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Impact of Etching Chemistry and Sidewall Profile on Contact CD and Open performance in Advanced Logic Contact Etch

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Abstract

As the advanced logic semiconductor technology moves to 65nm node and beyond, contact etch process technology has encountered significant challenges, such as inadequate top-view contact open of high aspect ratio, insufficient amount of photo-resist (PR), and the undesirable trade-off between polymer-rich etch process for enabling the critical dimension (CD) shrinkage and polymer-lean etch process to enlarge the process window. In this paper, we focus on resolving these challenges. Results obtained demonstrate that (a) CHF_3 delivers the best top-view of contact hole, (b) lower ratio of source power to bias power gives more vertical profile of contact hole, and (c) O_2 ratio, with respect to other etchants, is also an effective knob to control contact open window.

Introduction

As the advanced logic technology is scaled to 65nm node and beyond, the contact etch has been shown to play a key role for the robust function of integrated circuit. The control of sidewall profile, CD uniformity, selectivity to under layer, and contact open in contact etch processes are becoming intensively critical for yield enhancement. Currently, the post-etch CD is required to shrink the pre-etch CD by more than -35nm (CD bias) due to lithography limitations. Such a large CD shrink in contact etch processes poses challenges to ensure free open contacts for high aspect ratio conditions. The large CD bias also necessitates a polymer rich etch process to enable the CD shrink. Polymer rich etch tends to reduce the process window for free open contacts and impacts the sidewall profile of high aspect ratio contact hole and CD uniformity. All these requirements are increasingly tightened by the electrical specifications [1-4]. A thinner photoresist layer with less resist scumming is the desired starting point for etch. However, this demands a higher etch selectivity to photoresist to protect the contact hole from roughness. In this work, we study these emerging issues in 65nm contact etch and beyond and present corresponding solutions. The influence of etching chemistry/gas ratio, the ratio of source power to bias power, and the amount of critical etchant gas O_2 on contact etch process have been investigated.

Experiment

Three different of etching gases, CH4, CHF_3, and CH_2F_2, and the corresponding gas ratios were examined in the mask open step, with percentages obtained from our previous researches. The source power, the bias power, and their ratio in the main etch step are varied for sidewall profile of the contract hole. The gas ratio of fluorine-carbon to oxygen in the main etch step, found as the dominant factor impacting the final contact open, is also investigated. The contact CD and the hole roughness were monitored with a Hitachi CD-SEM (Scanning electron microscope) tool. Transmission electron microscope (TEM) was used to check the sidewall profile. The corresponding contact open performance was inspected by electronic beam inspection (EBI) defect scan right after contact tungsten polishing process.

Results and Discussion

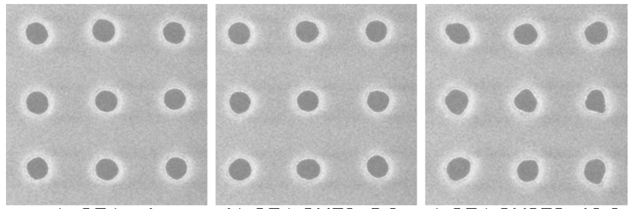
3.1 Effect of etching chemistry and gas ratio on CD and contact hole roughness

CF_4 gas is the primary etchant gas in mask open step. Either CHF_3 or CH_2F_2 is introduced into this step for the purpose of generating more polymer during this step, which helps to enable the CD shrink from incoming defined contact hole. The gas ratio experiments and corresponding results are summarized in Table 1. CH_4/CHF_3 ratios were changed from 3.3 to 10. Due to the thick polymer deposition of CH_2F_2, the ratio of CH_4/CHF_3 is selected as the half of that of CH_4/CH_2F_2 to achieve the on-target CD. Their impact is evaluated based on the final AEI CD and hole roughness (circularity). Etch selectivity to PR is also included.

Table 1 Effect of etching chemistry and gas ratio on AEI CD and roughness

Condition	Etchant chemistry	Etchant gas ratio	AEI CD, nm	CDU, nm	Circularity, nm	Etch selectity to PR
1	CF4	CF4 only	a+8	6	0.4	2.4
2	CF4+CHF3	CF4 : CHF3 = 10.0	a+4	6	0.5	1.8
		CF4 : CHF3 = 5.0	a	4	0.5	1.2
		CF4 : CHF3 = 3.33	a-1	4	0.9	1.0
3	CF4+CH2F2	CF4 : CH2F2 = 20.0	a+3	7	1.5	0.9
		CF4 : CH2F2 = 10.0	a	6	1.9	0.8
		CF4 : CH2F2 = 6.66	a-5	5	2.1	0.6

Note: Value "a" is the final CD target.



a). CF4 only b).CF4:CHF3=5.0 c).CF4:CH2F2=10.0

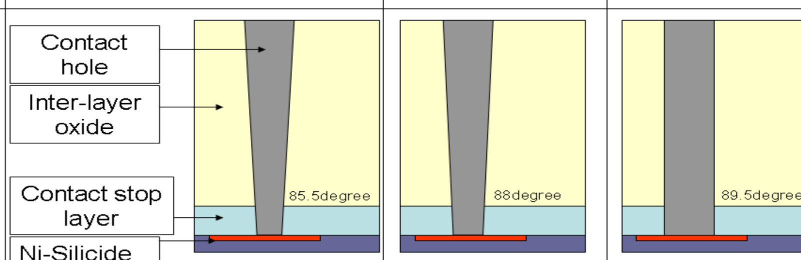
Figure 1 Typical top view of contact hole under different polymer gas conditions

Results show that the introduction of either CHF_3 or CH_2F_2 degrades the PR selectivity. The PR selectivity goes down as the CH_4/CHF_3 ratio decreases. Although CF_4 is superior to other conditions in terms of PR selectivity, it gives 8nm larger AEI CD than desired. In contrast, both CF_4/CHF_3=5.0 and CF_4/CH_2F_2=10 successfully meet the AEI CD to target. However, if we examine the top view of the CF_4 only condition and two on-target AEI CD splits in Fig.1, the CF_4/CHF_3=5 is a potential candidate to achieve both good roughness (circularity) and on-target AEI CD. Too heavy polymer from CH_2F_2 results in worse roughness of the contact hole as shown in Fig. 1 (c).

3.2 Effect of source/bias power ratio on the sidewall profile

The source power is designed to alter the plasma density in the etcher while the bias power aims to adjust the bombardment energy for ions. Hence the ratio of source power to bias power would be a good candidate to control the sidewall profile. Three typical profiles, shown in Table 2, reveal that the sidewall angle increases from 85.5 degree to 89.5 degree as the ratio of source power to bias power goes down from 1.0 to 0.66. This indicates excessive by-products are deposited on the sidewall when the ratio is high. Excessive by-products coupled with heavy polymer form the tapered sidewall.

Table 2 Effect of source power and bias power ratio on sidewall profile

Power ratio Source/Bias	Source/Bias = 1.00	Source/Bias = 0.80	Source/Bias = 0.66
Profile			
Sidewall angle	85.5	88.0	89.5

3.3 Effect of critical etchant gas O_2 on contact open reduction

Contact etch normally consists of two main etch steps. The first step has a lower selectivity between oxide and the etch stop layer, mainly for CD control. The second step usually includes a heavy polymer gas C_xF_y to increase the selectivity to the etch stop layer and ensures a sufficient over-etch window. Because of the high aspect ratio of the contact hole (>7.0) and rich polymer or byproducts in the 2^{nd} step, random etch stop may happen. O_2 gas or other de-polymerizing gases are needed in the two etch steps to reduce the polymer and/or byproduct and avoid the random etch stop. The effects of O_2 splits on contact open and final AEI CD are shown in Table 3.

Table 3 Effect of O2 gas addition on contact open and CD

O2 gas usage, sccm	α - 4	α - 2	α	α + 2
contact open total count	>10	~5	0	0
Final Contact CD, nm	a-5	a-3	a	a+3

Note: "α" is the optimized usage of O_2, "a" is the final CD target.

Additional amount of O_2 can reduce the amount of contact open defects. However, it also results in a larger AEI CD. This shows that the O_2 ratio, with respect to other etchants, has also to be optimized in both etch steps to achieve not only free contact open processes but also on-target AEI CD.

Conclusions

In this work, we investigated the impact of etching gas ratio of $CF_4/CHF_3/CH_2F_2$ on contact hole roughness and AEI CD, the effect of source power to bias power ratio on the sidewall profile of the contact hole, and the influence of the etchant gas O_2 on contact open performance and AEI CD. The results demonstrate the introduction of CHF_3 polymer gas in the mask open step outperforms CH_2F_2 and delivers the best top-view of contact hole with on-target AEI CD. It is also found that a lower ratio of source power to bias power in the main etch forms a more vertical sidewall of the contact hole. In addition, O_2 addition in the main etch steps has been identified to be an effective knob to improve the contact open window as well.

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