High throughput Copper Removal of Frontside Circuit Edit

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Abstract: Circuit Edit (CE) is widely used for debug, characterization and prototyping in the IC industry. With the adoption of stacked dies in modern IC and unique packaging, backside CE is becoming more common approach for CE [1],[2]. The modern CE requires precise and gentle copper removal without exposing underlayer in the critical steps. The primary way to achieve the goal is the use of unique CE chemistry. The secondary option is to optimize recipe and utilize special beam scanning technique with bitmapping and exclusion mill, etc. On the other hand, frontside CE is still common in the IC industry. Its application and requirement can be very different from backside edit. One of them is to be able to quickly remove RDL and/or thick copper layer (~3um or thicker) because sometimes this step could take more than 50% of operation time of the whole CE job. In this study, we present high throughput copper removal technique with water chemistry and low-keV beam (5kV).

Keywords: Circuit edit, Copper removal, Low-KV, Frontside CE, Water assisted etch.

1. Introduction

Circuit Edit (CE) is widely used for IC debug, characterization and prototyping. Although backside CE became more common technique, frontside CE is still needed because of several reasons: 1) experience and knowledge required on both of sample preparation and backside CE, 2) system capability for backside CE, and 3) facility to validate IC after completing backside CE. Frontside CE application and requirements are very different from backside. One of them is to be able to quickly remove RDL and/or thick copper layer (~3um or thicker) included dummy layers because sometimes this step could take more than 50% of operation time of the whole CE job. It is a critical issue of time management in the FA lab when the FIB system time is heavily spent on thick copper removal. In this study, we present high throughput copper removal technique with water chemistry and Low-KV beam (5kV). The technique helps improve productivity on frontside CE.

2. Challenges of Copper removal

Since the adaption of Copper metallization in IC, Copper removal has always been challenging due to several reasons [4]. 1) Grain structure. These grains etch at different rates depending on grain orientation relative to ion beam. 2) No accelerated removal of Copper like Halogen etching for Aluminum. Copper etch solutions were to protect the Inter Layers Dielectric (ILD) and therefore etching process is slower. 3) Oxidizing Copper makes it non-conductive. 4) Oxidizing SiO2 makes it more sputter resistant. 5) Chemistry application.

In the report, we will demonstrate oxidizing both Copper and SiO2 with water assisted etching and low beam energy to reduce etching rate on SiO2 layer this time.

3. Proposed technique for thick copper removal

3.1. Low Beam Energy for reduced SiO2 damage

Gallium ion milling using low beam energy is a common technique on TEM sample preparation. It has not been common in CE applications because the CE jobs demand the highest imaging resolution and milling resolution. Therefore, CE FIB system is generally optimized with higher beam energy at 30kV. Recently the low beam energy technique is adapted on backside CE workflow for advanced technology nodes. It decreased Gallium penetration into FinFET layers allowing the device still be intact after fully exposes active region. So, the low beam energy technique is expected to reduce damage on SiO2 layer as well. We performed 1x1μm milling into SiO2 layer with Dose 2.0[nC/μm^2] at different beam energies (30, 16, 8 and 5kV) and estimated SiO2 etching rate vs different beam energies with cross section view.

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The lower beam energy decreases etching rate as shown in Table 1 and Figure 1.

Table.1: Beam energy vs Milled depth per Dose without chemistry assistance.

Beam energy [kV]	Milled depth[um]/Dose[nC/μm^2]
30	0.26
16	0.22
8	0.17
5	0.15

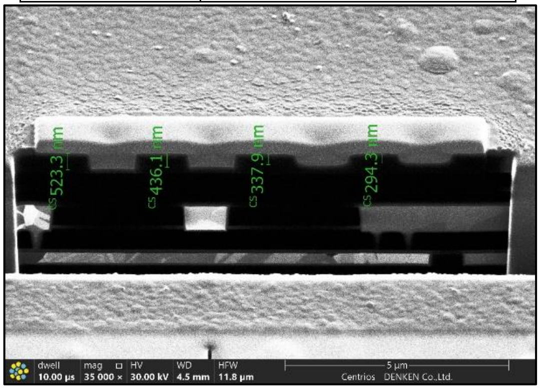

Figure.1: Cross section view of etched SiO2 without chemistry application. From left to right, the beam energies are 30, 16, 8 and 5kV.

3.2. Water assisted etch

The Copper etching solution has been developed along with the advanced technology nodes since adaption of copper metallization. Today, the chemistry application like CU2 and DX delayering are more suitable for Copper etching over Low-K dielectric layer than water assisted etch. Water is oxidizer during copper removal and is difficult to work on low-K dielectric layer. However, it is still an attractive solution for thick copper and/or RDL removal in frontside CE. Water is an attractive solution as a precursor on copper etching process for several reasons: 1) promoting copper surface oxidation; 2) reducing the channeling effect; 3) nontoxic and 4) easy to deliver into the vacuum.

We tested 1x1μm milling into SiO2 layer with Dose 2.0[nC/μm^2] at different beam energies (30, 16, 8 and 5kV) with water assistance and checked cross section to see beam energy influence on SIO2 etching rate. As expected, the lower beam energy with water clearly decreases etching rate as shown in Table 2 and Figure 2.

Table.2: Beam energy vs Milled depth per Dose with water assisted etch.

Beam energy [kV]	Milled depth[um]/Dose[nC/μm^2]
30	0.08
16	0.06
8	0.04
5	0.03

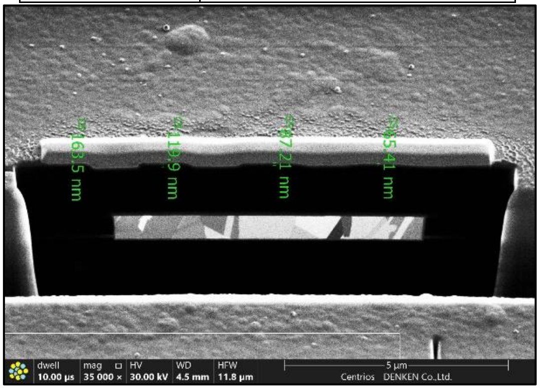

Figure.2: Cross section view of etched SiO2 layer with water assisted etch. From left to right, the beam energies are 30, 16, 8 and 5kV.

Here is summary of Low beam energy with/without water etching on SiO2. Significantly water assisted etch decreases the etching rate on SiO2 layer as shown Figure.3.

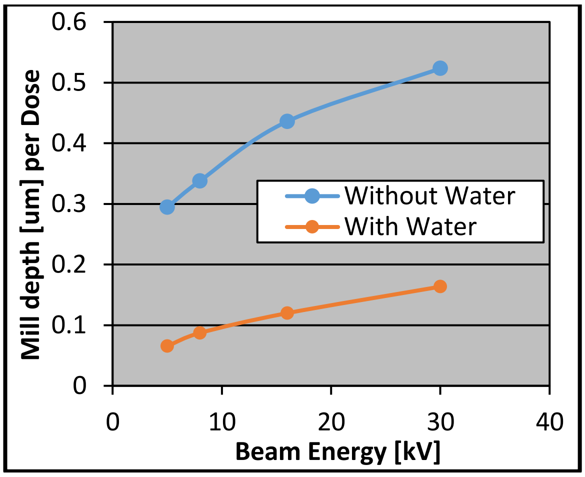

Figure.3: Comparison of SiO2 etching rate with/without Water.

3.3. Water assisted etch with high beam current density

Beam current density is also a key to accelerate copper removal and enhance productivity on CE. In other way, it might impact SiO2 etching, even with the same dose[nC/μm^2].

To study beam current effect, we performed 10x10µm milling into SiO2 layer with Dose 2.0[nC/µm^2] at different beam current densities (~10, ~25 and ~90[pA/µm^2]). The SiO2 etch rate vs beam current density are as shown in Table 3 and Figure 4 & 5.

Table.3: Beam current density vs Milled depth/Dose with water assisted etch.

b/c density [pA/µm^2]	Milled depth[µm]/Dose[nC/µm^2]
93	0.32
24	0.27
9.1	0.26

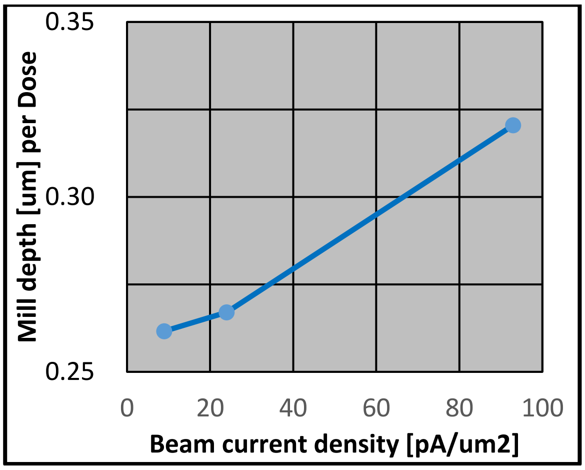

Figure.4; Beam current density vs Mill depth [µm] per Dose.

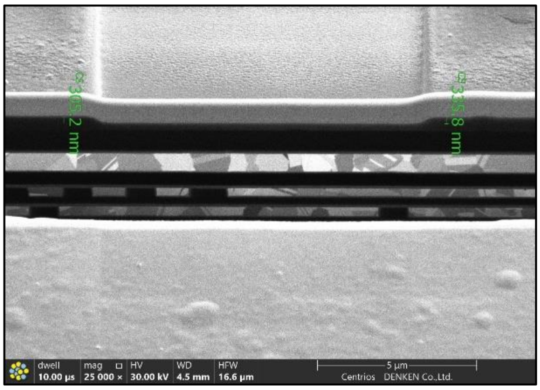

Figure.5: Cross section view of 10x10µm trench floor after performing water assisted etching with high beam current density (~90[pA/µm^2]).

4. High throughput thick copper removal in Frontside CE

4.1. Thick copper exposure

The following illustrates workflow for thick copper removal with 30x30µm area in frontside CE. The thickness of copper is 900nm. Navigate over the target location. Typically, high beam current is used to work for larger area and to accelerate removal process. Once on destination, tilt stage 45 degree to prevent discharge over the target then start to etch dielectric and expose copper layer with XeF2. Exposed Copper layer with 30x21.2µm is shown in Figure 6. Bring tilt stage back to 0 degree. Here we obtain approximately 30x30µm trench floor as shown in Figure 7.

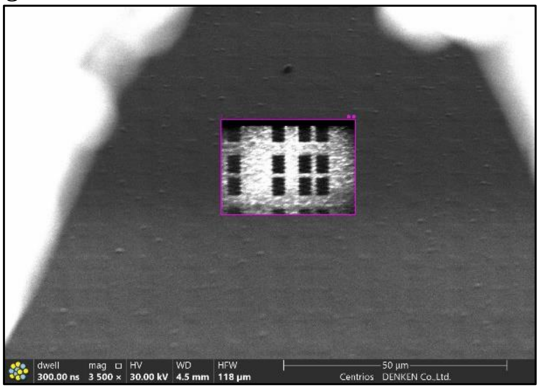

Figure.6: Copper layer exposure with angle 45 degree. Successfully reach thick copper layer.

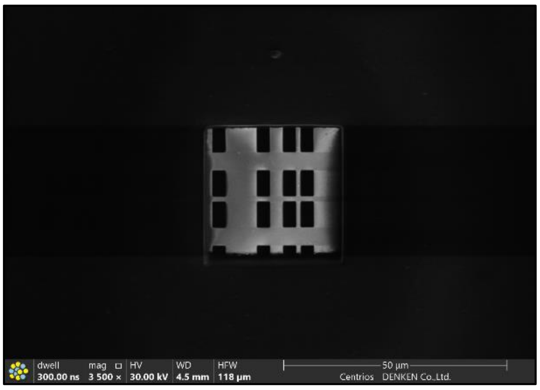

Figure. 7: Obtain 30x30µm trench floor.

4.2. Over etching for ILD

The trench floor is a mixed field with copper and ILD as shown 8. As illustrated in the previous section, Water and Low-KV etching wouldn't etch the ILD much during thick copper removal. Need to perform over etching for ILD to maintain planarity on the trench floor after completed thick copper removal. This is the key to CE success rate. Perform the over etching process based on dose or time on the copper exposure process.

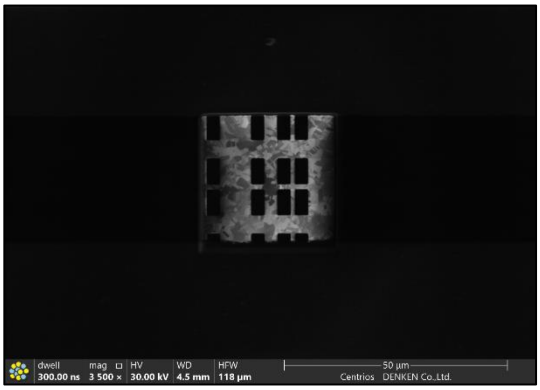

Figure.8: Complete over etching process. Ready for thick copper removal.

4.3. Thick copper removal at 30kV

Increase beam current at 47nA to accelerate copper removal as shown Figure 9.

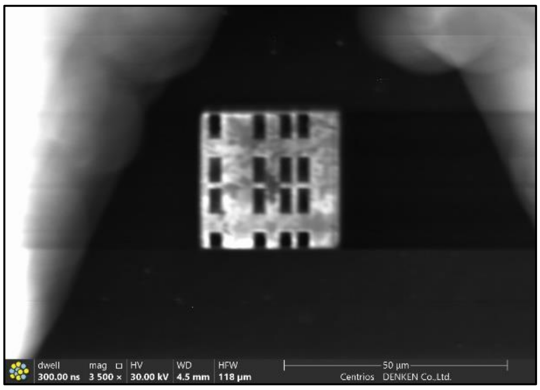

Figure.9: Switch higher beam current at beam energy 30kV for thick copper removal.

Perform thick copper removal process with high beam current at beam energy 30kV. Once etched through copper layer and expose ILD (SiO_2) partially as shown Figure 10, here is the endpoint and then reduce beam energy to 5kV. It takes about 1min.

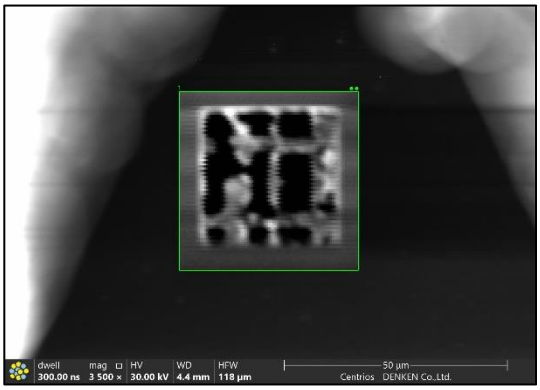

Figure.10: Etch through copper and expose ILD layer partially. Here is endpoint on thick copper removal at beam energy 30kV.

4.4. Thick copper removal with Low-kV

Continue Copper removal with H_2O after reduced beam energy 5kV and beam current at 13nA as shown in Figure 11. The endpoint is the black and white contrast on live milling image. Complete copper removal without underlying exposure as shown Figure.12. The low beam energy at 5kV process takes for 8mins. The total removal time over 900nm thickness is approximately 10mins.

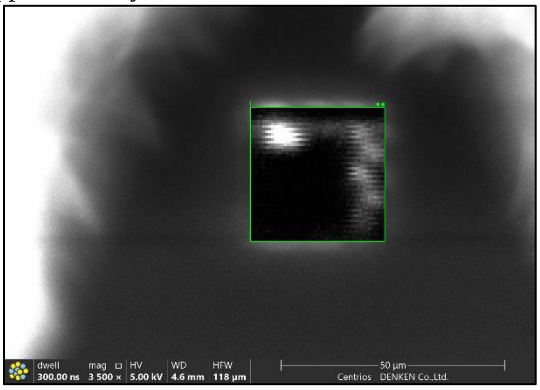

Figure.11: Perform copper etching with water and low-KV.

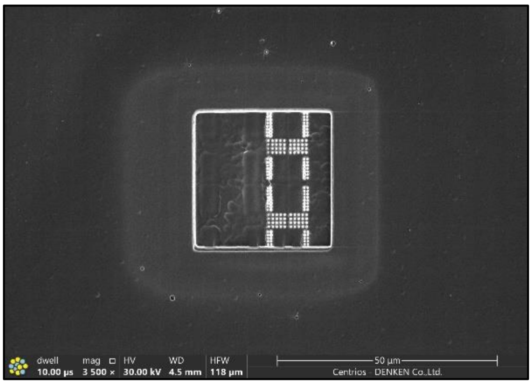

Figure.12: Completion of Copper removal without underlying exposure.

Obtain the tilt image on the trench floor to make sure underlayer intact. This is shown in Figure 13.

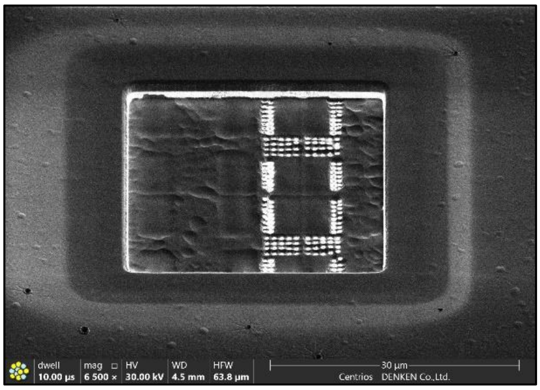

Figure.13: Trench floor validation with tilt image.

Expose underlying on central trench floor with 15x15µm. Expose the copper layers as shown Figure 14. The result demonstrates frontside CE capability.

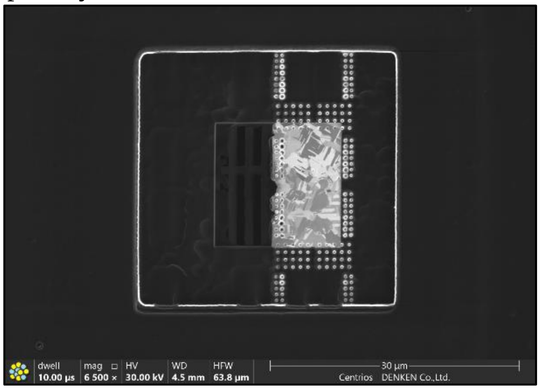

Figure.14: Underlying exposure on central trench floor with 15x15µm after completed thick copper removal.

We validate the technique on two practical frontside edit as shown in the following.

(1) Cut Metal 3 layers on 9 stacked layers underneath ~3µm thick copper dummy layers.
With low kV & Water assisted etch, the thick copper dummy removal took approximately 15mins. Whole CE job was completed approximately 3-4hours. Without low kV & Water assisted etch, the RDL removal over 40x20µm area will take approximately 2-3 hours and the whole CE job will take 7-8 hours. The technique improves approximately 50% productivity .

(2) Tie Metal 2 to Metal 2 and cut Metal 2 on 3 stacked layers underneath ~6µm thick RDL.
With low kV & Water assisted etch, the RDL removal over 40x20µm area took approximately 20mins. The whole CE job can be done within 90mins. Without low kV & Water assisted etch, the RDL removal over 40x20µm area will take approximately 2-3 hours and the whole edit will take 3-4 hours. The technique enhances more than 60% productivity.

5. Conclusions

This work shows utilization of low beam energy (5kV) and Water (oxidizer) assisted etch on frontside CE. It allows to decrease etching rate on SiO2 layer and also worked underneath thick copper and/or RDL layer. Therefore, the technique is able to use higher beam current than general CE process during thick copper and/or RDL removal process. This work also demonstrates the improvement of frontside CE productivity. The removal process is accelerated aby ≥50%.

Acknowledge

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References

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