

Removal of Gold Impregnated Post-Etch Residue from Front and Backside Vias in a Single Process

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Abstract

Compound semiconductor processing often uses high density plasma etching to establish through-via metal contacts that typically stops on an inert metal such as gold (Au). The etch process may enter from the front or backside through the substrate and/or an organic dielectric such as polyimide or bisbenzocyclobutene (BCB). An inherent by-product of the etch process is the formation of post-etch residue containing a mixture of species stemming from the plasma ions, resist pattern, etched region, and lastly, material from the etch stop (Au) that impregnates and coats the residue.[1,2] Common strippers are ineffective on Au impregnated post-etch residue, requiring a separate KI-leaching of the metal before the residue is removed. This paper describes a simple and rapid technique to simultaneously remove post etch residue in a single process using common fab manufacturing tools.

INTRODUCTION

Small via technologies has been developed to meet many device demands for thermal conduction and contacts. These include power GaAs MMICs for military and satellite communications with sizes ranging between 30-75 μ m as well as high power, high frequency GaAs PAs for low cost MESFET, HBT, and pHEMT for handsets and VSAT applications.[3] Although most of these vias are "drilled" through the wafer substrate, they also exist in dielectrics such as BCB [4] or polyimide [5] where device performance is in the lower frequency bands, allowing the use of amorphous materials without resonant frequency effects. Further, combining frontside dielectric layering with gold backside plating adds substrate strength that benefits thinning to <75 μ m, backside processing, and a robust pick & place of very thin die from dicing tape.

Via "drilling" into GaAs media may be conducted by reactive ion etch (RIE) or inductively coupled plasma (ICP) using gas mixtures containing Ar and BCl₃/Cl₂ for effective etch rates and acceptable anisotropic control. There are four major varying parameters during etching: chamber pressure, RF power, BCl₃/Cl₂ ratio, and Ar flow rate, and DOEs have been published.[6,7] For etching into organic layers, such as BCB, a CF₄/O₂/N₂ mix provides a balance between high throughput and anisotropic etching, by richening of O₂ or N₂, respectively.[8] In the case of N₂ enrichment, redeposition and graphitization of organic carbon will help focus reactive species into the substrate media and increase resolution. In

most cases, the etch stop is an inert metal such as Au. Although Au layers may either be sputtered or electrochemically deposited (ECD), the predominant practice for economic and throughput interests is ECD Au.[9] Definition of sputtered and ECD Au vary from a smooth to irregular topography, as shown in the post-etch SEM photos in figure 1.

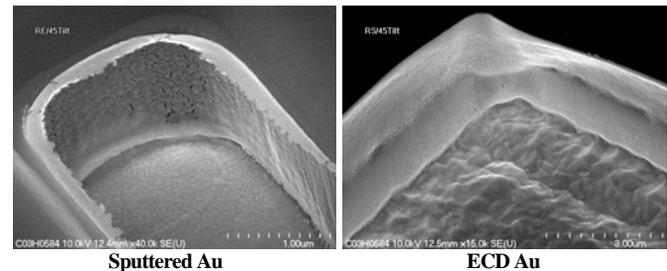


Fig.1 Post-etch SEMs of sputtered (left) and ECD (right) Au metal showing a significant difference in surface morphology.

Following via etching, residue is removed to allow for subsequent processing including lithography and/or plating steps. Although residue removal processes exist in a variety of forms, cleaning Au impregnated residue commonly involves an etch composed of a mineral acid and potassium iodide (KI). The iodide acts to dissolve and etch Au. Subsequently, the underlying organic residue is then removed with solvents. For tenacious residues, multiple steps are alternated between etchants and solvents. This paper describes the product, GenSolve™ 525, to offer a single-process approach to remove the residue composed of both the inert metal (Au) and the organic.

EXPERIMENTAL

Studies were run on both front side vias into BCB on 100mm (4") non-thinned wafers and back side vias into GaAs on 150 mm (6") wafers thinned to 90 μ m and mounted on carrier substrates using a thermoplastic material. Both wafer sets contain a gold etch stop coated on the corresponding opposing side of the etched vias.

Frontside via etching into BCB uses a CF₄/O₂ and stops onto ECD Au. For backside GaAs vias, an ICP Ar/BCl₃/Cl₂ chemistry etch is used with an electrostatic chuck (ESC) and helium backside cooling to below 100°C at the wafer surface

to protect the photoresist and adhesive. Although ashed specimens were tested, it was the intention of this work to simplify the overall cleaning process and try to eliminate ashing steps. Therefore, all wafers tested are not ashed.

SEM (Hitachi 4700) with energy dispersive X-ray analysis (EDS or EDX) is used at a minimum tilt angle of 30 degrees for top-down measurements at the center and edge of wafers. Frontside vias are cleaned in a common wet-bench with robotic cassette handling, equipped with both ultrasonic (i.e. 40 kHz) and y-axis agitation. Backside via cleans use a modified Equinox™ single wafer processing tool, marketed as the Raider™ with Capsule™ from Semitool, Inc. [10].

The GenSolve™ products are tested as pre- and post-dip chemistries, tested along with GenSolve™ 525, in attempts to remove unwanted organic residue. The following descriptions in table 1 represent those chemistries tested.

Table 1. GenSolve™ tested in various process conditions.

GenSolve™	Solvent	pH (indirect)	Additive
525	DMAC	Neutral	Complexing
680	DMSO	Basic	Acid-base
475	NMP	Basic	Acid-base
360/365	Hydrocarbon	Acidic	Saponifier

RESIDUE ANALYSIS

Via drilling and trough cutting to produce holes and lines are performed in plasma etch tools with aggressive gases. Preparative etch steps commonly use a high temperature bake-out to outgas the resist, increase its T_g to improve adhesion, and inadvertently promote crosslinking.[11,12] Plasma etching will redeposit by-products from the resist and substrate over the entire wafer. This continues until a dissimilar material or metal (etch stop) is detected, whereby the etch is terminated. The residue is largely composed of species from the resist, substrate, and on the very surface, the etch stop material. In figure 2, sidewall EDS results of backside GaAs etched via show the presence of the substrate (GaAs), carbon/oxygen (resist), and Au (etch stop).

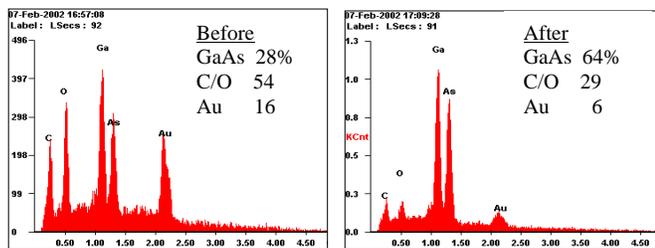


Fig.2 EDS results before and after of etched vias showing GaAs richening and removal of residue (C/O and Au).

When an irregular etch stop is met, such as the example of ECD Au, an "over-etch" may proceed to allow complete removal of substrate (i.e. BCB). As a result, residue may be composed of a composite organic from cross-linked resist and

BCB-related matter as well as Au on the top surface. A complete cleans may involve formulations which remove the Au as well as BCB-like material.

CHEMICAL CLEANS

Although the data presented in figure 2 for a backside via etch suggests residue composed of GaAs species, the same data from a frontside via drilled into BCB is likely to contain organic originating from BCB. Residue removal may require formulated chemistries with strong acids, alkalis, or complexing agents to break bonds and allow for bulk solvent penetration and dissolution. Without the bond breaking and complexing capacity of the stripper, more aggressive or time consuming measures may be necessary [13,14].

For Au leaching, chemical via cleans involved the addition of a complexing agent to a neutral solvent system. The complexing agent of choice would require a non-KI based system with high solubility in a good organic solvent, such as DMAC. Initial tests on blanket Au films suggest moderate etch rates (table 2).

Table 2. GenSolve™ chemistries using complexing agent for Au into various solvent systems indicating a range of etch rates.

GenSolve™	Solvent	Etch Rate (Å/min)
625-D	DMSO	44.5
725-D	BLO	12.7
525 (A)-D	DMAC	7.1

The rates in table 2 were determined at 60-70C for 15min on sputtered Au. Considering the limited amount of Au present within a via residue, it was determined that a low etch rate is desirable at elevated temperature. The higher temperature allows for good organic penetration and dissolution. Therefore, DMAC was chosen, however, the complex agent was increased to aid throughput (figure 3).

Au Etch Rate vs Agent Concentration Sputtered Au @ 60-70C

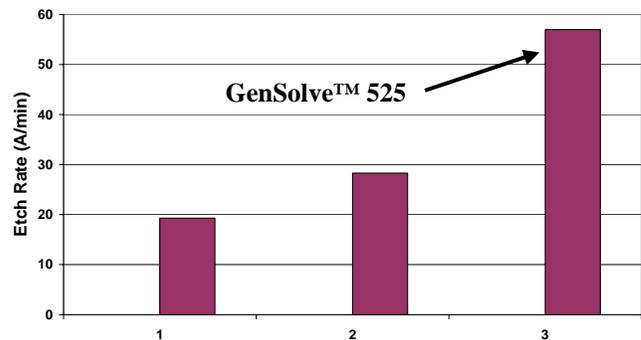


Fig.3 Etch rates of sputtered Au with varying concentrations of complexing agent in DMAC-based solvent system.

The neutral solvent system of the DMAC chemistry (table 1) proved safe for GaAs and related materials as test data in another study (not shown) was demonstrated to be consistent

with pure neutral solvent systems, namely, no measured corrosion effects [15].

VIAS WITH BCB RESIDUE

Studies were conducted using the GenSolve™ 525 in a standard immersion tank system at 60-70C, for approximately 15min. A DI water rinse and dry followed the strip. Results suggest that cleaning is complete with sputtered Au, however, some sidewall/edge residue is present in ECD Au (figure 4).

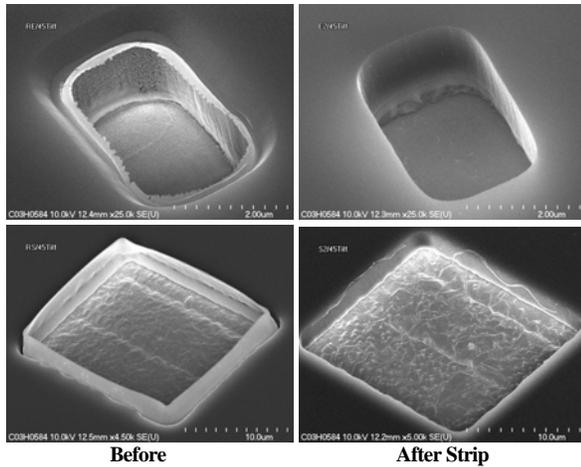


Figure 4. SEMs of frontside vias in BCB on sputtered Au (top) and ECD Au (bottom); before strip (left) and cleaned (right).

Considering the morphology differences between sputtered Au and ECD Au as seen from the SEMs (figs. 1 & 4), etch conditions are likely more aggressive for irregular ECD surfaces. In turn, etch residue is expected to be more tenacious, requiring a more aggressive strip process. Tests on ECD Au indicate that ultrasonic agitation will clean the vias as compared to the no-cleans for simple y-axis cassette mixing (fig. 5).

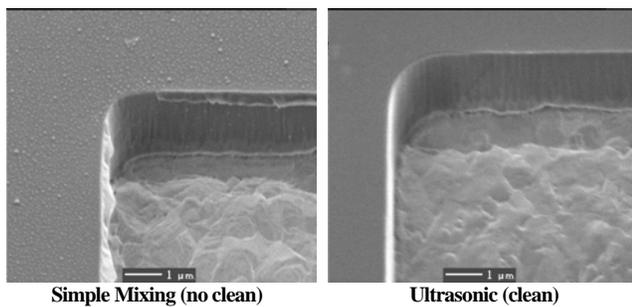


Figure 5. SEMs of frontside vias in BCB on ECD Au for no-clean simple mixing (left) and clean for ultrasonic (right).

The residue noted in figure 5 is removed by the surface sensitive (boundary layer) agitation of ultrasonics. It is observed that no Au is present in the residue, rather, the material is likely to be a composite organic species of resist

and BCB. Analysis of this residue for respective functional groups is impractical due to the limited and extremely small sample size. Therefore, empirical tests commenced by combining chemical polarities and testing the effects by SEM observations. The chemistries and materials are compared in table 3 and tested at 60-85C and 10min, results in figure 6.

Table 3. Polarity comparison between materials and chemistries.

Chemistry	Polarity
GenSolve™ 525	Polar
GenSolve™ 670	Polar
GenSolve™ 475	Polar
GenSolve™ 360/365	Non-polar
Hydroxystyrene Resist	Polar
BCB	Non-Polar

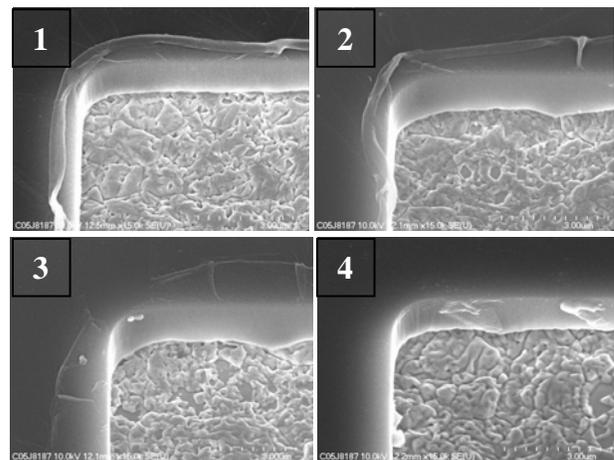


Figure 6. SEMs of frontside vias in BCB on ECD Au using a single process composed of two chemistries in sequence: (A) GenSolve™ 525 + (B), where (B) represents items 1-4; 1) none (ref), 2) GenSolve™ 680, 3) GenSolve™ 475, and 4) GenSolve™ 360/365; process #4 is dissolving residue.

Additional optimization tests with a single process having only simple mixing produced clean results showing representative removal of the veil residue in figure 7. No differences were observed in processing forward or backward using the sequence (A) GenSolve™ 525 + (B) GenSolve™ 360/365. This data supports the chemical maxim, “like dissolves like,” the similarities between BCB and 360/365.

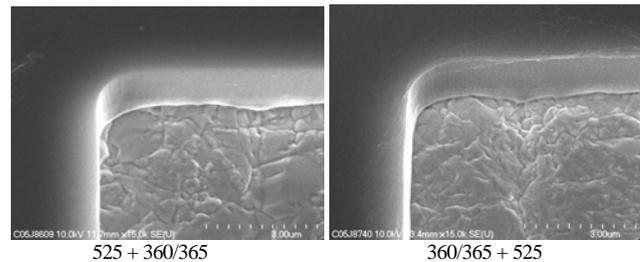


Figure 7. SEMs of frontside vias in BCB on ECD Au using a process of two chemistries in sequence, GenSolve™ 525 and GenSolve™ 360/365, each are interconvertible.

VIAS WITH GaAs RESIDUE

Cleaning backside vias of residue composed of GaAs and Au was conducted on a single wafer-processing tool. This tool, manufactured by Semitool,[10] is a horizontal platform with nozzles directed onto a facedown wafer (figure 8).

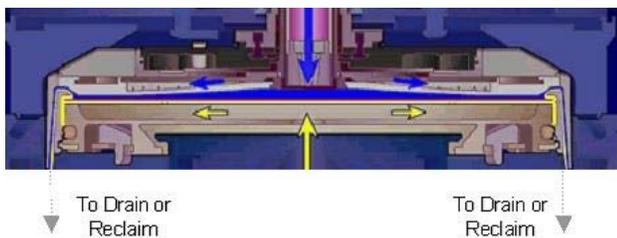


Figure 8. Single wafer-processing tool shown here as the Capsule™ with fluid flow to wafer (center) and drain (edge).

The GenSolve™ 525 is used for the evaluation without any addition of a second chemistry as no BCB or other demonstrated tenacious residue exists. The main effects in the tool include nozzle manifold, nozzle port size, manifold distance from wafer, and pressure. The temperature of the chemistry was held at 70C for a duration of approximately 8minutes for each wafer. The nozzle manifold is a cross-shape with 4 arms, three of which are blocked, to produce a configuration similar to a “wand.” Nozzle ports include six (6) and are designed to be small in the center and the outer two, while the other three are larger, resulting in a desired pressure differential effect for improved uniformity. The manifold is approximately 2” from the wafer surface. Cleaning is observed to be excellent in 24hrs, acceptable in 48hrs, while at 72hrs, the cleanliness dropped significantly. It is not known at this time if the trend in cleanliness follows Au etch rate as shown in figure 9.

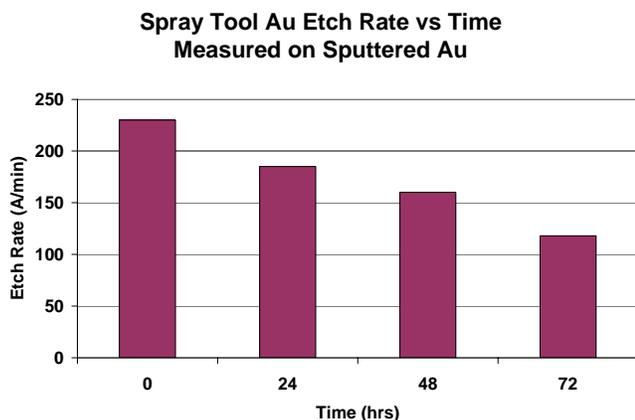


Figure 9. Au etches rate as measured on specimens in a single-wafer spray tool. Note: a relationship between cleanliness and etch rate is not confirmed.

CONCLUSION

Via etching is performed in front and backside processes for III-V wafer manufacturing. Cleaning is possible in a

single process as carried out with one or two chemistries. Variation in chemistries is dependent upon the make-up of the residue and in turn, on the substrate etched. For BCB etched vias, two chemistries were needed to dissolve and remove what is believed to be, BCB-related matter. For GaAs etched vias, a single chemistry is possible. As with any cleaning process, agitation with ultrasonic or spray nozzles is a primary benefit. Further work should explore bath life as compared to a multi-process KI etch.

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ACRONYMS

- PA: Power Amplifier
 MMIC: Monolithic Microwave Integrated Circuit
 HBT: Heterojunction Bipolar Transistor
 pHEMT: pseudomorphic High Electron Mobility Transistor
 VSAT: Very Small Antenna Terminal
 DMAC: Dimethylacetamide
 DMSO: Dimethylsulfoxide
 NMP: n-Methylpyrrolidone
 BLO: Butyrolactone