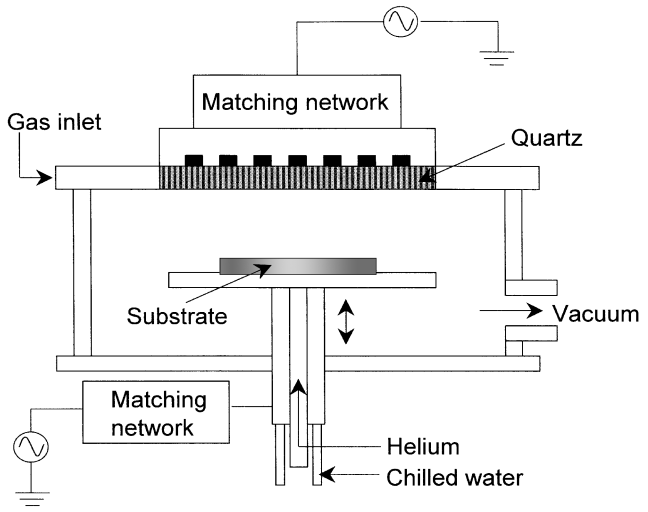

Fig. 2. The schematic of the ICP RIE system.

oxides were deposited on Si substrates by plasma-enhanced chemical vapor deposition (PECVD). For the etch rate and etch selectivity, polysilicon films of 300 nm in thickness were deposited and patterned with conventional photoresist (PR) by photolithography. For nanometer-sized patterns on polysilicon films, 100 nm-thick polysilicon films were prepared and e-beam lithography was employed. The pattern sizes formed by the e-beam resist were in the range of 50-100 nm.

The etch equipment used in this study was a high density inductively coupled plasma reactive ion etcher (ICPRIE). Two separate RF power supplies were utilized to this etch system. This etcher was equipped with an advanced cooling system that cooled the wafer by helium on a chilled substrate susceptor. A 13.56 MHz RF power was applied to the coil which was placed on the lid of the etching chamber to generate high density plasma. The substrate susceptor was connected to another RF power at 13.56 MHz, and a self-bias voltage induced by the RF power was capacitively coupled to the substrate susceptor to control ion energy. The schematic of this etch system is illustrated in Fig. 2.

In this study, chlorine and fluorine gas chemistries were chosen for the formation of the nanometer-sized patterns on polysilicon films. The etch rates of polysilicon and silicon oxide films were measured by a surface profilometer, and the etch profiles were observed by field emission scanning electron microscopy (FESEM). The effect of etch gas on the etch rate, etch selectivity and etch profile was investigated. Finally, the etching of polysilicon films with nanometer-sized patterns was carried out in Cl_2/Ar and HBr/Ar plasmas.

RESULTS AND DISCUSSION

The etch rates and etch selectivities of polysilicon thin films by using Cl_2/Ar and HBr/Ar gases are shown in Fig. 3. These etch results were obtained at the etch condition containing coil power of 600 W, gas pressure of 5 mTorr, and 200 V dc-bias to wafer susceptor. This condition was fixed as a standard etch condition through the entire etch experiment.

As the concentration of Cl_2 gas increases, the etch rates of polysilicon and photoresist increase, but the selectivity of polysilicon to

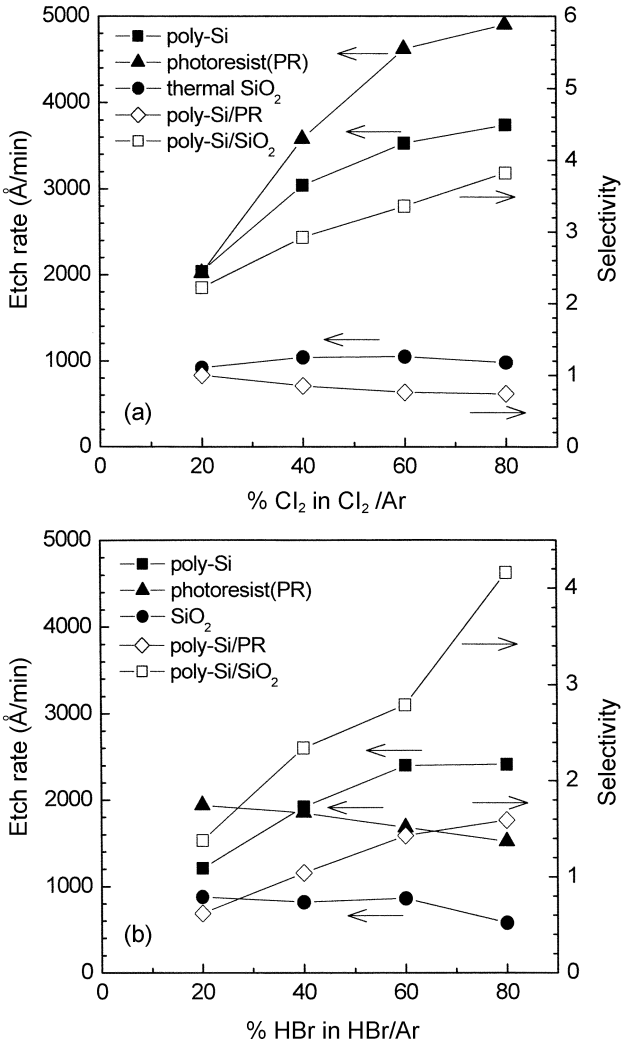

Fig. 3. The etch rate and etch selectivity of polysilicon thin films by (a) Cl_2/Ar and (b) HBr/Ar gases.

photoresist gradually decreases. The decrease of selectivity with increasing Cl_2 gas is due to the fact that the increase in the etch rate of photoresist is larger than that of polysilicon. This low selectivity indicates the corrosive nature of Cl_2 gas to the photoresist. The etch rate of silicon oxide is much lower than that of polysilicon so that the selectivity of polysilicon to silicon oxide is relatively high [Gadgil et al., 1992; Yi, 2001].

In the case of HBr gas, as the concentration of HBr gas increases, the etch rate of polysilicon increases while that of photoresist decreases. As a result, the selectivity of polysilicon to photoresist is greatly enhanced. The phenomenon of decreasing in the etch rate of photoresist with increasing HBr gas can be explained by the fact that the protection layer formed on and at the side of the photoresist survives longer than that formed on the polysilicon [Vyvoda et al., 1998; Tuda et al., 2001; Chung et al., 2002]. The etch rate of silicon oxide is low and the selectivity of polysilicon to oxide becomes high. From these results, the fast etch rate of polysilicon films was found in a Cl_2/Ar gas and an HBr/Ar gas showed higher selectivity of polysilicon to photoresist than a Cl_2/Ar gas. High selectivity of polysilicon to silicon oxide, which is critical for the channel forma-

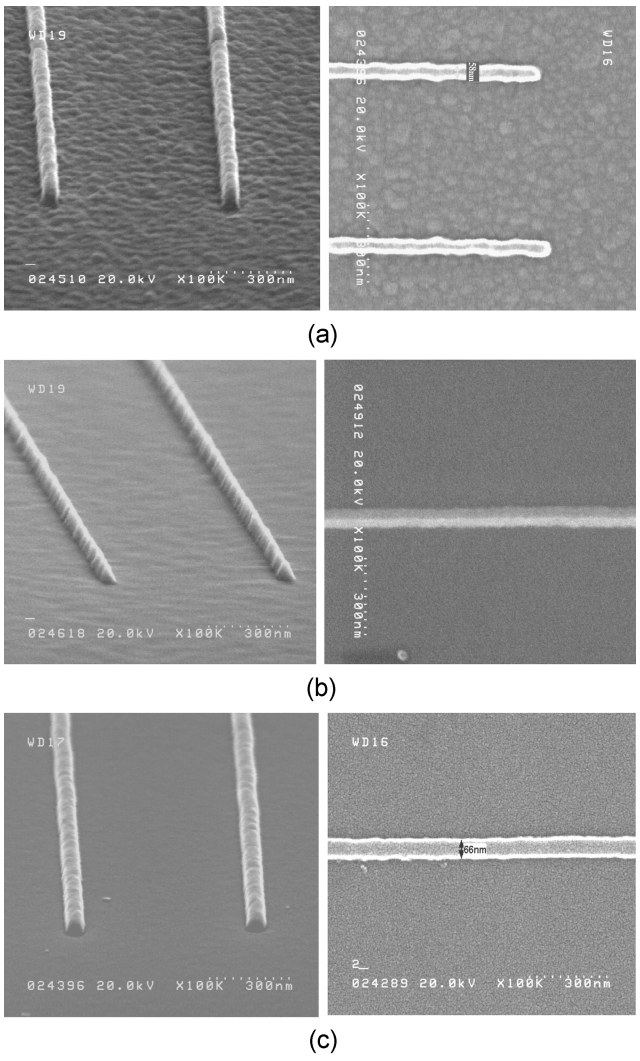

Fig. 4. FESEM micrographs of the polysilicon thin films etched by (b) Cl_2/Ar and (c) HBr/Ar gases. The resist profile before etching is shown in (a).

tion by the etching on a SOI wafer, was obtained in both Cl_2/Ar and HBr/Ar gases.

The etching of polysilicon thin films with nanometer-sized patterns was carried out in order to examine the effect of etch gas on the etch profile. The mask pattern was formed by e-beam lithography using polymethylmethacrylate (PMMA) [Gaboriau et al., 2000]. The gas concentrations of Cl_2 and HBr gases were fixed at 40%, respectively. Fig. 4 shows the etch profiles of the polysilicon thin films etched with Cl_2 and HBr gases for 60 nm lines. The profile of e-beam resist before the etching is also given in Fig. 4(a) for comparison. The resist profiles are well defined with a vertical wall for the 60 nm line.

Fig. 4(b) is the etch profile etched with Cl_2/Ar etch gas. The sidewall angle of the etched pattern was shallow compared to the resist profile before the etching. This result shows the typical etch characteristic of Cl_2 gas, which erodes in the lateral direction as well as the vertical direction of the film. When HBr/Ar gas was used to etch the polysilicon films, an etch pattern with a high degree of anisotropy was obtained, which was almost comparable to the resist profile before the etching. It is notable that the selectivity of polysilicon to photoresist in HBr/Ar gas is higher than that in Cl_2/Ar gas. From the comparison of two etch profiles of polysilicon with nanometer-sized pattern, it is evident that HBr/Ar gas is more effective in achieving the vertical etch profile than Cl_2/Ar gas. These results seem to be related to the selectivity of polysilicon to photoresist.

As a result, the etch chemistry is considered as one of the critical factors in the etching of polysilicon films with nanometer-sized pattern. A further study for the nanometer-sized etching of polysilicon thin films remains to examine the effect of etch parameter on the etch profile.

CONCLUSIONS

Inductively coupled plasma (ICP) etching of polysilicon thin films by using a photoresist was carried out for nanometer-sized patterns. Cl_2, and HBr gases were employed, and the etch rate, etch selectivity and the etch profile of polysilicon films were examined. The etch rate of polysilicon films was fast in Cl_2/Ar gas, and high selectivity of polysilicon to photoresist was obtained in HBr/Ar gas. High selectivity of polysilicon to silicon oxide is critical for the channel formation by the etching on a SOI wafer and was attained in both Cl_2/Ar and HBr/Ar gases.

In the etching of polysilicon films with a nanometer-sized pattern of the 60 nm line, good etch profiles with high fidelity were achieved in HBr/Ar gas chemistry. The etch profiles of polysilicon films with a photoresist appear to be related to the etch selectivity of polysilicon to photoresist. It is concluded that polysilicon thin films with nanometer-sized pattern can be etched with good etch profiles by using a photoresist mask.

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