A UHF-ECR Plasma Etcher for Insulation Films

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OVERVIEW: In the rapid evolution of VLSI technology toward smaller geometries and increased levels of chip integration, minimum features of 0.18 μm are already being mass produced, and feature sizes of 0.13 μm are being developed. At the same time, 300-mm fab lines are being built, and this is driving a demand for new etching technologies that support smaller tolerances and larger wafer sizes. Insulation layer etching demands good selectivity between mask and substrate and high-aspect vertical processing to deal with increasing aspect ratios and thinner mask thicknesses that go along with shrinking geometries and increasing integration levels. Meanwhile, damascene processes (electroplating for chip interconnects) using a combination of low-κ (low dielectric constant) insulation materials and Cu interconnects are being investigated, and etchers capable of processing these structures will be in great demand. To address these issues, we have developed an insulation layer etcher that uses UHF-ECR (ultra high frequency electron cyclotron resonance) plasma. The unique advantages of this approach are that it enables good control over CF_2/F radicals, an important etchant for selectivity and high-aspect openings, and good control over the ratio of ions to CF_2, which is important in achieving vertical profiles. This etcher is capable of (1) producing stable and uniform medium-to-high density plasmas over a large area at low-to-medium pressures using UHF wave (450 MHz) ECR, and (2) increasing the doubled-near-surface effect and good radical ratio control through control over the UHF wave flat antenna and antenna bias. Taken together, these capabilities amount to a powerful plasma process tool able to process fine features below 0.13 μm.*

INTRODUCTION

DEVICE structures and material systems are also undergoing tremendous changes as integration densities increase and feature sizes decrease (see Fig.1). Besides increasing the aspect ratio of self-aligned contact (SAC) and high aspect ratio contact (HARC) processes, low dielectric constant materials such as SiOF and SiOC and organic films are being investigated for interlayer insulation films[1]. At the same time, a damascene process for Cu on-chip metallization is starting to become viable[2], and this is fueling demand for more sophisticated plasma processing technologies for etching that can readily adapt to diverse processes.

Meanwhile, the scale-up of wafer size to 300-mm diameter not only requires better uniformity across a larger area, it also mandates lower levels of contaminants, less charging damage, and reduced running costs, all at the same time.

Hitachi, Ltd. has sought to accommodate these demands with the development of a UHF-ECR (ultra high frequency electron cyclotron resonance) plasma processing tool designated U-622. This article will give an overview of the U-622, highlighting the system's primary features, performance, and a number of process application examples.

KEY FEATURES OF THE UHF-ECR PLASMA PROCESSING TOOL

Insulation layer etching proceeds various radicals dissociated from fluorocarbon gas coupled with ion-

*Doubled-near-surface effect: The rebombardament of back-to-back wafers due to diffusion by products of surface reactions.

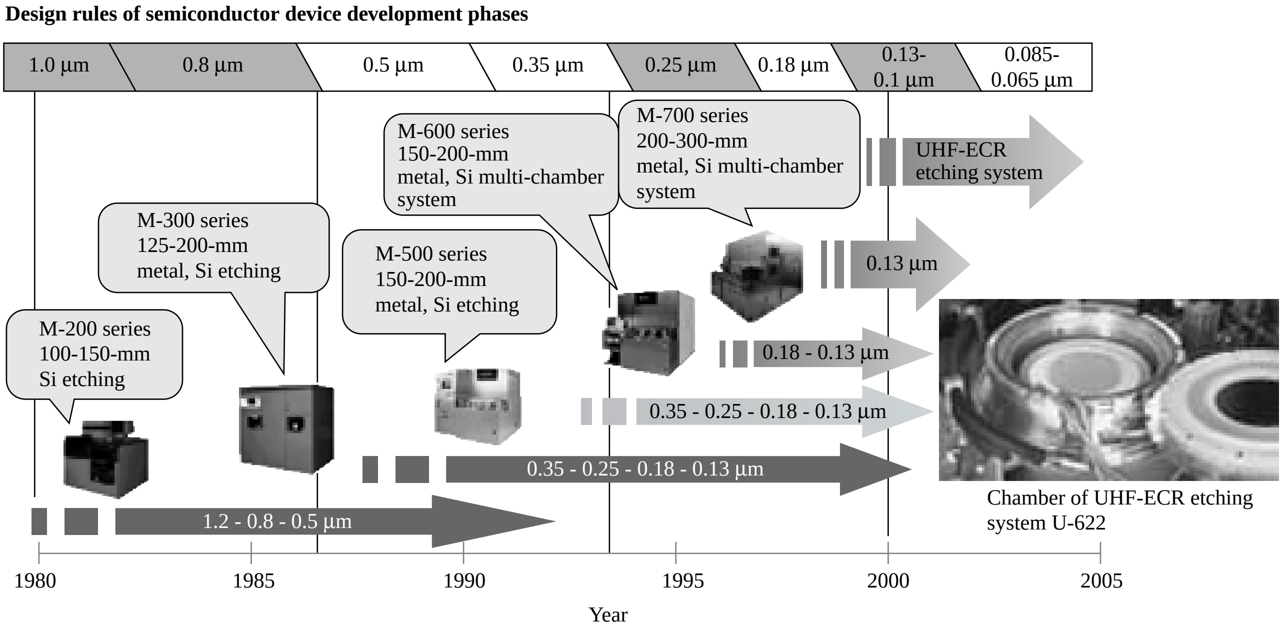


Fig. 1—Road Map Depicting Design Rules and Dry Etching Systems for Different Semiconductor Device Development Phases.
UHF-ECR etcher proposed by Hitachi, Ltd. as a powerful plasma process tool capable of processing fine features below 0.13 µm.

assisted etching reactions. This means that to achieve greater etch accuracy, it is essential to impose greater control over dissociation species bombarding the wafer. Among these dissociated species, controlling the ratio of CF_2/F radicals affects the selectivity of the mask and the substrate and high-aspect openness.

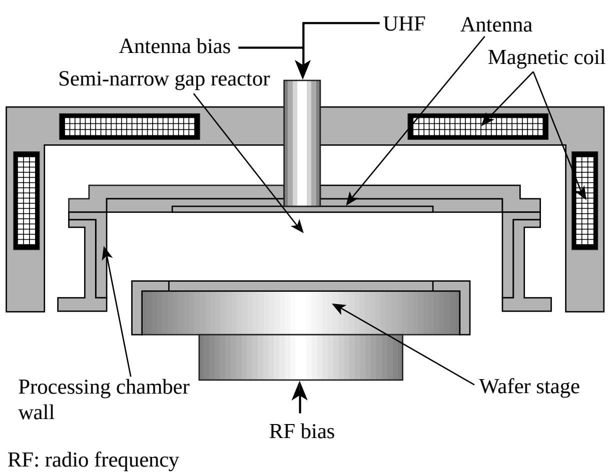


Fig. 2—Schematic Representation of Insulating Layer UHF-ECR Etching Chamber.
Stable, uniform plasma is produced in a semi-narrow gap by UHF waves from a flat antenna coupled with magnetic field.

Control of the ion ratio to CF_2 is also important, for this affects the etching profile.

By achieving better control over these parameters, our UHF-ECR etcher is capable of etching 0.13-µm and smaller features. Fig. 2 shows a schematic representation of the etching chamber for insulating layers.

Here we will highlight two main features of the UHF-ECR system:

(1) The ECR plasma is formed using 450-MHz UHF waves. This enables the formation of a medium-to-high density plasma at low-to-medium gas pressure that is required for fine feature processing. Fig. 3 shows measured plasma densities as a function of UHF power at various gas pressures. The figure reveals that densities of 10^{11} to 10^{12}/cm^3 are stably and continuously generated when pressures are held at 0.5 to 3 Pa.

In addition, the current density uniformity of ions bombarding the wafer is also less than ±10% across the 300-mm wafer (see Fig. 4).

(2) The UHF waves are introduced to the chamber using a flat antenna structure. There is a gap of 30 to 100 mm between the flat antenna and the wafer, and in this semi-narrow gap, the number of collisions between gas molecules and electrons is reduced due to limited plasma volume, and F atom radicals are

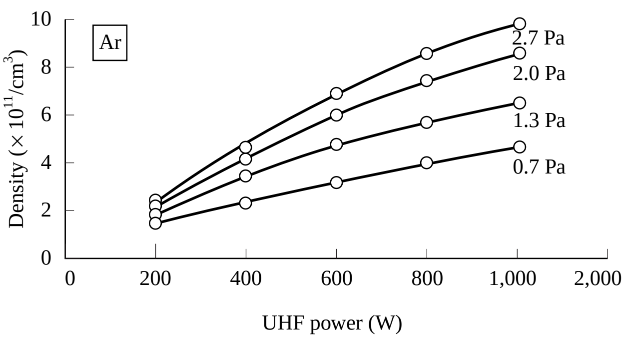


Fig. 3—Measured Plasma Density as a Function of UHF Power.
Medium-to-high density plasma is stably produced at low-to-medium pressure.

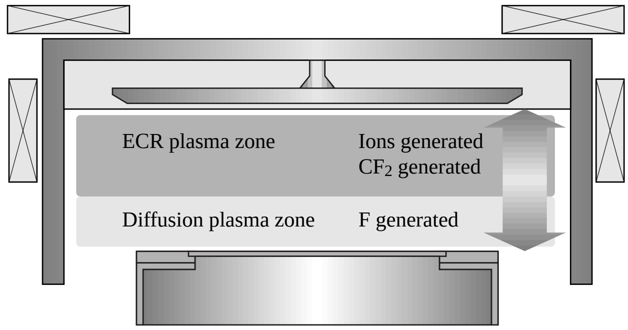
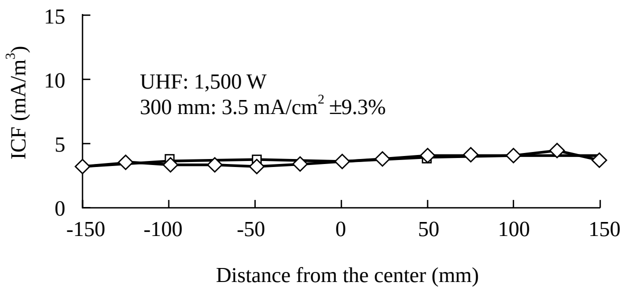


Fig. 5—UHF-ECR Plasma Structure.
UHF-ECR plasma is generated under the flat antenna, and diffused over the area below that. The ratio of F atom radicals to CF_2 can be controlled by controlling the size of the ECR plasma area and the diffused area.



ICF: icon current flux
◇ : X axis □ : Y axis

Fig. 4—Measured Current Density Distribution of Ions Bombarding Wafer.
A uniform plasma is produced over a 300-mm area using the UHF flat antenna structure.

controlled by excessive dissociation of chemical species. What is more, the efficiency of conversion to active species is increased by the doubled-near-surface effect due to rebombardament by products of surface reactions between the biased wafer and the biased flat antenna[3]. This configuration results in an ECR plasma zone beneath the flat antenna of about 30 mm and diffusion plasma zone under the ECR plasma zone. The ECR plasma produces ions and relatively high concentrations of CF_2 radicals. The diffusion plasma zone produces relatively high concentrations of F radicals (see Fig. 5).

Using the gap and antenna bias to independently control the plasma source and optimizing the ratio of CF_2 to F radicals, wide process applications — holes, masks, damascene trenches, vias, and so on — can be accommodated.

ETCHING PROCESS EXAMPLES

High-aspect-ratio Hole Processing

In hole processing, balance must be achieved among CF_2, C and F radicals dissociated from fluorocarbon gas, and a number of parameters must be improved: high-aspect apertures, vertical profiles, and selectivity to masks[4].

In the U-622 etcher, the hole aperture and selectivity of mask and substrate is reconciled by reducing the gap and controlling the antenna bias. Processing examples of a 0.1-µm hole with an aspect greater than 20 and a self-aligned contact (SAC) are shown in Figs. 6 (a) and (b), respectively.

Low-κ Material Damascene Processing

A number of different materials are being evaluated for use as a low-κ (low dielectric constant) insulation material including SiOF, SiOC, and organic films. There is thus a ready demand for an etcher that can support etching processes tailored to these different materials.

One of the virtues of the UHF-ECR system is that it is capable of producing stable gas pressures and plasma densities over a wide range, so it can be readily adapted to low-κ damascene process applications.

In etching damascene structures, the selectivity of the mask and stopper layer and precise critical dimension control are even more exacting; for this etching, a good vertical profile and mask/stopper layer selectivity is obtained by slightly widening the gap between the antenna and wafer.

Fig. 7 shows SiOF layer damascene structure processing examples. Mask losses are minimized with a taper angle of 87.5 degrees. Similar examples for

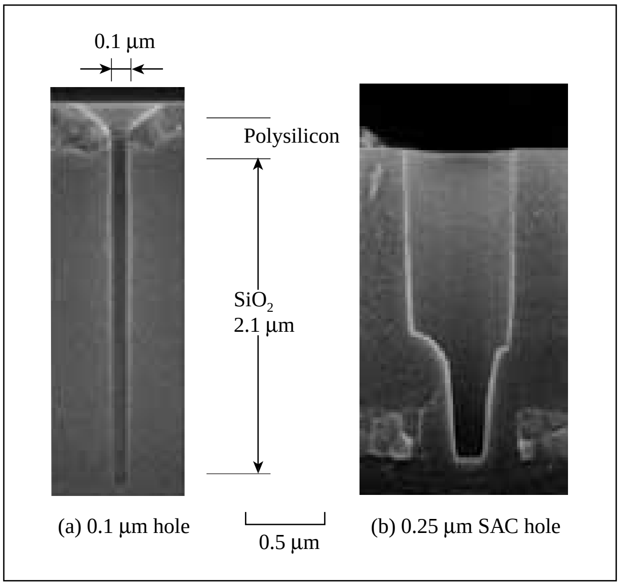


Fig. 6—Examples of Hole Etching Processing.
Good hole opening and high mask selectivity are obtained by controlling CF_2/F radicals ratio and CF_2 to ion ratio. In self-aligned contact (SAC) processes, good vertical profile and high SiN shoulder selectivity are obtained.

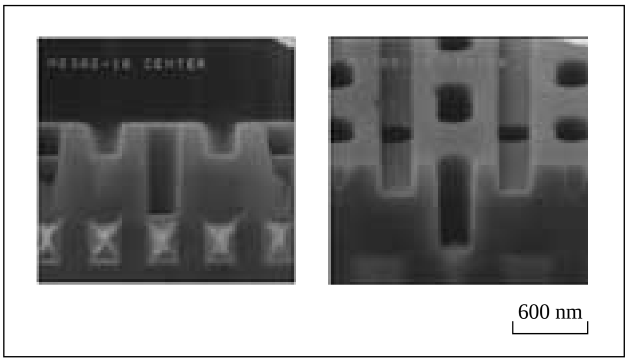


Fig. 7—Examples of SiOF Film Damascene Etching Processing.
In UHF-ECR etchers, processes for etching damascene masks, holes, trenches, and bottom films can be easily implemented by controlling the gap and antenna bias.

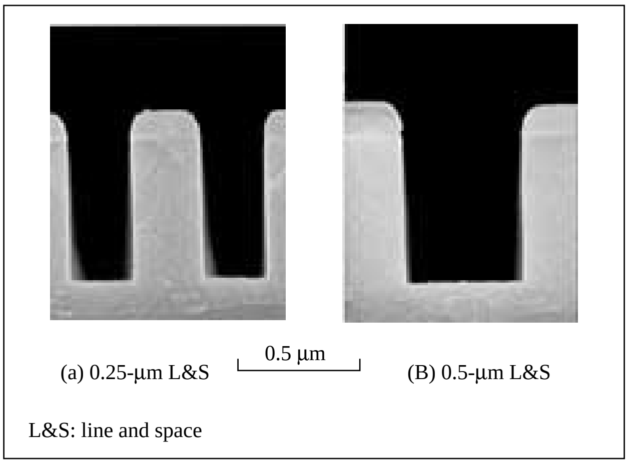


Fig. 8—Examples of Organic Film Etching.
By controlling the antenna bias and wafer bias, excellent vertical profile, mask selectivity, and non residue etching are obtained.

organic film processing are shown in Fig. 8. In this case, however, besides the selectivity of the mask, all unwanted residual materials must be removed. Vertical profile without any residual material can be achieved by optimizing the wafer bias and the antenna bias.

We have seen that UHF-ECR plasma etching technology is capable of etching high-aspect holes with excellent selectivity by controlling CF_2/F radical ratio and CF_2 to ion ratio, and that this type of etcher can be applied to wide process applications including damascene and mask etching that have more exacting critical dimension tolerances.

SYSTEM PERFORMANCE

The UHF-ECR etcher for insulating layers is configured as a dual chamber system featuring Hitachi's M-600 series equipment for 200-mm wafers, and the company's M-700 series for 300-mm wafers, and sharing a common base-frame. Reliability of the base-frame including wafer transfer, control system, and software are demonstrated previously in many customers' plants. For handling 300-mm wafers, a commercial version front opening unified pod (FOUP) loader that is compliant with Semiconductor Equipment and Materials Institute (SEMI) standards will soon be available.

The low-aspect chamber and low magnetic field coil structure are also unique to UHF-ECR processing; by providing swappable kits for the small chamber volume, maintenance can be carried out in under four hours.

Fluorocarbon and other gases that are high deposition chemistries are used in insulation layer etchers to boost process performance. A potential problem is that gas emitted from the deposition layer can interfere with the stability of the etching process. This is addressed by maintaining the temperature in the chamber at less than 80˚C, which effectively controls gas emissions from the deposition layer. Fig. 9 shows continuous processing test results for the etcher. Maintaining a constant temperature in the chamber, stable etch rate and profile were obtained during more than 100 hours of discharge time.

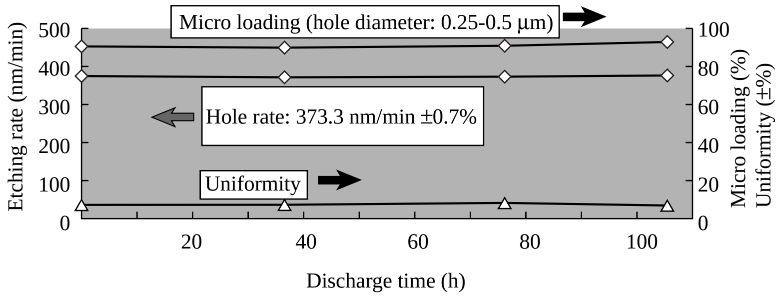


Fig. 9—Continuous Processing Stability Test Results.
In the UHF-ECR chamber with temperature control function, a high-degree of stability is obtained after 100 hours of discharge time.

CONCLUSIONS

In this article, we have presented an overview of the UHF-ECR plasma etcher U-622 for insulation layers, a powerful plasma process tool capable of processing fine features under 0.13 µm.

An etching system for insulation layers must be capable of accommodating a wide range of process applications including high-aspect holes, masks, and low-κ damascene structures. By providing enhanced controllability of radical concentrations and ratios of ions to radicals, the U-622 etcher can be easily adapted to a wide range of process structures. Currently, UHF-ECR plasma process systems are developed for gate and metal etching[5], we are confident that these etchers will emerge as the solution tools of choice for fine feature etch processing.

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