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Intermittent Electroless Nickel Deposition in a Fine Trench Flip Chip Bump Pad

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An intermittent electroless nickel deposition process was examined which involved periodically removing and reinserting the silicon wafer in the deposition bath. this process results in electroless nickel deposits with a smooth surface appearance and uniform thickness within the bump opening. The intermittent deposition process also results in enhancement in deposition speed. The benefits of this process are ascribed to replenishment of the surface concentration and the breakdown of entrapped gas bubble in the trench area of bump pad.

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Amorphous Ni-P alloys produced by electroless deposition are among the under bump metallurgy (UBM) alternatives for solder bump of flip chip technology.[1,2] The amorphous structure lacks grain boundary and other extended defects which aid diffusional process and thus is ideal for diffusion barrier application.[3] Nickel also reacts relatively slowly with Sn.[4] In manufacturing solder bumps electroless nickel alloy may be deposited on the patterned openings that are produced lithographically.[5]

A typical flip chip solder bump may have a diameter of less than 100 μm with a trench depth of 10∼30 μm. Problems have been encountered with deposition in such features largely due to the effects of nonuniform concentration gradients that develop during the deposition process.[6,7] For example, deposition in a concave geometry such as a trench, suffers from anisotropic deposition, which significantly alters shape of the deposit. Surface adsorption of a stabilizer from the deposition bath may be used to poison the deposition reaction at the edge of the deposit, resulting in a pyramidal geometry.[7] This paper describes a novel method for improving deposition speed, geometry, and surface properties of electroless nickel alloy deposited in fine patterned concave structures.

Experimental

Electroless nickel was deposited on silicon wafer simulating the UBM of flip chip solder bump. Accordingly, Al and Cu films were deposited on silicon wafer followed by photolithography to produce the bump opening.[5] Photolithography was then applied to produce desired bump opening of 100 × 100 or 60 μm in diam. Electroless nickel was deposited on the opening by using nickel sulfate as metal source and nickel hypophosphite as reducing agent at pH 4.6 and 90°C. The composition of the bath consists of 87 g/L nickel sulfate, 24 g/L sodium hypophosphite, 30 g/L sodium acetate, 2 g/L citric acid, 4.1 g/L sodium succinate, and 0.0015 g/L lead acetate.[3] The wafer was set vertically and clipped to a piece of iron in order to activate the copper surface for electroless nickel deposition. The intermittent electroless nickel deposition was conducted by periodically removing the substrate from the deposition bath for a few seconds during deposition. The periodic nature of this operation results in a deposition behavior, shown in Fig. 1, analogous to that of pulse electroplating[8] and is thus termed "intermittent electroless nickel deposition." The duration of the "on-interval" is varied while the "off-interval" is as short as 1-2 s. The deposit thickness of the electroless nickel bump was measured with a profilometer. The surface appearance of the bump was investigated with scanning electron microscopy (SEM).

Results and Discussion

For comparison purposes, the electroless nickel deposited without interruption on 60 μm diam bump pads gave rise to bump height of 1.54, 3.22, and 3.17 μm when deposited for 30, 60, and 90 min, respectively. The corresponding standard deviation of the bumps are 1.11, 2.24, and 2.00 μm, *i.e.*, 1.54 ± 1.11, 3.22 ± 2.24, 3.17 ± 2.00. It is quite evident that the electroless nickel bump heights are widely scattered. The above results suggest that the bump growth almost stops after 60 min deposition. Nevertheless, the continuous deposition speed on 100 × 100 μm bump pad can be as great as 0.160 μm/min, *i.e.*, a bump height of 9.5 μm was achieved in 1 h. Furthermore, as shown in Fig. 2, the electroless nickel bumps obtained on 60 μm bump pad were unsatisfactory even after 1 h of reaction, although this poor result was not observed for 100 × 100 μm bump pad. The imperfections include incomplete deposition and pudding geometry. The rim of certain bumps show thin deposits. The bump then exhibits pudding shape structure. The bump surface also exhibits porosity. The above-mentioned results and observations indicate that electroless nickel deposition in a trench of high aspect ratio like 10 μm (trench wall)/60 μm (pad size), in comparing with normal pad size of 100 μm or above, would result in slow deposition speed, pudding bump, and defected bump structure.

Figure 3 is an SEM image of the bump deposited by intermittent deposition at an on-interval of 5 min for a total deposition period of 90 min. In comparison with Fig. 2, it is evident that the bumps obtained with intermittent deposition exhibit smooth surface appearance as well as complete coverage of the pad.

Figure 4 presents the growth of the electroless nickel bump obtained by various on-intervals, including continuous deposition. The lowest curve shows that continuous deposition without intermission can only obtain a maximum bump height of around 3 μm. On the other hand, all other curves show that much greater bump height (as presented by deposit thickness) was obtained by intermittent deposition especially after 30 min of deposition time. For instance, a bump height of only 1.54 μm is obtained for continuous deposition at 30 min, while an on-interval of 5 min gives rise to a bump height of 5 μm for the same total deposition time.

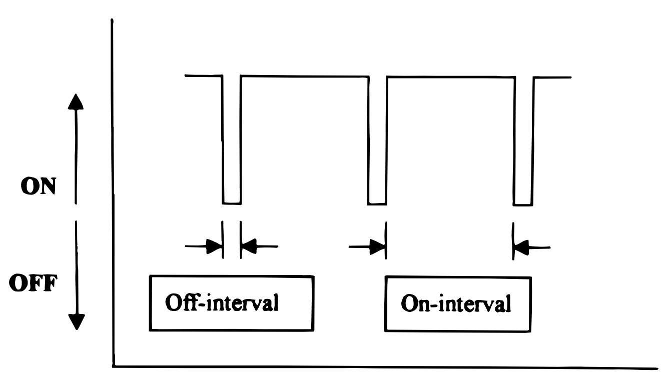

Figure 1. Intermittent electroless nickel deposition process.

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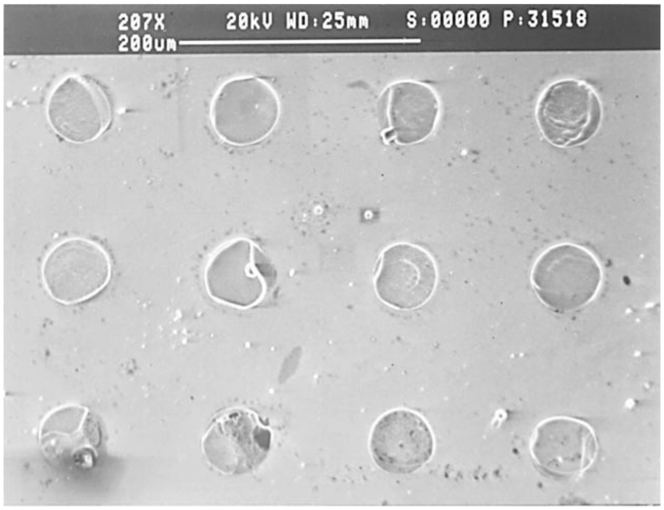

Figure 2. Defected appearance of electroless nickel bump deposited on 60 μm bump pad without intermittent.

In addition, all intermittent deposition curves show a sigmoid behavior. It is evident that an on-interval of 5 min gives rise to the fastest deposition speed. The inflection point of the sigmoid curve is a function of the deposition interval. The inflection time is in the order of continuous deposition > 10 min (interval) > 1 min > 3 min > 5 min. Note that the deposition behavior of the continuous deposition follows a parabolic curve, indicating a typical diffusion control mechanism. However, the intermittent deposition, especially when the on-interval is 3 or 5 min, would give rise to a more linear correlation rather than a parabolic curve after the inflection point. The linear correlation corresponds to a much faster deposition speed than that achievable with continuous deposition. For instance a bump height of around 12.5 μm was obtained at 90 min for on-interval of 5 min, while only 3.17 μm was deposited by continuous deposition.

The deposition of electroless nickel bump was performed on the bump opening. Electroless nickel deposition produces hydrogen gas in addition to nickel deposit. Hydrogen gas is easily entrapped, attaching to the hydrophobic photoresist, as indicated in Fig. 5. The hydrogen gas bubble tends to stay and grow, especially when the opening is as fine as 60 μm. A large gas bubble that completely covers the 60 μm opening, Fig. 5a, will definitely stop the deposition reaction while a small gas bubble attached to the opening wall, Fig. 5b, affects the growth and thus the geometry of the deposit. Subsequently, the bump deposit become puddinglike structure with a thin deposit on the perimeter of the feature. Both cases shown in Fig. 5a and b would result in the imperfect deposit as seen in Fig. 2.

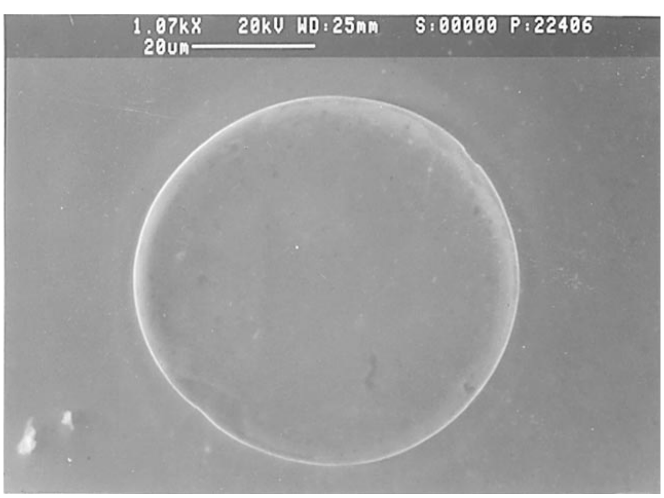

Figure 3. Electroless nickel bumps deposited on 60 μm bump pad with on-interval of 5 min.

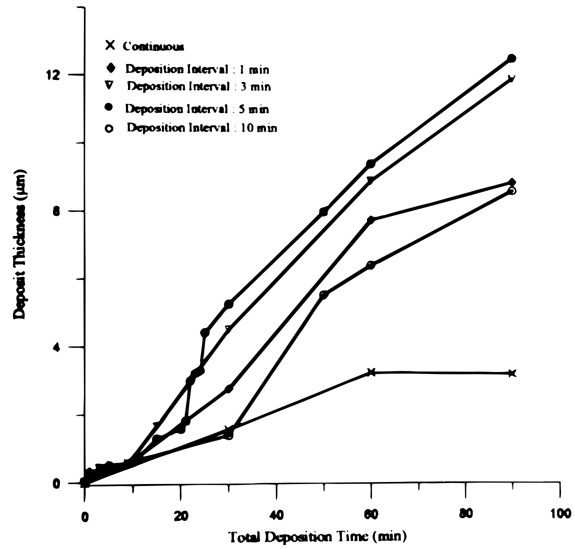

Figure 4. Variation of deposition speed with respect to deposition intervals.

The hydrogen gas bubble was destroyed when exposed to air during off-interval. In such a case, the opening always provides clear path for deposition reaction. Therefore, the intermittent deposition process results in elimination of hydrogen gas bubble and thus uniform smooth bump is obtained as visualized in Fig. 3. It is expected that hydrogen bubble phenomenon becomes more prominent for high aspect ratio opening. Nevertheless, the intermittent deposition operation eliminates this effect and thus the smooth nickel bump deposit can be obtained regardless of aspect ratio.

Conclusion

Intermittent electroless nickel deposition provides removal of trapped gas bubbles and complete replenishment of the metal ion concentration within the small bump opening, resulting in a higher

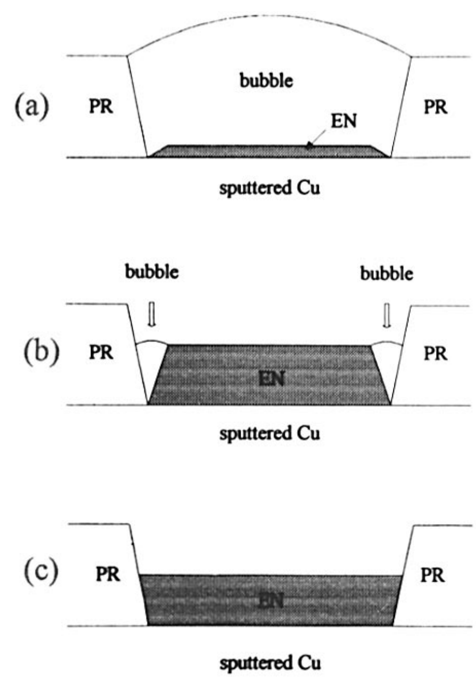

Figure 5. The entrapment of hydrogen gas bubble by hydrophobic photoresist opening wall, (a) complete coverage by gas bubble, (b) partial coverage, (c) no entrapment due to intermittent process.

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deposition rate. Intermittent deposition also gives rise to smooth bump deposit with complete coverage of the bump opening. An on-interval of 5 min gives the highest deposition speed.

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References

1. G. O. Mallory and J. B. Hajdu, *Electroless Plating: Fundamentals and Applications*, Chap. 9, AESF, Orlando, FL (1990).
2. M. Inaba, K. Yamakawa, and N. Iwase, *IEEE Trans. Compon. Hybrids. Manuf. Technol.*, **13**, 119 (1990).
3. K. L. Lin and C. J. Chen, *J. Mater. Sci.: Mater. Electron.*, **7**, 397 (1997).
4. I. V. Kadija, J. A. Abys, J. J. Maisano, E. J. Kudrak, and S. Shimada, *Plat. Surf. Finish.*, **82**, 56 (1995).
5. K. L. Lin and Y. C. Liu, in *Electronic Components and Technology, Proceedings of the 49th Conference*, IEEE (1999).
6. A. M. T. van der Putten and J. W. G. de Bakker, *J. Electrochem. Soc.*, **140**, 2221 (1993).
7. A. M. T. van der Putrten and J. W. G. de Bakker, *J. Electrochem. Soc.*, **140**, 2229 (1993).
8. J. Cl. Puippe, in *Theory and Practice of Intermittent Plating*, Chap. 1, J. Cl. Puippe and R. Leaman, Editors, AESF, Orlando, FL (1986).
9. J. Cl. Puippe, in *Theory and Practice of Intermittent Plating*, Chap. 3, J. Cl. Puippe and R. Leaman, Editor, AESF, Orlando, FL (1986).