Development of TSV electroplating process for via-last technology

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***Abstract*—10um x 100um TSV was prepared by deep reactive ion etching process. Barrier and seed layer were deposited by physical vapor deposition process and prior to Cu electroplating, Ni was electroplated on seed layer. Cu electroplating was optimized for solid TSV filling. To remove excessive Cu on field area, chemical mechanical polishing process is used in conventional TSV fabrication process. In this study, new excessive Cu removal process was developed. Electroplated Cu and Ni had poor adhesion and this characteristic was applied to remove excessive Cu from Ni surface.**

Keywords-through silicon vias, electroplating, overburden

I. INTRODUCTION

To fill high aspect ratio of TSV, bottom-up filling is required, which is established in Damascene technology. But TSV is much larger in diameter and deeper in depth than Damascene structure. New electroplating process and chemicals are developed for TSV metallization. Major components of TSV electroplating chemical are Cu ion based on Cu sulfuric acid, chloride and additives. Three additives (suppressor, accelerator and leveler) are used and balanced concentration of electroplating chemical components enables bottom-up TSV Cu filling. While TSV is filled with Cu, wafer surface area also electroplated with Cu simultaneously. Excessive Cu so called Cu overburden causes wafer warpage during electroplating and annealing and it has to be removed by chemical mechanical polishing (CMP) for following process. Though electroplating chemical concentration is well balanced and optimum TSV Cu electroplating process is developed, 2~3um thickness of Cu overburden is formed on wafer surface including Cu seed layer. And usually larger TSV requires longer process time and electric charge. So overburden thickness could be thicker as TSV size becomes larger and longer CMP process causes high cost, longer process time and lower throughput. In particular, for via-last TSV technology that wafer has warpage after temporary bonding for backside process, thick Cu overburden worsen wafer warpage causing non-uniform CMP. Cu residues between TSVs make electrical short failure and further CMP process can damage dielectric liner and hard mask exposing bare Si wafer.

A few approaches were tried to remove or reduce Cu overburden. Cu overburden can be removed by isotropic wet etching using diluted sulfuric acid and hydrogen peroxide (dSPM). In this method, TSV Cu was not damaged because Cu hump at TSV and Cu overburden on wafer surface have different Cu height [1]. Very thin Ta deposition on top of seed layer so called Ta-flash also can be used to reduce Cu overburden. This method is to inhibit Cu electroplating on Ta because of overpotential difference between Cu electroplating on Cu and Cu electroplating on Ta [2].

In this study, we suggested new approach to remove Cu overburden for TSV Cu electroplating process. Some materials make natural oxide on it when exposed to air and deposited film on these materials has weak adhesion because of native oxide. This surface oxide is not preferred in thin film and metallization process and thus chemical removal or Ar sputtering process is applied to remove oxide layer. But adhesive properties of native oxide can be utilized for TSV Cu electroplating. Weak adhesion between films can provide easy removal of films. Ni was electroplated on seed layer and its adhesion to electroplated Cu was evaluated.

II. TSV FABRICATION

Fig. 1 shows the conventional TSV fabrication. Hard mask with 200 nm thickness was deposited at 400°C and phtoresist with 6um thickness and gh-line process were used for TSV lithography. TSV was formed by deep reactive ion etching (BOSCH process) followed by 8kA dielectric liner oxide deposition for electrical isolation. 2kA Ti as barrier layer and 8kA Cu as seed layer were deposited by physical vapor deposition (PVD) process. Cu electroplating is carried out to fill TSV structure, followed by Cu annealing. Excessive Cu on wafer surface is removed by CMP.

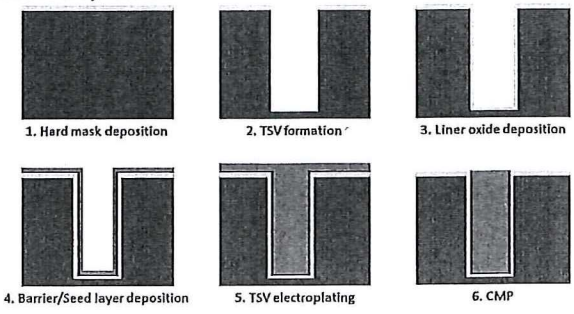

Figure 1. Conventional TSV fabrication process

In Fig. 2, TSV fabrication process was nearly identical to conventional TSV fabrication process. After barrier and seed layer deposition, material with native oxide can be deposited by PVD, CVD and electroplating process. In this study, Ni was electroplated prior to TSV Cu electroplating. Constant direct current at 3ASD was applied to deposit conformal 2kA Ni layer along wafer surface. Cu electroplating process was applied for TSV metallization. Stepwise increasing current and TSV chemical with three additives were used for bottom-up TSV filling. After TSV Cu electroplating, Cu layer on wafer surface can be easily removed resulting in no Cu overburden and no Cu residue on wafer surface

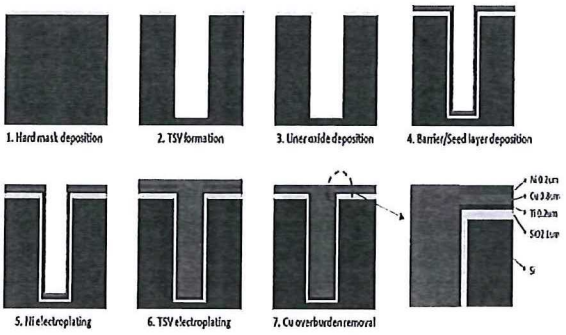

Figure 2. TSV fabrication process in this study

III. RESULTS

A. *Cu removal test*

While electroplated Cu and Ni have poor adhesion, continuous and mirror-like Cu film was formed on wafer surface without any defects such as entrapped air or crack (Fig. 3(a)). Kapton adhesive tape was used to test adhesion between electroplated Cu and Ni. After attaching Kapton adhesive tape on wafer surface, it was slowly pulled at about 5cm/sec rate. As can be seen in Fig. 3(b), electroplated Cu was easily peeled from Ni surface. Remained Cu was also easily removed as a Cu foil without applying strength. After electroplated Cu peeling, Cu residue was not shown and only clean Ni surface can be seen (Fig. 3(c)). Cu seed layer at wafer edge exclusion zone was remained because Ni and Cu were not plated at this zone.

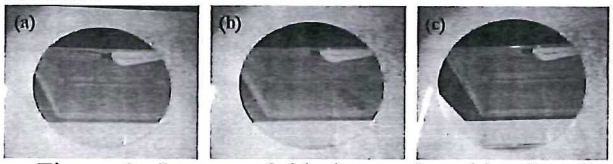

Figure 3. Images of blanket wafers (a) after Cu electroplating (b) after partial Cu removal (c) after complete Cu removal

The effect of Ni and Cu electroplating conditions on Cu adhesion was studied. Various thickness of Ni and current density were also evaluated. For the study of Ni electroplating, 2um Cu was plated by applying 3ASD on Ni layer and for Cu electroplating evaluation, 3ASD was applied for 2kA Ni electroplating with 10mins queue time between Cu and Ni electroplating.
Ni thickness and electroplating current density didn't make any significant changes on Cu adhesion (Table 1, 2).

Table 1. Cu removal test on various Ni thickness

Ni thickness	0.2um	0.5um	2um
Peeling test	Peeled	Peeled	Peeled

Table 2. Cu removal test on various current density of Ni electroplating

Ni ECP ASD	0.5ASD	1.5ASD	3ASD	6ASD
Peeling test	Peeled	Peeled	Peeled	Peeled

It seems that native Ni oxide is formed once wafer is exposed to atmosphere (Table 3). Cu film which is deposited consecutively after Ni electroplating was difficult to remove from Ni surface but after 10mins queue time between Ni and Cu electroplating, Cu film was easily peeled.
Current density of Cu electroplating has little effect on Cu adhesion. Cu film plated at lower current was slightly more difficult to be peeled though Cu film doesn't leave any Cu residue on wafer surface (Table 4). But too low current made powdery Cu films. Higher current density made hard Cu film which is easier to be removed.

Table 3. Cu removal test on various queue time after Ni electropalting

Queue time	0mins	10mins	30mins	1hr
Peeling test	Not peeled	Peeled	Peeled	Peeled

Table 4. Cu removal test on various current density of Cu electroplating

Cu ECP ASD	0.01ASD	0.02ASD	0.1ASD	0.2ASD
Peeling test	Peeled	Peeled	Peeled	Peeled

B. *TSV electropalting*

Fig. 4(a) is the microscope image of TSV after barrier/seed layer deposition. Wafer has bright and mirror-

like surface. After 2kA Ni electroplating at 3ASD, wafer shows rougher surface than barrier/seed layer (Fig. 4(b)). It's because Ni chemical in this study was optimized for low stress film which doesn't include additives like leveler and brightener. Stepwise increasing current from 0.02ASD to 0.2ASD was applied for TSV Cu electroplating. Compared to conventional TSV electroplating, Fig. 4(c) shows rough surface due to rough Ni surface with 0.5um Cu protrusion. Cu film at filed area were removed by Kapton adhesive tape. There is no Cu residue on wafer surface and interface between TSV and wafer filed area is clear.

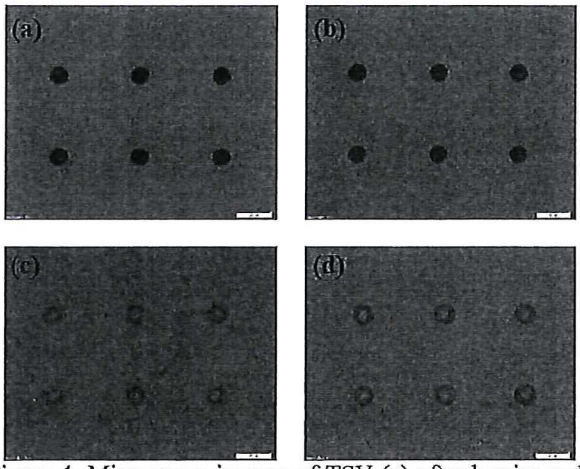

Figure 4. Microscope images of TSV (a) after barrier and seed layer deposition (b) after Ni electroplating (c) after Cu electroplating and (d) after Cu overburden removal

To fill up TSV, normal electroplating condition was applied and result is shown in Fig. 5. In X-ray image, TSV center is slightly brighter than another area, which means TSV has small voids. It could be because of electrical conductivity difference of Ni and Cu seed layer. In normal TSV electroplating, current pass through Cu seed layer. But in this study, Ni which has lower electrical conductivity than Cu seed layer, is plated on barrier and seed layer prior to TSV Cu electroplating. It seems that overpotential change caused by Ni resulted in void defect formation in TSV. Electroplating parameter were optimized for defect-free TSV filling.

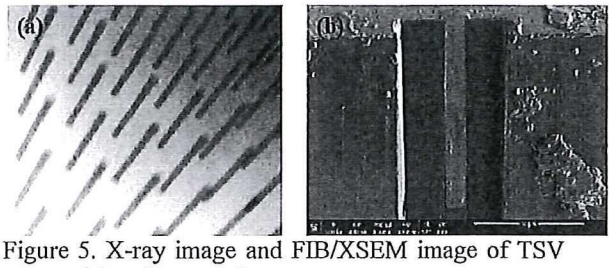

Figure 5. X-ray image and FIB/XSEM image of TSV after normal Cu electroplating.

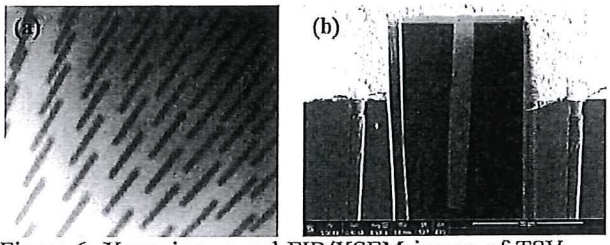

Figure 6. X-ray image and FIB/XSEM image of TSV after Cu electroplating with optimized condition.

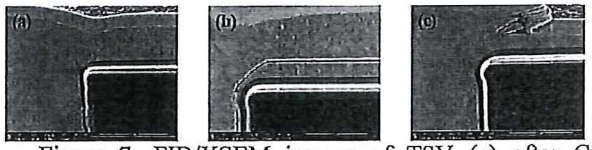

Figure 7. FIB/XSEM images of TSV (a) after Cu electroplating by conventional TSV process (b) after Cu electroplating by this approach (c) after Cu overburden removal.

Fig. 6(a) is X-ray image of solid-filled TSV with optimized electroplating condition. Dark TSVs means TSV are filled by Cu without void defect. Defect-free TSV is clearly seen in XSEM image (Fig. 6(b)).

Higher magnification XSEM images show each dielectric layer, seed/barrier layer, electroplated Ni layer and electroplated Cu layer (Fig. 7). Fig. 7(a) and 7(b) are XSEM images of TSV using conventional process and this approach, respectively. Electroplated Ni on barrier/seed layer and Cu overburden on Ni layer can be seen in Fig. 7(b). Because of poor adhesion between electroplated Cu and Ni, Cu overburden can be easily peeled (Fig. 7(c)).

Though this approach has advantages of easy Cu overburden removal, further researches are required. First one is to clarify the root cause of delamination between electroplated Cu and Ni. In this study it assumed that delamination is caused by native Ni oxide and poor adhesion between electroplated Cu and Ni. But in the case of electroless Ni layer, this delamination was not shown [3] and different factor like hydrogen during electroplating can cause film delamination [4]. Second one is to find out solution to remove Ni layer. Conventional CMP process is optimized for Cu removal. And chemical removal of Ni is difficult due to its corrosion resistant property. Third one is to prevent Ni electroplating inside TSV. This is achievable by optimizing pre-wetting process before Ni electroplating.

IV. CONCLUSION

10um x 100um TSV was prepared by conventional TSV fabrication process consisting of 2kA hard mask, deep Si etching for TSV formation, barrier and seed layer deposition. Material with native oxide can be deposited on

Cu seed layer by PVD, CVD and electroplating. Electroplated Ni was used in this study. Subsequent TSV Cu electroplating was carried out using stepwise increasing current from 0.02ASD to 0.2ASD. Native Ni oxide provides weak adhesion to electroplated Cu on wafer surface. And electroplated Cu can be easily removed from wafer surface. This approach has advantages of easy Cu overburden removal, no residual Cu on wafer surface resulting in no electrical short failure between TSVs and cost effectiveness to shorten CMP process.

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