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Uniform Delayering of Copper Metallization

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Abstract- Integrated circuit chips of newer technology usually have a larger die size and an increase number of metallization. Hence, pure usage of polishing to remove the layers would induce severe edge rounding. An alternative method is proposed to decrease the polishing time for copper metallization removal while reducing edge rounding on the sample during sample preparation that will preserve the integrity of the layers for further failure analysis.

Keywords: Delayering, sample preparation, polishing, copper metallization

I. INTRODUCTION

As the market demands for higher performance and better technology, many of the integrated circuit (ICs) manufacturers have been continually seeking ways to cater to the demand, at the same time lowering costs. To achieve this, the ICs of current days is moving towards a bigger dimension with more layers, circuits or devices integrated on a single die [1]. Copper (Cu) has replaced aluminium (Al) as the metallization material because of its better properties such as better resistance to electromigration and lower RC delays for faster speed [2]

In sample preparation, Cu can be removed by methods such as polishing (with slurry), wet etching or plasma etching. However, pure polishing for a prolong time leads to severe edge rounding on die [3], wet etching may cause over etching if not carefully monitored and controlled. Lastly Cu is difficult to remove by plasma etching [4]. Edge rounding and over etching will cause loss of information during failure analysis and this is undesirable. Retaining the integrity of the layers during sample preparation is thus important if inspection of the ICs for root cause analysis is required.

In this paper, the aim is to propose alternative methods to enhance the established sample preparation methods for Cu metallization removal at a faster removal rate while maintaining global uniformity on a large sample. The experiments are separated into two parts. The first part looks into how the manner of polishing would affect the sample in term of edge rounding effect and the focus of the second part is on whether the addition of H₂O₂ to the slurry (colloidal silica) will reduce the polishing time as well as achieving global uniformity. Both sets of experiments will be studied and analysed.

II. EXPERIMENTAL DETAILS

A. Physical Polishing Technique

The samples were manually cut from a wafer into the size of approximately 5 mm x 5 mm. The sample consists of 9 metal layers. Before the experiment, the top layers of non-interest would be removed (e.g. die passivation, Al layer, barrier etc.) until exposing the first top Cu metal layer. The sample was then mounted on a mounting plate fixture and polished using an automatic polisher (Ultrapol). The polishing parameters such as force, time, rotation speed of polishing platen and non-crystallizing colloidal silica slurry were kept constant. The samples were polished with two different methods so as to understand whether the way of polishing would affect the samples qualitatively. Fig. 1a depicted Method A, where mounting fixture is in oscillation (left and right motion) and rotation mode while Method B is illustrated by fig. 1b, where mounting fixture is in oscillation mode only.

Fig. 1. Polisher set up (a) Mounting fixture in oscillation and rotating mode (b) Mounting fixture in oscillation mode only.

B. Chemical Mechanical Polishing

The package was first chemically decapsulated, after which the top layers of non-interest (e.g. die passivation, Al layer, barrier etc.) were removed. The samples used also consist of 9 metal layers. Upon exposing the first top Cu metal layer, the experiments were conducted. A constant force was applied

throughout the polishing, while the polishing pad and non-crystallizing colloidal silica slurry were kept the same for the experiments.

To investigate if the addition of catalyst, in this case hydrogen peroxide (H_2O_2) was used, to the slurry allows the Cu metallization to be removed in a shorter time, a reference sample was polished purely by slurry and the time was recorded. On the other hand, three different concentrations of H_2O_2 were also added to the same amount of slurry to compare if the addition of more H_2O_2 increases the rate of removal on the sample. Table 1 shows the parameters set for the experiments.

Table 1: Different amount of H_2O_2 added into slurry

Sample	Polishing Parameter
Reference	Only Slurry
A	1 drop of H_2O_2 to 1 ml slurry
B	5 drops of H_2O_2 to 1 ml slurry
C	10 drops of H_2O_2 to 1 ml of slurry

III. EXPERIMENTAL RESULTS

A. Edge Rounding

In first part of the experiments, when different samples were polished for 5 - 6 min using Method A and Method B, edge rounding was observed on both samples as shown in fig. 2a and 2c without much significant difference. However, when both samples were polished for a longer time for 10 min, the area of the exposed white region (pointed with red arrows) shown in fig. 2b, was significantly larger than that in fig. 2d at the edge. This indicates that the edge of the uppermost layer of sample in fig. 2b had been polished more than the sample in fig. 2d. Thus, samples polished in rotation with oscillating mode led to more severe rounding than polishing purely in oscillating mode for 10 min. By setting the polisher to only oscillate the mounting fixture, it helps to reduce the edge rounding effects to a certain extent at longer polishing time.

Fig. 2. Sample polished for (a) 5 min and (b) 10 min using Method A, (c) 6 min and (d) 10 min using Method B.

Although automatic polishing is faster and able to provide more reproducible results, manual polishing would allow user to have better control of polishing depth than automatic polishing [5]. This could be important when the features are small and requires small polishing force and frequent inspection during prolonged polishing time in sample preparation. Therefore, in the second part of the experiments, manual polishing was utilized instead of automatic polishing. Samples were manually polished using a minimal force with only oscillating motion on stationary polishing pad so as to minimize rounding where possible.

B. Rate of Metallization Removal

The time taken to remove the Cu metallization completely for each sample is shown in Table 2.

Table 2: Time taken to remove copper metallization completely for sample

Sample	Time taken to remove copper metallization completely (min)
Reference	100
A	45
B	50
C	50

From the table, it was observed that pure polishing of Cu metallization with slurry took the longest time, i.e. 100 min. In addition, severe edge rounding and exposure of underlying metal layer could also be observed as shown in fig. 3a. This result shows that adding drops of H_2O_2 into the slurry did shorten the polishing time by almost 50% to 45-50 min. In this case, the edge rounding could be reduced significantly as well (see fig.3b-3d). However, increasing amount of H_2O_2 used did not result in major decrease in polishing time. This indicates that the quantity of H_2O_2 is unlikely to have a huge impact on the removal rate beyond a small amount.

Besides reducing edge rounding, adding H_2O_2 also allows the integrity of the layer to be retained, such as the dual damascene Cu vias. If the Cu metallization was removed by wet etching, the copper via would have been etched away due to the selectivity of the wet etchant. The scanning electron microscope (SEM) image in fig. 4a shows the holes where vias were located when wet etching was used while the SEM image in fig. 4b shows the

outstanding solid vias when removal was done by chemical mechanical polishing.

Fig. 3. Sample polished with (a) only slurry, (b) 1 drop of H_2O_2 to 1 ml slurry, (c) 5 drops of H_2O_2 to 1 ml slurry and (d) 10 drops of H_2O_2 to 1 ml slurry.

Fig. 4. SEM image of sample after (a) wet etching (b) chemical mechanical polishing

IV. RESULT DISCUSSION

In this section, the possible mechanism that leads to the observations obtained in the experiments will be further elaborated.

For Method A, when polishing is done under oscillation with rotating mode, the sample can be assumed to be divided into 3 regions (fig. 5).

Fig. 5. Schematic of sample under Method A.

R1 denotes the region at the corners, R2 is the region at the 4 sides, and R3 is the region at the centre of the sample. When the sample rotates, the 4 corners (R1) are being exposed to fresh abrasive particles and will be polished first, followed by the sides (R2). The centre region (R3) starts to get polished after the abrasive particles seep in. This denotes that the amount of abrasive particles that is used to polish the centre would be less than the corners and sides.

If the polishing rate for $R1 = 10 \text{ nm/s}$, $R2 = 5 \text{ nm/s}$ and $R3 = 3 \text{ nm/s}$, and a thickness of 100 nm needs to be removed, the centre region will take approximately 33 s to remove 100 nm. For a period of 33 s, 330 nm will already be removed in R1 while 165 nm will be removed in R2. Hence, the difference in the thickness of R1 and R3 is 230 nm. This significant difference is likely to be the reason for the severity of corner rounding when samples are polished in oscillation with rotating mode.

In case of Method B, when polishing is done in oscillation mode only, the sample is assumed to be divided in 2 regions R1 ($R1 = R1'$) and R2 (see fig. 6).

Fig. 6. Schematic of sample under Method B.

R1 is the region of both left and right sides and R2 is the centre region of sample. As sample oscillates to the left, the abrasive particles will polish the side of R1 and the removal rate for $R1 \geq R2 \geq R1'$. When sample oscillates to the right, the abrasive particles will polish the side of R1' thus resulting in the removal rate for $R1' \geq R2 \geq R1$. Hence removal rate for $R1+R1' \geq R2+R2$ when sample oscillates left and right. If thickness of 100nm is to be removed, an approximately 100 nm would be removed for both R1(R1') and R2. This may be the reason for lesser corner rounding on samples polished in oscillation mode compared to oscillation with rotating mode. However, it is noted that the side R1/R1' will always come in contact to fresh abrasive particles first followed by R2, hence certain extent of rounding will still occur.

As for the use of H_2O_2 oxidizer with the slurry, it provides both physical and chemical forces to remove Cu metallization. The overall reaction is as follows:

As Cu oxidizes with H_2O_2 , CuO is formed. It is likely due to the poor adhesion between the oxidized CuO and Cu which gives rise to CuO being removed more easily when force is applied during polishing of the sample [6, 7].

One possibility that the different concentration of H_2O_2 slurry mixture has no effect on the time required to remove the Cu completely can be because the 1:1 mixture ratio has reached the maximum reaction rate, thus regardless of the amount of H_2O_2 added, the time taken for Cu removal is similar.

During polishing, the reason behind the edge rounding being reduced significantly when mixture of H_2O_2 and slurry is used is that when a shorter polishing time is required, the amount of

abrasive particles attacking the sample will be limited. As mentioned previously, the sides are exposed to more abrasive particles as compared to the centre portion, thus during prolonged polishing time, the material at the edges tends to have a higher removal rate and thus, edge rounding occurs.

V. CONCLUSION

In conclusion, by combining manual polishing with smaller force in oscillating motion and use of slurry with the addition of H_2O_2 , it shows that the edge rounding could be reduced to a large extent while the polishing time required for material removal is shorter. This further benefits the user by easing the sample preparation process while at the same time retaining the integrity (e.g. Cu vias) of the sample for further failure analysis. This chemical mechanical polishing method enhances the conventional mechanical polishing method as well as eliminating the damage of wet etching as over etching causes the etchant to seep down the layer of interest, affecting the underlying layers if wet etching is not well controlled. Moreover, the usage of wet etchant can also be reduced.

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