Research of diamond concentration in dicing blade effect by electroplating parameter

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Abstract. In order to study the effect factors of diamond concentration in Dicing Blade prepared by composite coating method, a uniform distribution diamond composite coatings was prepared by suspension and high-low speed interval agitation method on the aluminium alloy blade hub. The effects of suspension diamond content, stirring speed, current density, surface tension and solution temperature to diamond concentration in composite coatings were studied. And the result shows the concentration of diamond in the coating is proportional to the suspending content in electroplating solution, the suspending diamond content increases, and the concentration of diamond in the coating increases until reaching a saturation value. The diamond concentration of coatings is inversely proportional to the stirring speed of sand, and obtained maximum concentrations when current density is 2.0 A/dm2 and temperature is 50°C. The surface tension has little effect to the concentration of diamond in the coating layer.

Key words: suspension diamond concentration; internal agitation; stirring speed; current density; temperature; composite coating.

1. Introduction
Wafer dicing is an important process to separate apart the single dies on the raw finished wafer by using dicing saw for further packaging and assembly [1, 2]. Wafer have highest value at the die separation stage. Dicing does not add value to the finished dies, but it has a significant impact to die packaging and assembly yield. In many applications, wafer dicing has become the most challenging process to meet both yield and cost targets [3]. High precision dicing blade has been widely used in the packaging process with the development of semiconductor industry. And dicing blade was manufacture by series high precision process include diamond powder and nickel metal electro-deposited on the aluminum alloy hub and special machine finishing process. Chipping refers to a machining damage from dicing in which small fragments are removed alongside the die edge. Depending on its occurrence either at the top or bottom surface of die, edge chipping is further partitioned into top side chipping and bottom side chipping. Different diamond concentrations is one of key parameters of cutting quality effectors that’s because higher diamond concentration lead to more cutting life and improvement of top side chipping but worsening of bottom side chipping, by contrast lower diamond concentration lead less cutting life and improvement of bottom side chipping but worsening of top side chipping[4]. When the diamond
concentration changes from low to high, saw blade sharpness and sawing efficiency gradually decreased, and the life gradually extended, but the concentration is too high, the blade will become blunt. Nevertheless, which will be improved by low concentration blade [5].

Therefore, a precision method of control dicing blade diamond concentration is directly effect of the value of the dicing blade and semiconductor performance. Composite electroplate technology as a method for acquiring composite material, has advantages as being simple to operate, variety materials co-deposition and low cost compared with traditional powder metallurgy technology [6]. Composite coatings is prepared by insoluble particles and metal ions co-electroplated on the cathode surface, which of the advantages like high hardness, less wear ratio, long service life. With the rapid development of manufacturing industry, diamond tools are more and more widely used for processing hard and brittle non-metallic materials nowadays.

For now, coarse-grained abrasive material (41~1090μm) composite coatings was prepared by co-deposition method of inter-sand, and fine-grained abrasive material (0~40μm) composite coatings was prepared by co-deposition method of suspension sand [7]. More and more composite electroplate technologies was reported with advances in plating technology. Hu [8] reported a method to achieve a single layer of diamond composite coatings via pre-nickel plating, suspension sand composite plating and thicken plating. Fang [9] reported a method to achieve Nickel-diamond composite coatings prepared by electroless pre-nickel plating firstly and then thicken barrel plating.

In this work, a uniform distribution diamond composite coatings was prepared by suspension and high-low speed interval agitation method on self-made cathode work piece. The effects of suspension diamond content, stirring speed, current density and surface tension on diamond concentration in composite coatings were studied. A newly method that diamond powder suspension during the whole processing to prepare composite coatings was reported, furthermore diamond concentration effect factors was researched.

2. Experiment

2.1. Material
(1) Aluminum alloy base material (Alloy model: 5A05);
(2) Diamond powder (Particle size: 3.1~3.3μm);
(3) Anode: Nickel anode (0.02% Sulfur) purchase from Vale Inco Company;
(4) Plating solution: Nickel Sulfamate. And Table 1 shows the composition of plating solution bath.

| Item                  | Make up     |
|-----------------------|-------------|
| Nickel Sulfamate      | 280~330 g/L |
| Nickel chloride       | 35~45 g/L   |
| Boric acid            | 35~45 g/L   |
| Sodium Allylsulfonate | 8.0 g/L     |
| Sodium dodecyl sulfate| 0.1g/L      |
| pH                    | 3.8~4.2     |

2.2. Equipment
(1) Self-made plating bath with mechanical stirring.
(2) High frequency infrared Carbon/Sulfur determinator (Leco CS230H).
(3) Scanning electron microscopes (FEI S50).
(4) Automatic surface tension determinator (SHFR-QBZY).
(5) Precision electronic balance (BSA223S).
2.3. Method

2.3.1. Pre-treatment of Diamond powder. Firstly, add diamond powder to Sodium hydroxide (NaOH, 20g/L), stir and keep for 30mins, then use ultra-pure (UP water) washing diamond powder until rinsing water’s pH is 7.0, afterwards, add the diamond powder to boiling nitric acid (50%) solution for stirring 30mins, then use ultra-pure (UP water) washing diamond powder until rinsing water’s pH is 7.0. In the last, sonicated diamond powder in the ultrasonic washer about 30mins and add the diamond powder into plating solution.

2.3.2. Base material installing. Cover the flank and basal plane of the alloy base with insulation to isolate with plating solution, then install it on the self-made plating jig.

2.3.3. Preparation of composite coating. Composite coating is prepared by plating method according to the following procedure: Firstly, Alloy base material is dipped in the soak cleaning solution and kept for 2mins, then rinsed by city water. Secondly, the alloy sample is dipped in the Alkali solution and kept for 2mins, which is used to remove the surface oxidation layer, then rinsed by hot water (60°C). Thirdly, put the alloy sample into the acid solution and kept for 1min, which is used to neutralize the alloy surface, then rinsed by city water. Finally, put the alloy sample into Nickel Sulfamate solution for electroplating.

2.3.4. Preparation of sample analysis. Composite coating layer obtained from the alloy substrate surface is used for characterization when electroplating process was finished. The composite coatings could be easily peel off from the base material due to the pretreatment process do not have zincate treatment process.

2.4. Characterization
Diamond powder quantity is weighed with electronic balance. Surface tension of plating solution is monitored by automatic surface tension determinator. Morphologies of the composite coatings surface is examined by Scanning Electron Microscope (SEM). Concentration of diamond in the coatings is analyzed by high frequency infrared Carbon/Sulfur determinator.

![Figure 1. Schematic of composite plating equipment](image)

1. Nickel anode; 2. Nickel sulfamate solution; 3. Mechanical stirring equipment; 4. Alloy substrate cathode

3. Results and discussion
Numerous of factors that affect concentration of diamond in the coating blade is been researched, which of including suspension of diamond powder quantity, current density, stir velocity, surface tension of solution and temperature of plating solution. Univariate analysis will be discussed in the subsequent sections.
3.1. The effect of cutting quality by surface diamond concentration of blade

![Figure 2](image2.png)

**Figure 2.** Schematic of composite coating with diamond powder

**Figure 3(a), (b).** SEM image of surface of composite coating layer from a, b direction of blade in Fig. 2; **Figure 3(c).** Wafer cutting picture

**Figure 4(a), (b).** SEM image of surface of composite coating layer from a, b direction of blade in Fig. 2; **Figure 4(c).** Wafer cutting picture

Fig. 3 (a) and Fig. 3(b) shows a uniform distribution diamond composite coatings from front side and back side of blade was prepared by suspension and high-low speed interval agitation method on self-made cathode work piece. Fig. 3(c) shows blade of uniform diamond distribution presents a good cutting Street due to same diamond concentration of both sides. In contrast, Fig. 4(c) shows the effect of cutting will have undesirable result like big chipping when the blade have asymmetry concentration on the blade surface. Diamond concentration is most critical when blade loading is of major concern and quality concerns prevent the use of a larger diamond grit size. Air agitation and mechanical agitation had been use in the plating process to get composite coatings with diamond and nickel. In the previous experiment result, air agitation technology and mechanical with same rotational speed in the whole process all shows asymmetry diamond concentration on the front and back side of blade. However high-low speed interval agitation method can improve the diamond powder distribution in the plating solution and present uniform concentration in the coating layer from begin to the end plating process.
3.2. Affection of suspension diamond powder dosage on concentration of diamond in the blade
Table 2 shows the concentration of diamond in the coatings relationship with suspension diamond dosage. It can be seen that concentration of diamond in the coatings is increased with suspension diamond powder dosage. However, the concentration of diamond in the coatings will not increase again and keep in a range between 15.28% and 15.89% when the dosage is more than 24.0g/L. For this phenomenon, the more dosage of diamond powder suspended in the solution that means more diamond powder around with alloy substrate cathode, more chances of diamond powder co-deposited with the Nickel layer are. Furthermore, the diamond concentration will not growth due to the concentration per unit volume is supersaturating.

| No. | Diamond suspended in solution (g/L) | Diamond concentration in blade (w.t%) |
|-----|-----------------------------------|--------------------------------------|
| 1   | 3                                 | 5.15                                 |
| 2   | 6                                 | 7.30                                 |
| 3   | 9                                 | 8.91                                 |
| 4   | 12                                | 10.46                                |
| 5   | 15                                | 12.52                                |
| 6   | 18                                | 13.98                                |
| 7   | 21                                | 14.59                                |
| 8   | 24                                | 15.28                                |
| 9   | 27                                | 15.29                                |
| 10  | 30                                | 15.67                                |
| 11  | 33                                | 15.53                                |
| 12  | 36                                | 15.72                                |
| 13  | 39                                | 15.89                                |
| 14  | 42                                | 15.64                                |

3.3. Affection of current density on concentration of diamond in the coatings
Table 3 shows the concentration of diamond in the coatings relationship with current density. It can be found that concentration of diamond in the coatings is increased with current density running to 2.0A/dm². But if the current density continue to increase, the concentration of diamond in the coatings instead reduce. It’s because that Nickel metal deposition speed increase with current density, the quantity of diamond powder around with alloy substrate cathode will not increase, that means the chances of diamond powder co-deposited with the Nickel layer will reduce within a certain time[10]. Because of that, some scholars [11] thought with the increase of the current density, cathodic superpotential and cathode hydrogen segregation will increase. Diamond and Nickel co-deposition is also affect by Hydrogen release.

| No | Electric current density (A/dm²) | Diamond concentration in blade (w.t%) |
|----|----------------------------------|--------------------------------------|
| 1  | 1.0                              | 5.58                                 |
| 2  | 2.0                              | 5.94                                 |
| 3  | 3.0                              | 5.30                                 |
| 4  | 4.0                              | 4.96                                 |
| 5  | 5.0                              | 3.56                                 |

3.4. Affection of stirring velocity to concentration of diamond in the blade
According to previous reports [12-14] about how to make a mixture of solid and liquid phase more uniform, high and low speed intermittent agitation method was be advised and high velocity agitation
time was less than low velocity. To study the affection of stirring velocity for concentration of diamond in the coatings, other influencing factors are kept same in this set of testing. Intermittent agitation method is adopted in the preparation process of composite coatings, which of every agitation cycle time is set for 40s including 10s of high velocity agitation time and 30s of low velocity agitation time. In this work, high velocity agitation has the function of lifting diamond powder and avoid of quick settlement, therefor high velocity agitation is named for suspend agitation. Instead, low velocity agitation is named for co-deposition agitation.

Table 4. Concentration of diamond in the blade prepared by series stirring velocity

| Serial No. | Co-deposition agitation (rpm) | Suspend agitation (rpm) | Concentration of diamond in the coating (wt.%) |
|------------|-------------------------------|-------------------------|-----------------------------------------------|
| 1          | 10                            | 300                     | 7.51%                                         |
| 2          | 20                            | 300                     | 7.22%                                         |
| 3          | 30                            | 300                     | 6.69%                                         |
| 4          | 40                            | 300                     | 6.27%                                         |
| 5          | 50                            | 300                     | 5.28%                                         |
| 6          | 60                            | 300                     | 4.72%                                         |
| 7          | 70                            | 300                     | 4.23%                                         |
| 8          | 80                            | 300                     | 3.54%                                         |
| 9          | 90                            | 300                     | 3.22%                                         |
| 10         | 100                           | 300                     | 2.22%                                         |

Table 4 shows concentration of diamond in the coatings relationship with stirring velocity. The results indicate that concentration of diamond in the coatings decrease with the increase of co-deposition agitation velocity. Base on the co-deposition theory proposed by Yuan [15], static and homogenous suspension of powder, as a matter of priorities, will be deposited on the cathode surface with metal ion in the plating solution. The effort of diamond powder scourd by solution increase with agitation velocity, which also can lead to some of diamond powder have not finished the whole co-deposited process and run into solution again.

3.5. Affection of surface tension on concentration of diamond in the coatings

The surface tension of plating solution is related with temperature, compositions, and other factors. It also can be reduced by sodium dodecyl sulfate, which is as a wetting agent added in the solution. Meanwhile, coating level off performance and internal forces [16] can be improved by surface tension decrease. In this work, the affection of surface tension on concentration of diamond in the coatings is been researched via change the surface tension of plating solution. Table 5 shows concentration of diamond in the coatings relationship with surface tension. It can be seen that there is not a systematic change with the increase of surface tension, which means there is no influence of concentration of diamond in the coating by surface tension as the maximum difference value is 0.49% in these series results.

Table 5. Concentration of diamond in the blade prepared by series surface tension

| No. | Surface tension of plating solution (mN/m) | Diamond concentration in blade (wt.%) |
|-----|-------------------------------------------|--------------------------------------|
| 1   | 24                                        | 5.22                                 |
| 2   | 28                                        | 4.83                                 |
| 3   | 32                                        | 5.14                                 |
| 4   | 36                                        | 5.06                                 |
| 5   | 40                                        | 4.86                                 |
| 6   | 44                                        | 5.32                                 |
| 7   | 48                                        | 5.18                                 |
| 8   | 52                                        | 4.89                                 |
3.6. Affection of temperature to diamond concentration in the blade

Table 6 shows that the diamond concentration in the blade takes a parabolic curve relation with plating solution temperature increase from 20°C to 80°C, the maximum diamond concentration obtained when temperature is 50°C. The higher temperature increase from 20°C to 50°C, the higher nickel deposition rate of redox reaction, more and more diamond particle deposit with nickel ion in the cathode reaction. However, cathodic hydrogen evolution reaction is more violently when temperature exceed 50°C. Which can lead to nickel crystal lattice disfigurement grow with more and more hydrogen adsorption on the cathode, and cause diamond particle and nickel composite deposit coatings more and more difficultly. As the main salt of electroplating solution, nickel sulfamate start to decompose when the temperature reach 60°C, and the decomposition rate is proportional to the temperature. That caused nickel ion take part in the actual reaction reduced and further lead the diamond deposited centration is reduced. In the other hand, the solution viscosity drops with the incensement of solution temperature caused the amount of suspended diamond particle reduced in the deposition process.

Table 6. Concentration of diamond in the blade prepared by series temperature of plating solution

| No. | temperature of plating solution(°C) | Diamond concentration in blade (w.t%) |
|-----|-----------------------------------|--------------------------------------|
| 1   | 20                                | 4.30                                 |
| 2   | 30                                | 5.25                                 |
| 3   | 40                                | 5.96                                 |
| 4   | 50                                | 6.80                                 |
| 5   | 60                                | 5.61                                 |
| 6   | 70                                | 5.32                                 |
| 7   | 80                                | 4.18                                 |

4. Conclusion

The concentration of diamond in the coating increase with the dosage of diamond powder added in the solution, and it will not further increase after the diamond powder dosage get to a certain amount. The maximum concentration of diamond in the coating was obtained with the increase of current density get a certain value, and it will reduce with the current density increase continuously. The concentration of diamond in the coating decrease with increase of co-deposited speed. Surface tension has little effect on concentration of diamond in the coating, there was no regular changes with the increase of surface tension. Solution temperature takes a parabolic curve relation with the diamond concentration in the blade and the maximum diamond concentration could be got when solution temperature reach to 50°C.

Taking all above affecting factors for concentration of diamond in the coating, the result shows that dosage of diamond powder in solution has greatest effected, co-deposited agitation less, current density and temperature more less and surface tension the least.

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