A Simple Approach to Eliminate Occasional Grass Formation In ICP Backside Via Etch Process

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Abstract

'Grass' formation is the very common defects for via etch process when using a BCl_3/Cl_2 as basic gases in an inductively coupled plasma (ICP) system. Presence of grass can potentially degrade device performance due to poor metallization coverage. In this study we found that grass formation strongly depends on GaAs surface condition prior to etch. Any surface contaminants, such as photo resist residues and/or scumming can contribute to grass formation. We found that applying suitable chemical clean and O_2 plasma descum prior to via etch process would prevent the grass formation. To avoid changes to via profile and/or etch rate, etch parameters were not altered in this study.

INTRODUCTION

The demand for III-V semiconductor device has greatly increased in the wireless telecommunications industry, especially GaAs devices, such as HBT and pHEMT products. Backside via is a very important element for these applications; metallized vias provide low impedance grounds for RF (radio frequency) devices and thermally serves as a heat dissipation path for heat removal.

GCS has been successfully running backside via etch process with good quality for high volume production. The etch rate is about 7 um/minute and suitable via profile is achieved by using a BCl_3/Cl_2 process in an inductively coupled plasma (ICP) system. Early on we had occasionally seen wafers with varying amount of 'grass' formation. Wafers with grassy vias could be reworked; however, this action impacted cycle time and reduced throughput. The 'grass' inside via is a notable defect for backside via process in ICP systems. Several papers discussed the possible mechanisms of 'grass' formation and the factors affecting the formation of 'grass' (ref 1, 2, 3). These references proposed to reduce/eliminate 'grass' formation by focusing on wafer thinning methods, incoming EPI-wafer selections and etch process improvement, such as Cl_2/BCl_3 gas flow ratio, chamber pressure, substrate bias and ICP power. This article describes a simple and effective approach to eliminate grass formation without impacting via profile. Our focus was on wafer treatment prior to via etch. Wafer treatment consists of chemical clean, PR pre-bake and O_2 plasma descum. A simple DOE was conducted to optimize the pre-treatment process. The initial stage of 'grass' formation of GaAs backside via etching with Cl_2/BCl_3 was also studied in this paper. The observed results provided better understanding of 'grass' formation mechanism.

EXPERIMENTAL

All test wafers were 4-inch GaAs wafers with front side pattern. Wafers were mounted on 4.25-inch sapphires and thinned down to 100 microns by mechanical grind and chemical etch. Wafers were coated with photo resist and exposed to achieve photo vias with 50 microns in diameter. All wafers were etched in STS Mesc Multiplex ICP system. Plasma of etcher is inductively couple at 13.56MHz, with independent energy control provided by 13.56 MHz RF biasing of the wafer platen. Helium gas is used to help cool backside of the wafer. A capacitance manometer senses helium pressure and flow is controlled by MFC in order to achieve the desired pressure at backside of wafers. The substrate temperature was set at the desired temperature for all test conditions; however, wafer temperature slightly rose during etching process. The increased amount of temperature was dependent on etch parameters and etch time. All the etch parameters were kept at original setup and was not part of this DOE. The etch chemistry is a mixture of Cl_2/BCl_3 and etch rate was calculated based on the depth of via hole etched.

A three-factor two-level DOE was conducted to identify the significant parameter in grass formation. Chemical clean, post PR bake and finally in-situ O_2 descum were the three factors selected. The DOE layout is shown in table 1. Via quality was selected as the major output, judged by 'grass' density. Via quality was quantified by using a scale of 1 to 10; the higher the number, the better the via quality (lower grass density). Etch rate and selectivity of photo resist to GaAs were selected as secondary outputs. 'Grass' density, surface morphology, etch rate and via profile were evaluated by SEM and optical microscope.

TABLE I
DOE design (three factors and two levels)

	+1	-1
Chemical clean	1 minute	no clean
Post Bake	120C, 1 h	100C, 20 min
In-situ descum	2 minutes	no descum

TABLE II
DOE conditions and the results

RunOrder	CenterPt	pre-clean	Post bake	In-situ descum	via quality	etch rate (um/min)	Selectivity PR:GaAs
1	1	1	-1	-1	6	7.2	1:13
2	1	-1	1	-1	1	5.6	1:15
3	1	-1	-1	1	5	7.0	1:12
4	1	-1	1	1	4	6.6	1:13
5	1	1	1	-1	4.5	7.0	1:14
6	1	1	1	1	8.5	7.2	1:13
7	1	-1	-1	-1	2	6.6	1:13
8	1	1	-1	1	10	6.8	1:12

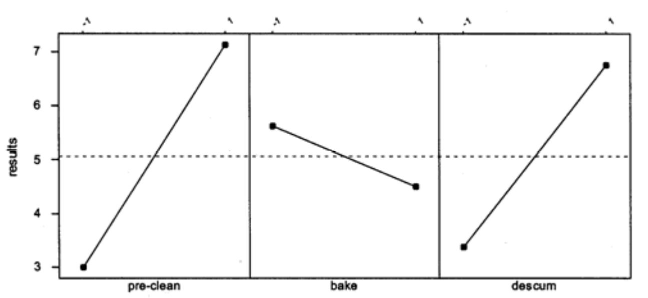

Figure 1 DOE Results – Main Effects Plots

RESULTS AND DISCUSSION

The etch parameters were kept un-changed and etch time was set for 5 minutes for each DOE run. Via mask opening was 50 microns in diameter. DOE results are shown on table 2. Figure 1 shows plots of main effects for this DOE. The steeper slopes found for chemical clean and in-situ O_2 descum indicate that both are main factors for 'grass' formation within the studied range. We found that the surface condition prior to via etch plays a more important role in the 'grass' formation than the back sputtering of reactor components or unbalanced etch parameters as discussed in previous works (2, 3). A possible explanation for this is that surface contaminants, such as photo resist residues or scumming, form or act as 'micro-masks' during initial via etch stage. The contaminated GaAs surface has lower etch rate compared to a clean surface. The different etch rates and the extreme anisotropic etch cause 'grass' to form in pillar shapes as the etching action continues. The optical micrographs of the etched GaAs and SEM cross section of vias are shown in Figure 2 and Figure 3 respectively. 'Grass' structures with straight vertical pillar shape similar to what was reported in previous works (1, 2, 3), were observed under certain pretreatment conditions. The size of 'grass' varies from 15-30 microns in height, and 1 to 3 microns in width, depending on the pretreatments-condition. The 'grass-free' via was obtained with surface chemical cleaning for 1 minute, post PR bake at 110^0C for 1 hour and in-situ O_2 descum for 2 minutes. GaAs Etch rate did not change much with pretreatment methods.

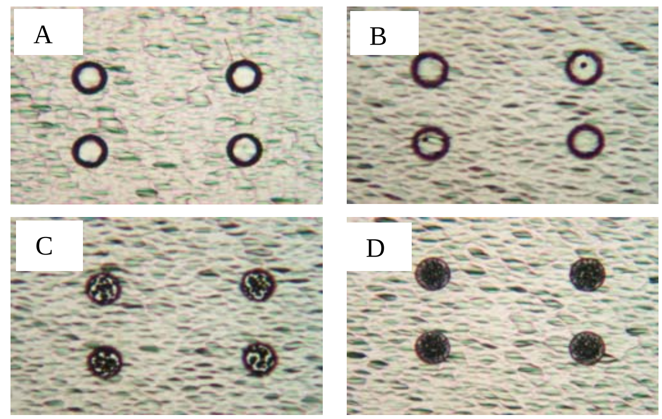

Figure 2 Optical microscope pictures of etched GaAs surface with 5 minutes etch at different pretreatment Conditions shown below:
(A) 1 minute chemical clean, post bake 20 minutes at 100^0C, and in-situ descum 2 minutes
(B) 1 minute chemical clean, post bake 60 minutes at 120^0C, and in-situ descum 2 minutes
(C) No chemical clean, post bake 20 minutes at 100^0C, and no in-situ descum
(D) No chemical clean, post bake 60 minutes at 120^0C, and no in-situ descum

Figure 4 shows the initial stage of grass formation. Wafers were etched for 15 seconds and 30 seconds. The pretreatment condition is: no chemical clean, post bake 60 minutes at 120^0C and no in-situ descum. It can be seen that 'grass' already started to grow after 15 seconds of etching. For the sample with 30 seconds via etch, the 'grass' grew bigger and the structure seems to be like 'stalagmites'. The 'grass' is about couple of microns in height and 0.5 micron in diameter. The similar structure and size of 'grass' during the initial etch stage further provide the evidence that surface condition prior to via etch plays a major role for 'grass' formation. The specific location in which grass can be formed is not clear at this time since the level of surface contamination is difficult to detect. Further study is needed to fully understand the 'grass' formation mechanism.

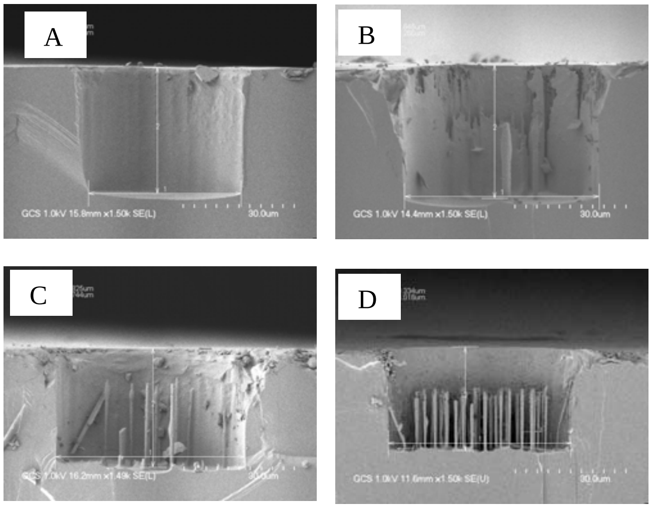

Figure 3 SEM cross-section pictures of etched GaAs via surface with 5 minutes etch at different pretreatment conditions shown below:

(A) 1 minute chemical clean, post bake 20 minutes at 100^{0}C, and in-situ descum 2 minutes
(B) 1 minute chemical clean, post bake 60 minutes at 120^{0}C, and in-situ descum 2 minutes
(C) No chemical clean, post bake 20 minutes at 100^{0}C, and no in-situ descum
(D) No chemical clean, post bake 60 minutes at 120^{0}C, and no in-situ descum

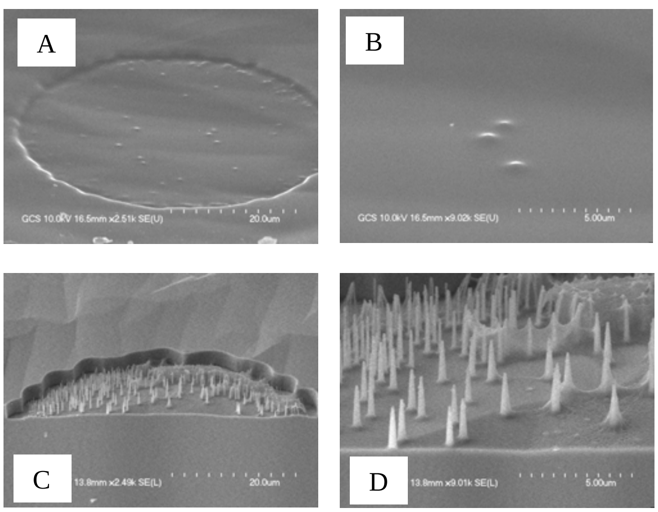

Figure 4 SEM cross-section pictures of etched GaAs via at different etch time
(A) Etch time 15 seconds, low magnification, (B) Etch time 15 seconds, higher magnification, (C) etch time 30 seconds, low magnification, (D) etch time 30 seconds, high magnification

A SEM cross-section picture of the completed via etch with plated gold is shown in Figure 5. The thickness of GaAs is 100 microns and pretreatment condition was the same as that in Figure 2A. The 'grass-free' via with smooth profile and the desired dimensions was achieved with the optimized surface pretreatment condition. More results will be given in the presentation.

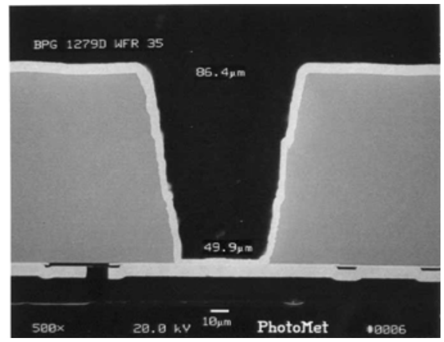

Figure 5
SEM Cross Section pictures of the completed via with metallization

CONCLUSION

In summary, the 'grass' formation during GaAs backside via etching strongly depends on the surface condition prior to via etch. Any surface defects, such as photo resist residues and other contaminations, would contribute to 'grass' formation. The grass formation can be simply controlled and eliminated by the combination of proper chemical clean and descum prior to via etch. The consistent via etch process, which produces 'grass-free' via and has minimal impact on via profile, was achieved by implementing these pre-etch surface treatments.

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ACRONYMS:

GaAs: Gallium Arsenide
RF: Radio Frequency
ICP: Inductively Coupled Plasma
Cl_2: Chlorine
BCl_3: Boron Trichloride
HBT: Heterojunction Bipolar Transistor
pHEMT: Pseudomorphic High Electron Mobility Transistor