Characterization of a Selectable-Mode Inductively Coupled Plasma (ICP_{SM}) Source for Advanced Dry Residue Removal Applications

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Abstract

A unique Selectable-Mode Inductively Coupled Plasma (ICP_{SM}) source has been characterized for advanced dry residue removal applications such as via cleaning, high dose implant resist strip, and post metal etch residue removal. The ion probe measurement showed extremely low ion current as compared to typical etchers. Both surface charge test using the SPV technique and CHARM-2 damage test showed no significant charge damage on test structures. Gate oxide integrity (GOI) was determined by measuring breakdown voltage, leakage current, and threshold voltage shift. The results showed no degradation of breakdown voltage levels, no increase in gate leakage, or shift in threshold voltage on the test structures with gate oxide as thin as 45 Å.

Introduction

Cleaning of post etch residues has become a very challenge process. Typical down stream plasma strip processes can no longer fulfill the need for this type of application. Wet processing is commonly used after strip in order to achieve clean results[1]. However, with a small amount of ion bombardment along with fluorine gas addition (e.g. CF4), tough residues such as post oxide etch via veils, post metal etch sidewall polymers, or high dose implant resist can be removed completely in a dry plasma strip system [2].

In this paper, a unique Inductively Coupled Plasma (ICP) source with the ability to operate in two different modes will be described. This ICP_{SM} source has been demonstrated to be an ideal source for advanced strip applications and will be described in detail.

ICP_{SM} Source Characterization

The ICP_{SM} source used in this study is a modified version of the field proven Aspen ICP source. The ICP_{SM} source utilizes a patented Faraday shield. The Faraday shield is electrically floating and can be grounded through an RF relay as shown in figure 1.

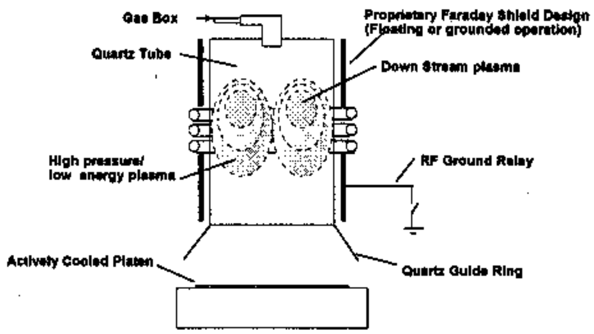

Fig.1 ICP_{SM} Source characterization

This allows the ICP_{SM} source to be operated in two different modes: an extremely low ionization mode when the Faraday shield is grounded (almost purely inductive coupling) [3] and a more excited mode with a small mount of capacitive coupling, when the shield is floating [2]. By controlling the status of the Faraday shield, it is possible to control the density and potential of ionized species in the plasma. This makes the ICP_{SM} source ideal for advanced strip processes like HDIS applications where a two-step process is utilized: the first step is optimized for crust removal with a small amount of ion assisted etching, and the second step is optimized for bulk photoresist stripping with minimum potential sodium drive in.

The ion current measurements for typical RIE type etchers and HDP etchers are compared to the measurements collected on the ICP_{SM} source. A Langmuir probe was used to measure the ion saturation current at the wafer surface with the Faraday shield in different modes. As shown in Figure 2, the ion current densities are extremely low (at <1E-5 A/cm^2). When the shield is grounded the ion density is 10 times lower than when the shield is floating (Lower ion current is preferred for bulk resist strip to minimize oxide loss and contamination drive-in). The small amount of ions that are created in the floating mode provide enough bombardment for residue removal without causing damage to the devices.

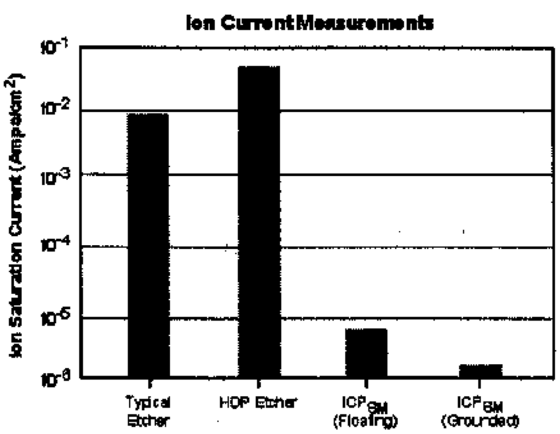

Fig.2 Ion saturation current

The voltage on the Faraday shield when in a floating mode was measured as functions of RF power and pressure, as shown in Figure 3. The shield voltage increases as RF power decreases, indicating a higher amount of capactive coupling to the shield. Higher pressure also showed a higher level of capacitive coupling, as indicated by higher voltage on the shield. Therefore, by simply varying these two parameters, one can easily control the amount of capacitive coupling for specific process needs. In this way, damage free process can be accomplished.

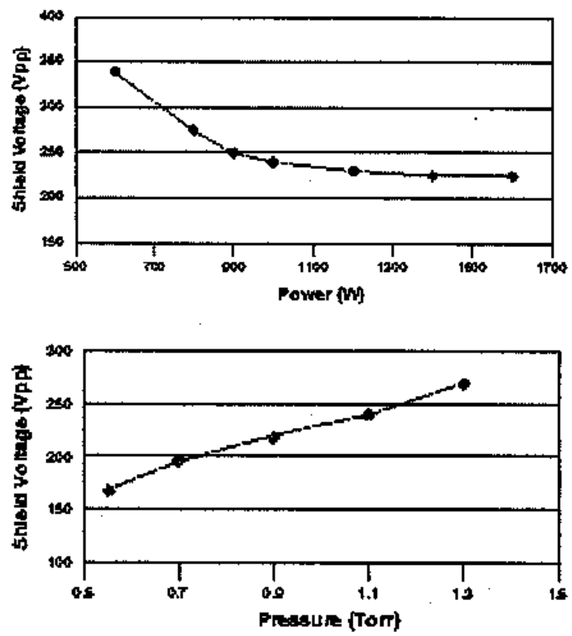

Fig.3 Shield voltage change as functions of RF power and pressure

Charge and Device Damage Results

To fully evaluate plasma damage performance, tests were conducted on both charge damage monitoring wafers and device test wafers. These results will be discussed below.

Figure 4 shows surface charge test results using Semiconductor Diagnostic, Inc. (SDI) Plasma Damage Monitor (PDM) system. Surface charge was measured using SPV technique on 1000 Å thermal oxide wafers [4]. V_{pdm} readings were well below the threshold of charge damage (< 5.0 V_{pdm}) for both grounded and floating modes.

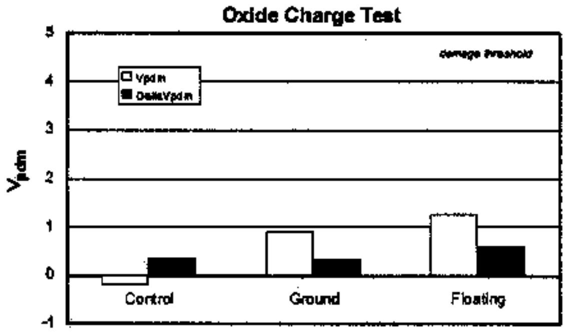

Fig.4 Oxide charge test results

A charge monitor wafer (referred to as a CHARM-2 wafer) was also used to test plasma charge damage. The CHARM-2 test structure is a floating gate EEPROM device which collects charges across the whole wafer (mapping) [5]. The CHARM-2 wafer was pre-measured before being processed with the ICP_{SM} source. Post measurements were performed to reveal any potential charge up on the devices. The results for all parameters (positive potential, negative potential, positive ion flux, and negative ion flux) showed no charge damage after being processed with ICP_{SM} source.

Gate Oxide Integrity (GOI) was evaluated by measuring breakdown voltage, gate leakage current, and threshold voltage shift using different antenna structures. Figure 5 illustrates the breakdown voltage distribution after being processed with ICP_{SM} source. The test structure used for this test had an 80 Å thick gate oxide with an antenna ratio of 100,000:1. No significant shift was observed as compared to the reference wafer, which did not receive any plasma processing.

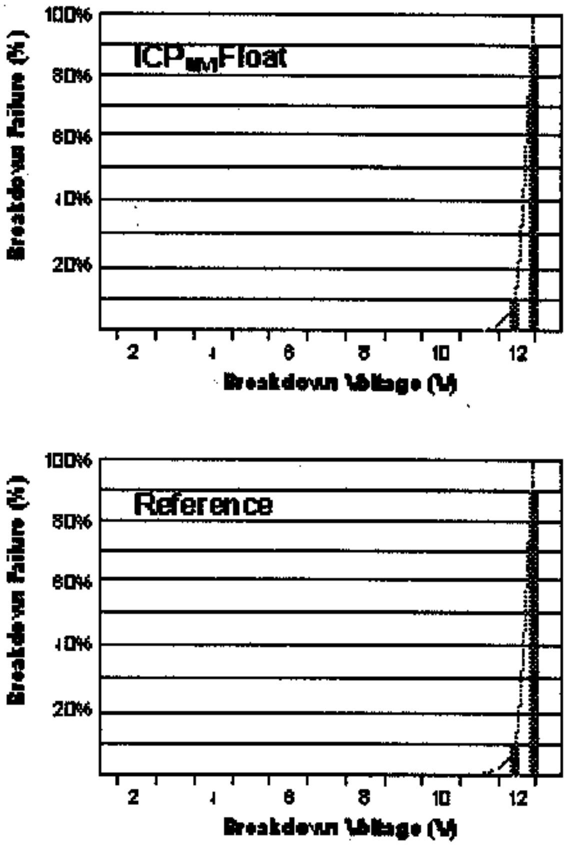

Fig.5 Breakdown voltage comparison

Sematech SPIDER-MEM wafers were also used as plasma damage monitors [6]. In these tests, both gate leakage and threshold voltage shift were monitored. Figure 6 shows the gate leakage current for different antenna ratios with gate oxide thickness as low as 45 Å. Monitoring wafers were processed using a two step process (floating shield at the first step then switched to ground mode for the second step). Figure 7 shows the threshold voltage shift for the same test. As indicated in both figures, no increase in the gate leakage current or shift in threshold voltage was observed.

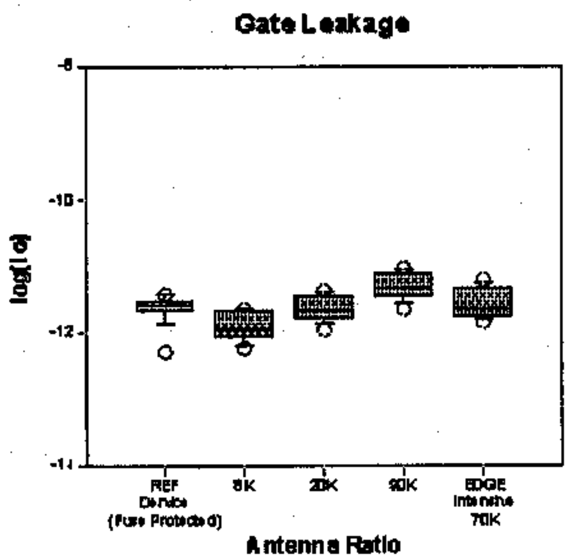

Fig. 7 gate leakage current distribution

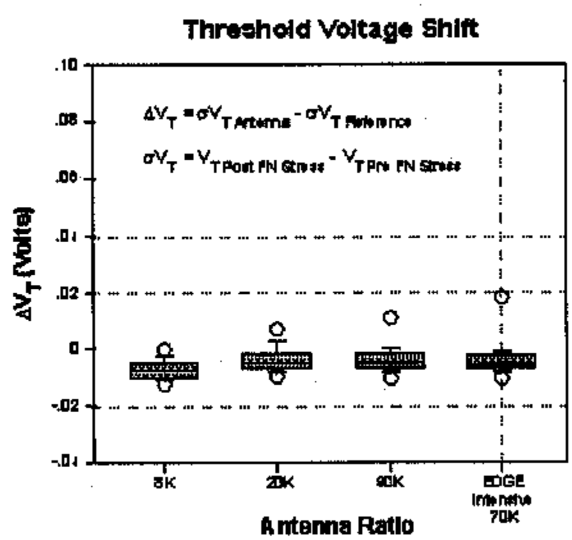

Fig.8 threshold voltage distribution

Conclusion

A unique selectable-mode ICP source was developed for advanced dry plasma strip/cleaning applications. This source allows two modes of operation, which provides flexibility for optimization of damage free residue removal processes. Extensive damage studies demonstrate that no plasma charge damage was induced by the ICP_{SM} source in grounded or floating mode.

References

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