Elimination of Defects Observed Following Patterned TiW-Au Metal Formation

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Keywords: defects, TiW, Au, Au electroplating, plasma etch

Abstract

For this work a physical vapor deposited TiW-Au metallization is used as the electrical continuity layer for subsequent patterned electroplating of metal features on GaAs devices. Once the pattern is plated and the Au seed has been removed via reverse plating, plasma etch is used to remove the field area TiW. Following plasma etch, defects were observed across the wafer surface. Auger electron spectroscopy (AES) revealed that the defects were Au particles. Several methods of eliminating the Au particles were identified including, 1) use of vacuum break during the TiW-Au deposition, 2) O_2 plasma ash prior to reverse plate, 3) a dual-iteration reverse plate process, and 4) a Au wet etch following reverse plate. The dual-iteration reverse plating process was determined as the best alternative.

INTRODUCTION

Electroplating is a common method of manufacturing patterned metal features on GaAs devices in our factory. As described in Figure 1, a multi-layer of electrically conductive "seed" metal is deposited onto a dielectric layer (a). The conductive seed layers are deposited by physical vapor deposition (PVD) sputter, consisting of titanium tungsten (TiW) followed by gold (Au). Metallization is done *in situ*, without a break in vacuum between the TiW and Au depositions. The wafer is then patterned using photoresist (b). Prior to electroplating, wafers receive a low power oxygen (O_2) plasma ash to remove potential resist "scum" in the areas to be plated. The wafer is then electroplated in non-patterned areas (c). Photoresist is removed following plating (d) then the seed Au layer is removed by reverse plating (e). Gold features are now formed, with TiW remaining in field areas. Finally, exposed TiW is removed via plasma etch, completing patterned metal formation (f). It should be mentioned that the plasma etch is not infinitely selective to the underlying dielectric layer.

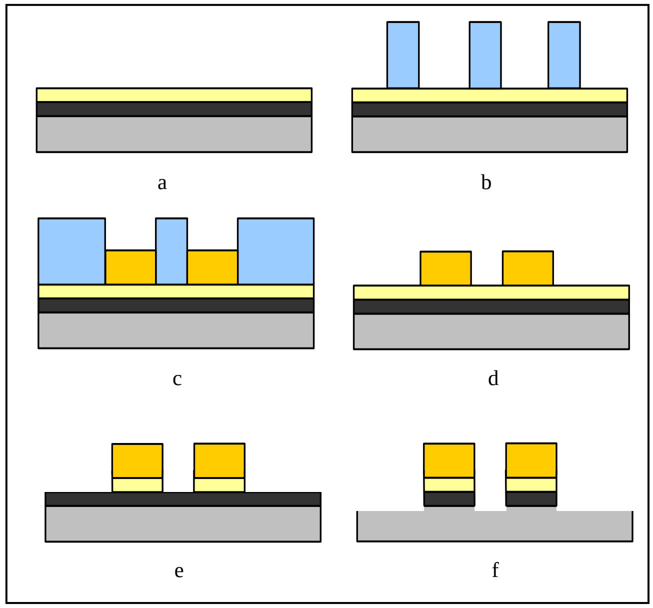

Figure 1: Representation of individual processing steps in formation of patterned, electroplated, metal features.

Following plasma etch, microscope inspection revealed point defects on the field areas of wafers. The defects were most easily observable with dark field microscopy at from 200 to 500x magnification (Figure 2).

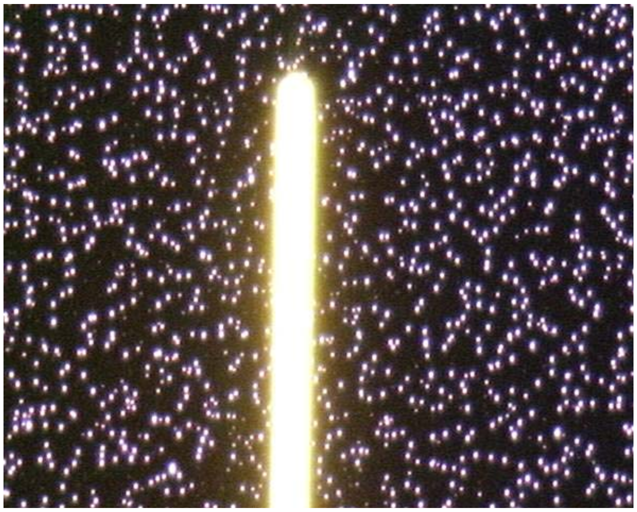

Figure 2: Dark field image of defects. Highlighted bar in center is a plated metal feature.

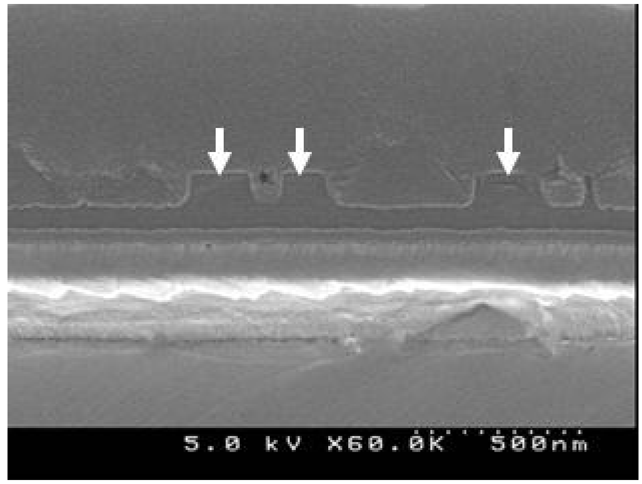

Figure 4: SEM cross-section. Arrows indicate mesa defects in dielectric layer.

Elemental maps of the surface using Auger electron spectroscopy (AES) identified the particles as Au (Figure 3). Cross-sections, viewed by scanning electron microscopy (SEM), provided evidence that the Au particles acted as a hard mask during the plasma etch, leaving behind "mesa-shaped" defects in the dielectric layer (Figure 4). Subsequent wet cleaning processes typically removed the gold particles, but the texture of the dielectric layer remained and, therefore, removal of the Au particles had little or no affect on the appearance under dark field microscopy. In extreme instances the Au particles were not sufficiently removed by the subsequent cleans, resulting in electrical failures for leakage current.

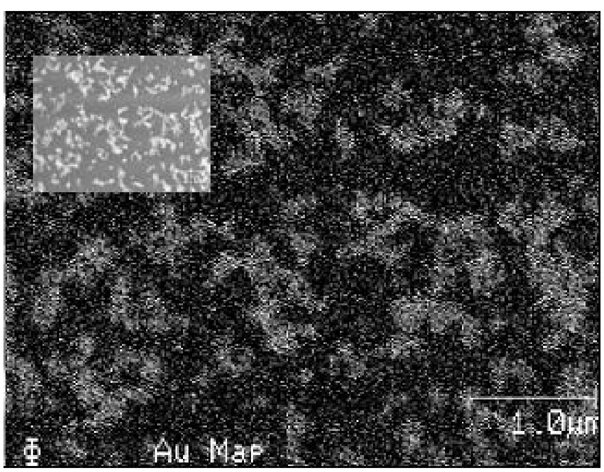

Figure 3: Auger Au map of field area after plasma etch. Highlights indicate detection of Au (secondary electron image inset).

EXPERIMENTAL RESULTS

Our initial theory for cause of this problem was incomplete reverse plating of the Au seed layer. This appeared likely, as the only process step involved in removing the Au seed is reverse plate. Confusing our theory, though, was the fact that the problem was unique to one particular metal layer on one specific part, i.e., other layers and part-types were not experiencing the same problem using the same reverse-plate process. The first experiment originated from questioning whether the photoresist had been sufficiently removed from the Au surface prior to reverse plate. A wafer was processed through an O_2 plasma (ash) after the resist strip, prior to reverse plate. Results were dramatic: the wafer had no defects. The second experiment was derived from the seed metallization. One of our other modules used similar metal layers, but each was sputtered separately on different systems. This module was not experiencing the same problem. Since it is known that TiW grain boundaries are "stuffed" with oxygen when exposed to atmosphere, the experiment involved splitting the TiW and Au depositions into separate steps with a vacuum break (to atmosphere) between each.[1] The results were again dramatic, with no defects for wafers with a vacuum break. Based on the results of the experiments above, our theory was modified to that of insufficient surface wetting of the reverse plate solution with the seed Au surface, resulting in insufficient reverse plating (Figure 5).[3]

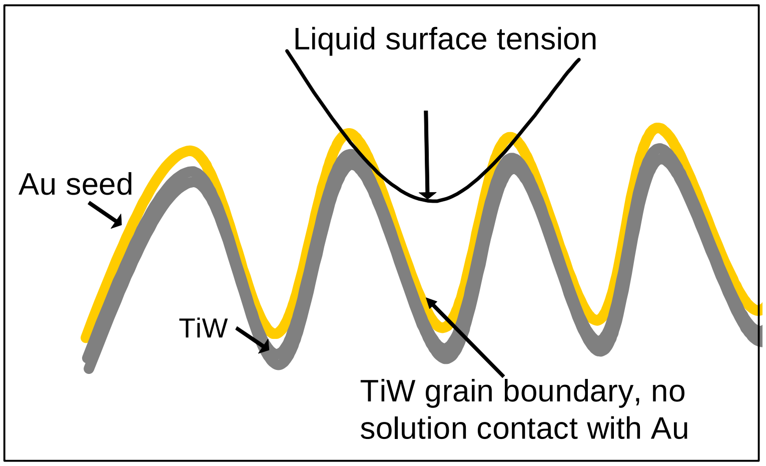

Figure 5: Representation of incomplete reverse plating

Although several attempts were made to validate the surface wetting theory with various analytical methods, e.g., contact angle[2], the focus of the work remained on finding a problem solution. The vacuum break method, although successful, was eliminated due to compromised TiW-Au adhesion. Plasma ash prior to reverse plate also was eliminated due to lack of manufacturability with its multiple steps on separate tools. Another solution that proved effective in removing the Au defects involved use of a wet chemical clean. A dilute Au wet etch chemistry was sprayed in a batch process tool following the deplate process. The process removed the Au particles and provided clean wafers following the plasma etch. This, too, was determined to be undesirable solution, as critical dimensions (CDs) were aversely affected. Our final solution was the result of observing that wafers with routine insufficient reverse plate were often, and successfully, reprocessed through reverse plating. Reprocessing was effective at removing the Au and did not adversely affect CDs. Using a modified reprocessing approach, our reverse plating recipe was broken into two steps with a spin-dry (in air) between each step. The spin-dry step is assumed to change (favorably) either the surface energy, roughness, or both, improving the efficiency of the second reverse plating step. The second initiation that occurs in the second reverse-plate step is also thought to contribute to its overall success. We refer to this process as "dual-iteration deplate", and it has proven to eliminate our problem (Figure 6).

Figure 6: Dark field image of wafer processed with dual-iteration deplate process.

Conclusion

The dual-iteration deplate has proven to be a successful method for removal of gold particles in the manufacture of TiW-Au features for our GaAs devices. The process has been implemented and is currently used in our factory. Through the removal of these defects, yields have increased resulting from reduced leakage current. Inspection quality also improved due to elimination of these defects that previously dominated the wafer surface.

Acknowledgements

CS-1 Haze Team – Adolfo Reyes, Dave Dixon, Susan Valocchi, Jan Campbell, Dave Young, Jim Cotronakis, Jeremy Hartman, Paul Ocansey, Chad Becker, Rick Cosway, Matt Parker.

PALAZ – Ha Le, Joe Vella, Arnold Yazzie for the analytical work.

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Acronyms

SEM: Scanning electron microscope
PVD: Physical vapor deposition
CD: Critical dimension
AES: Auger electron spectroscopy