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The Application of Gas Plasma to the Fabrication of MOS LSI

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The improvements of the photolithographic and etching techniques are very important to form more and more devices on a chip and increase the wafer yield. The conventional wet-chemical etching and stripping techniques have been used to etch silicon, silicon dielectric films and also chromium or chromium oxide films and to remove photoresist film used as an etching mask. These techniques, however, require various kinds of chemicals, which make inevitably the process and etching conditions complex. Futher, the chemical etching techniques show the inherent demerits such as an undercutting which reduces the yield and reliability of devices.

Recently, the gas plasma techniques for stripping of the photoresists and etching of silicon, silicon dielectric films and also chromium or chromium oxide films have been extensively developed. These new gas plasma techniques are found to overcome the demerits inherent to the conventional chemical techniques. In our factories, the conversion from the conventional chemical process to the new process with gas plasma techniques was successfully achieved in fabrication process of MOSLSI, Bip IC and hard masks.

The gas plasma techniques consist of gas plasma etching of silicon, its compounds, chromium and chromium oxide films and gas plasma stripping of photoresists. Freon gas plasmas generated by rf discharge at 13.56 MHz are used to etch Si, Poly-Si, SiO_2 and Si_3N_4 films. Chloric gas plasmas are available to etch Cr and Cr_2O_3 films. Oxygen gas plasmas are also available to remove the photoresists which does not contain the inorganic impurities. The etching and stripping mechanism is considered to be a surface chemical reaction between the above mentioned films and the radicals contained in gas plasmas.

In Fig. 1, the etching characteristics of single Si, poly-Si, thermally grown and CVD SiO_2, and Si_3N_4 by freon gas plasma are shown. From a point of view of production techniques, it is very important that freon gas plasma can etch Si_3N_4, Poly-Si about ten times as fast as it etches SiO_2 and their etch rates are in order of Poly-Si, Si_3N_4 and SiO_2, because in the usual MOS LSI or Bip IC, Si_3N_4 and Poly-Si films overlay SiO_2 layer and then gas plasma etching of Si_3N_4 and poly-Si films can be controlled closely enough to prevent it from etching the silicon substrate. For example, when Si_3N_4 film of 2~3000 Å, which is usually used as a selective oxidation mask in SOP process is etched by gas plasma, an underlying silicon oxide layer of several hundred angstrom can prevent gas plasma from etching silicon substrate due to non-uniform etch rate within the surface of 2 inch or 3 inch wafer. Further, as is easily found from Fig. 1, dry etching technique with freon gas plasma which is non-specific etchants for silicon and its compounds can give one solution to a problem of how to form a sloped multi-dielectric film layer such as Si_3N_4-SiO_2, Poly-Si-SiO_2, and Poly-Si-Si_3N_4-SiO_2 structure. Our experiments show that a sloped multi-dielectric film layer with an average angle of 60~70° can be easily obtained by etching these multi-dielectric film layers using a continuous gas plasma etching method, and there is no disconnection of $A\ell$-metalization at the edge of the sloped layers. This causes the increase of the wafer yield and the reliability of the integrated circuits.

One of the advantages of gas plasma etching techniques is the fact that a conventional photoresist film can be used as an etching mask to etch Si_3N_4 and poly-Si films as well as SiO_2, Cr and Cr_2O_3 films. This fact results in the simplification of the fabrication process of the integrated circuits due to the omission of the deposition step of mask CVD SiO_2 film over poly-Si or Si_3N_4 film, and the other associated step and causes the reduction of the pattern defects and the increase of the wafer yield. Further, the photoresist film are not post-baked necessarily, because the reactants such as fluorine or chlorine radicals in gas plasmas can not penetrate the interface between the photoresist film and the underlying film. The photoresist film used as etching mask can be easily removed using oxygen gas plasma which reacts with only the organic components in the photresist. This process must be performed with another plasma machine or an exclusive chamber for the removal in order to avoid the contamination except for the hard mask making process.

One of the important advantages of the dry process with gas plasma is the fact that MOS LSI, Bip IC chips and Cr-mask with high line accuracies can be easily manufactured, because there is little undercutting in gas plasma etching. In Fig.2, the relation between the pattern sizes W_2 after etching of Si_3N_4 film of about 2500 Å and those W_1 after development of photoresist is shown for wet-chemical and plasma etching process. Thus, the image patterns with accuracies within $\pm 0.5\mu$ can be easily obtained using gas plasma etching method. Further, Cr-patterns with no undercutting can be obtained by gas plasma etching method. The quantities of pattern-shift with this Cr-mask are less than $\pm 0.3\mu$ for negative and positive images, although those with Cr-mask produced by wet-chemical etching method are about $\pm 1.0\mu$ for both images. These means that plasma etching is an ideal etching technique for the fabrication of LSI and Cr-masks which need fine patterns with high accuracies.

These gas plasma techniques do not cause any degradation of the electrical characteristics and reliabilities of MOS LSI, and Bip IC's, because the initial damages due to the bombardment of charged particles in plasmas can be easily annealed out by the temperature treatment after gas plasma treatment. The simplification of the fabrication process and the increase of wafer yield can be achieved using dry process with gas plasmas.

Fig. 1

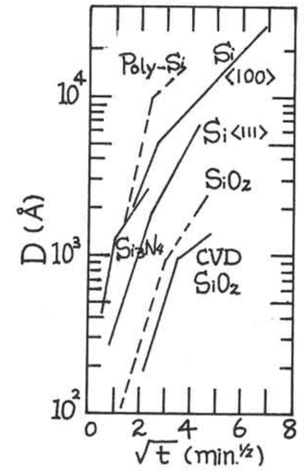

Fig.2