Methods for Removing TiOx Residue from Au Bond Pad

Lena Luu, Minkar Chen, Frank Monzon

Global Communications Semiconductors, Inc.
23155 Kashiwa Court, Torrance, CA 90505
1-(310)-530-7280
lluu@gcsincorp.com

Keywords: Bond pads, TiO_x removal, Dry etch, Wet etch, Bond pull test,

Abstract

Wire bond quality is crucial to the reliability of an IC device and its performance in the field. The quality of the wire bond is dependent on the strength of the interface between the wire and the bond pad. This paper reviews methods for removing TiO_x residue from Au bond pad and the effects of TiO_x on the wire bond quality. Auger microanalysis is used to analyze the TiOx-Au interface and bond pull test is used to review the bond quality of the bond pad after TiOx removal. Thermal cycling is also used to check for nitride delamination that could result from the TiO_x removal processes.

INTRODUCTION

For bond pad metal deposition, Ti is added on top of M2 as an adhesion layer between Au and nitride; however, GCS had reason to believe that TiO_x residue may lead to lower wire bond quality since Ti readily oxidizes and diffuses into Au and the TiOx [1]. Wet and dry etch methods were tested to remove the top TiOx layer. Each method was evaluated for its ability to remove TiOx and for any side effects on other device areas.

MATERIALS AND METHODS

Preparation of Samples

The bond pads of all samples consist of 30Å Ti on top of M2 and were deposited using E-beam evaporation. The bond pads are at least 79um x 79um. To match the metal pad conditioning with actual wafer processing, nitride was deposited with PECVD and the bond pad via was created by patterning with photo resist and etching the nitride using plasma dry etch. The nitride deposition heated the sample up to 275˚C; the resist patterning baked the samples up to 105˚C; and the plasma etch was done at room temperature. New batches of samples were generated for each TiO_x removal method. Batch to batch variation may result in different TiO_x diffusion thickness.

TiOx Removal

To remove the surface layer of TiO_x, dry etch with SF_6-based plasma, CF_4-based plasma etch, Ar-based plasma etch, and acid wet etch were tested. The SF_6 and CF_4 plasma etch options are an extension of the via etch process and was tested at 100% and 200% over etch (OE). The Ar plasma etch option was processed for 1min and represents an additional process after the via etch. It is mainly used for comparison with the SF_6 and CF_4 plasma etch options. The acid etch option is also an additional process step after via etch. The samples were etched in concentrated acid for 10-80 minutes at room temperature, rinsed in DIW and dried with N_2.

Auger Analysis

The scanning Auger microanalysis uses a focused beam of 5kV to analyze the surface compositions. All samples were tested as is; no pre-cleans, descum or sputtering was done to treat the samples. For depth profiles, Ar sputtering was used and composition measurements were at 10Å intervals up to 300Å. The rastering area is $20um^2$ so the TiO_x detection at each depth is considered to be from diffusion, not from any "knock-on" effect.

Bond Pull Test

Samples were mounted on Au-Ni substrates using epoxy resin. Ball bonds were made using 0.001" Au wire and tested in accordance with MIL-STD-883E, method 2011.7, test condition D. The first bond is made on the bond pad and the second bond on the Au-Ni substrate. Only the SF_6 dry etch sample (200% OE) and the wet etch sample (30min etch) were tested against the control. Each sample has a sample size of 8 bond pads.

RESULTS

For all samples after TiO_x removal processing, the bond pad metal did not show any visible discoloration under optical microscope inspection. Figure 1 shows the samples under SEM inspection. The bond pad metal of the dry etched sample looks very similar to that of the control sample. The wet etched sample shows significant discoloration. An explanation for the difference between the wet and dry etched samples is that surface removal using dry etching does not differentiate between TiO_x and Au but with wet etching, the acid is selective to Au. Since the diffusion of Ti through Au is mainly through the grain boundary [2], wet etching would highlight the different phases of TiO_x-Au.

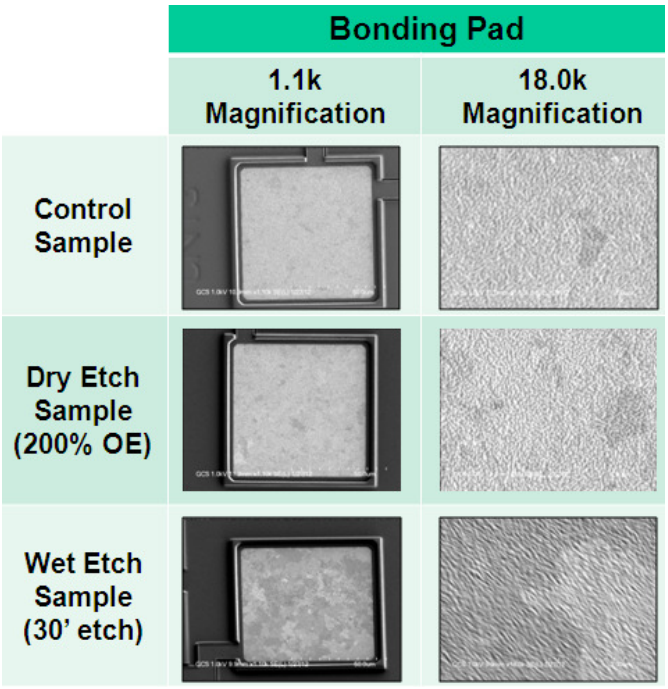

Figure 1: SEM image of bond pad area after TiOx removal.

Auger Analysis

The control sample's Auger scan is shown in Figure 2. TiO_x signal was detected up to 90Å even though only 30Å of Ti was deposited on top of Au. Since no significant Au signal was detected until 20Å deep into the sample, the diffusion zone thickness is determined to be about 70Å.

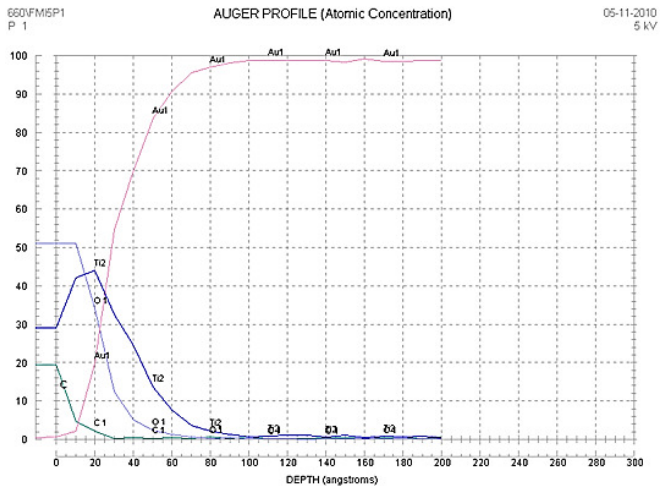

Figure 2: Auger depth profile of the control sample

For samples dry etched with SF_6 and 100% OE at the via etch step, TiO_x was still detected on the surface. The Auger scan depth profile in Figure 3 reveals that there was still Ti signal up to 30Å. With 200% OE, no Ti signal was detected. Dry etching with CF_4 and Ar yielded similar composition profiles as the dry etching with SF_6. These methods of TiOx removal also removed Au.

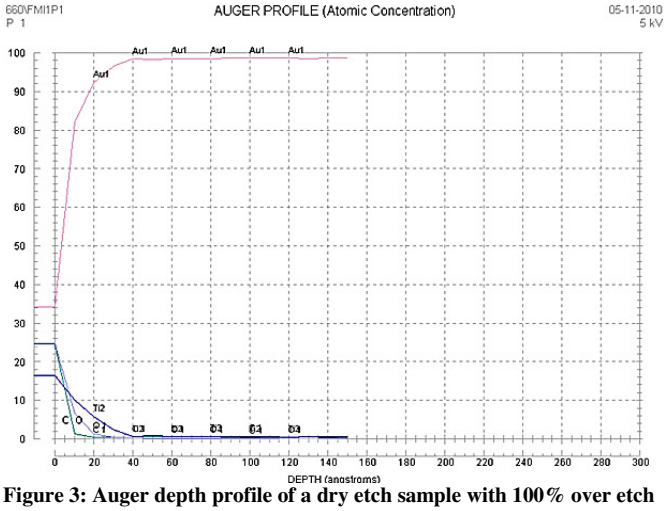

Figure 3: Auger depth profile of a dry etch sample with 100% over etch at via etch.

Concentrated acid was shown to etch TiO_x at over 200Å/hr. The acid solution is selective to Au. Surface compositions of samples at different etch time were tested and the result is plotted in Figure 4. The samples ideally have TiO_x and Au only so as TiO_x is removed, the Ti/Au ratio should exponentially drop to zero. The Ti-Au ratio as a function of etch time rapidly drops and after 20 minutes, it levels out near 1. Even with 800% OE, the acid solution could not completely remove TiO_x. From the Auger profile of the control sample (Figure 2), the Ti-Au ratio of 1 occurs at 20A which means that wet etch can readily remove the top surface TiO_x within 20mins while the TiO_x diffused within the bulk Au is much harder to remove. The aggressive acid etch did not cause any discoloration or nitride delamination in both the bond pad and GaAs street.

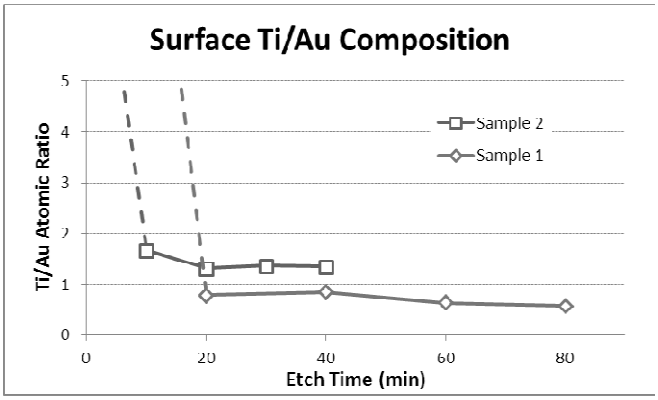

Figure 4: Surface Ti/Au Ratio of samples after wet etch

Bond Pull Test

The bond pull test was performed within 3 days of metal deposition. The bond pull strength at failure is listed in Table 1. For all three sample types, the only observed failure mode was 1st bond neck break and 2nd bond heel break. No metallization peeling or bond lifts were seen and all samples exceeded the minimum bond strength of 3gm. The control

sample and the dry etch sample had no significant difference in bond pull strength while the wet etch sample had lower bond pull strength.

Since both the control sample and wet etch sample still have TiO_x diffused into the top Au layer, the diffused TiO_x appears to have no effect on the bond pull strength. A possible explanation for the lower bond pull strength of the wet etch sample is the bond pad surface composition uniformity. As seen in Figure 1, the control sample and the dry etch sample have a much more uniform metal surface than the wet etch sample.

Table 1: Destructive Bond Pull Test

Sample	Bond Pull Strength (gm)	Failure Mode
Control	15.94 +/- 2.18	1st bond neck break/ 2nd bond heal break
Dry Etch	15.47 +/- 2.52	1st bond neck break/ 2nd bond heal break
Wet Etch	14.89 +/- 1.33	1st bond neck break/ 2nd bond heal break

Thermal Cycling

In addition to the bond pull test to check for the bond pad surface condition, thermal cycling from room temperature to 280˚C was done to the samples to test if the additional processing of the bond pad caused any nitride adhesion issues. The nitride adhesion was checked in any regions that are open at the TiO_x removal step and the results are shown in Figure 5.

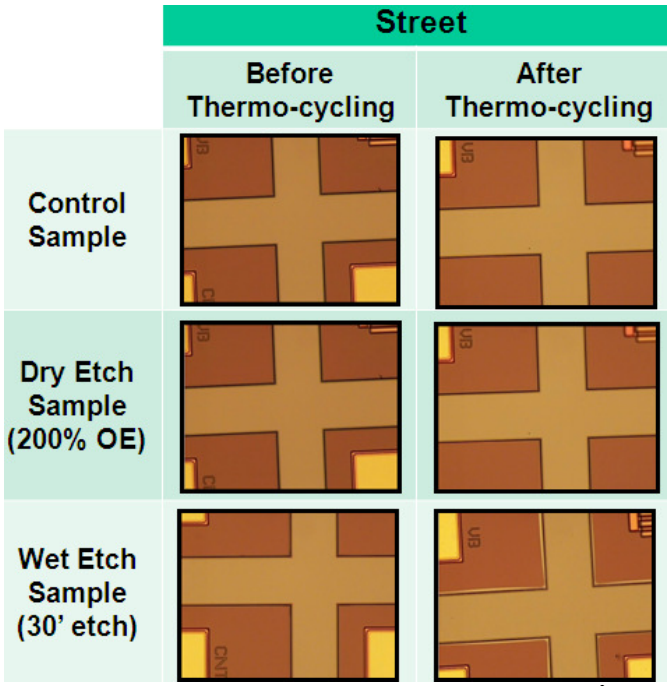

Figure 5: Street area after thermal cycling for 10cycles at 260˚C. Images are shown at 50x magnification. The lighter t-shaped area is the GaAs surface. The darker areas in the four corners are regions covered by nitride. In the wet etch sample after thermal cycling, the discoloration at the GaAs-nitride edge is an indication of nitride delamination.

Immediately after the TiO_x removal processing, no sign of delamination was detected in any sample. After thermal cycling, the control and both dry etched samples showed no sign of nitride delamination. The wet etch sample showed no issues at the nitride/ bond pad area; however, there was delamination in the street areas where nitride is open to GaAs. The nitride delamination is not uniform at the nitride-GaAs edge and is likely caused by GaAs undercutting. Any oxidized GaAs can be removed by the concentrated acid creating the undercut beneath the nitride. The GaAs oxide is not uniform which is consistent with the non-uniform delamination. The dry etch is anisotropic and does not have nitride delamination.

CONCLUSIONS

Dry etching with SF_6-based plasma, CF_4-based plasma, and Ar-based plasma are all capable of completely removing TiO_x from Au bond pad. Concentrated acid can remove TiO_x but only from the surface layer; the diffused TiO_x cannot be removed. It is found that the presence of TiO_x does not affect the bond pull strength, however, the compositional non-uniformity may reduce the bond strength of the bond wire to the bond pad.

For implementation into the wafer fabrication process, the dry etch options are the easiest since they are merely an extension of the current process step. Wet etch can be used for TiO_x removal only if the wet acid does not compromise the quality of other features.

ACKNOWLEDGEMENTS

Authors would like to thank Tung Dang, Marlyn Ylarde, Hua Tan, David Dahlgren, and the GCS production team for their support.

REFERENCES

[1] W. Martinez, et al. , *Titanium Diffusion in Gold Thin Films*, 2010 Thin Solid Films, pp. 2585-2591, March 2010

[2] T. Tisone, J. Drobek, *Diffusion in Thin Film Ti-Au, Ti-Pd, and Ti-Pt Couples*. 1972 Journal of Vacuum Science and Technology. Pp. 271-275, Jan 1972

ACRONYMS

OE: Over etch

PECVD: Plasma enhanced chemical vapor deposition