

Optimization of Probing Needle Design for Wafer-level Probing Test

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Abstract

The probing test is a typical quality control method for individual chips on a wafer. With a proper design, the service life of probing needles in the probe card can be sufficiently elongated and hence reduces the testing cost. In this work, we followed the Taguchi method with the $L_{18}(2^1 \times 3^7)$ orthogonal array to obtain an optimal geometrical design of the probing needle based on the minimization of the scrub length the probe tip travels during a wafer-level probing test procedure. Geometrical factors of the needle included tip shape, needle diameter, beam length, taper length, knee diameter, shooting angle, tip length, and tip diameter. Importance of these factors on the scrub length was also ranked.

Keywords: Wafer-level probing test, Finite element analysis, Scrub length, Optimization, Taguchi method

1. Introduction

The quality control of individual chips on a wafer is typically performed using a probe card as shown in Fig. 1 [1]. In order to achieve a good contact between probing needles in the probe card and pads on the tested chip, a force is applied to the probe card and a scratching motion is then followed to break the oxide films on the surfaces of the pads [2]. However, an excessive contact force exerted during the probing test may damage

the pad or may result in over-sized scrub marks on the pad surface that adversely influences wirebonding or flip-chip process quality in the subsequent packaging assembly process [3-7].

Previous studies have generally focused on the investigation of probing test parameters to improve needle card performance. Varnau [3] evaluated the reliability of a flip-chip package with aluminum pads in a probe-before-bump process with different overdrives and contact time. Tan *et al.* [4] studied the reliability of a flip-chip package using two alternative probe-before-bump processes with different overdrives, temperatures, and probe cards. Hotchkiss *et al.* [5] investigated the relationship between scrub mark damage (ranging from 10-45% of the total pad area) and reliability of a wirebonded flip-chip package assembly. Chen and Chiang [8] developed an analytical methodology for the probe-before-bump procedure to predict the probing mark depth and to identify suitable probing parameters that would minimize the size of scrub marks on the bump pad. Liu and Shih [9,10] combined experimental and finite element approaches to design a suitable multilayer probe card layout for tungsten probing needles and to establish a relationship between overdrive displacement, contact force, and scrub length.

Up to date, however, very little research has been focused on the relationship between needle geometry and scrub length. The scrub mark would appear on the aluminum pad surface after a wafer-level probing test. An excessive scrub length not only damages the bond pad but also unstabilizes the electrical contact of needles after repeated

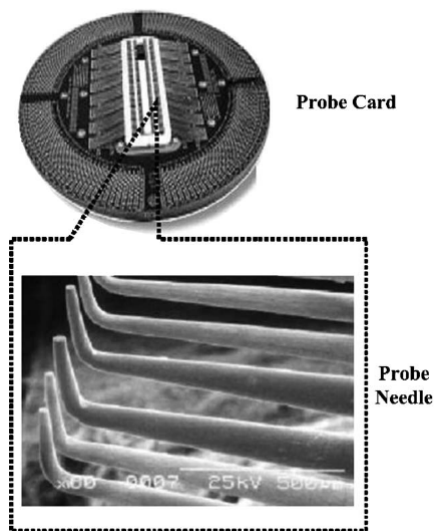


Fig. 1: Diagram of probe card and needles [1]

probing due to gradual accumulation of aluminum particles on the probe tip. It is therefore necessary to remove the probe card periodically in order to clean up the probe tips with a sand wafer. This cleaning process may damage the needles, thereby shortening the life of the probe card. Nevertheless, the selection of feasible needle geometry is still based on the time-consuming trial-and-error process with the probe station.

In this work, the Taguchi method [11-13] with the $L_{18}(2^1 \times 3^7)$ orthogonal array was employed to minimize the scrub length of needles during the wafer-level probing test of a memory device. Effects of different geometrical factors of the probing needle, including tip shape, needle diameter, beam length, taper length, knee diameter, shooting angle, tip length, and tip diameter on the scrub length were evaluated. Importance of these factors on the scrub length was also ranked.

2. Finite Element Modeling

Needles on the probe card are made of tungsten with the piecewise stress-strain curve obtained by Liu and Shih [10], depicted in Fig. 2. From the figure, Young's modulus, Poisson's ratio, and yield stress of a tungsten needle are 290.85 GPa, 0.28, 1.77 GPa, respectively.

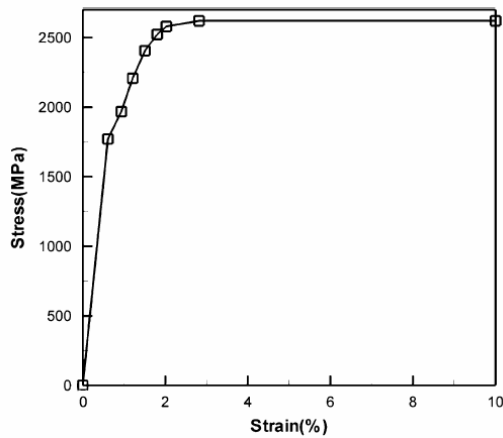


Fig. 2: Piecewise stress-strain curve for tungsten needle [10]

Following the geometry shown in Fig. 3, a three-dimensional finite element model for a single probing needle in contact with a $70 \mu\text{m} \times 70 \mu\text{m} \times 6 \mu\text{m}$ rigid pad was built using linear hexahedral solid elements, as shown in Fig. 4.

Since the pad was assumed to be rigid, the scrub length was defined to be the horizontal movement of the needle tip. We note that

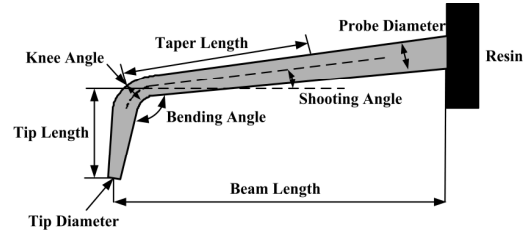


Fig. 3: Geometric parameters of probing needle

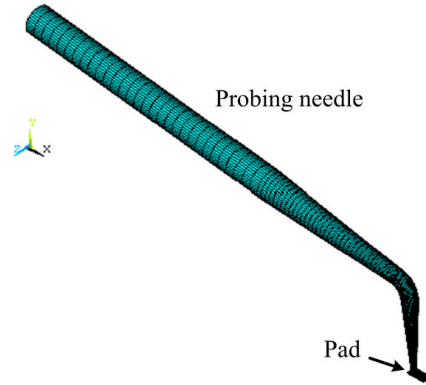


Fig. 4: Finite element model of probing needle

elastoplastic and wear behaviors of the pad in the thin film scale are difficult to obtain and such uncertainties can also possibly lead to inaccurate numerical results. Following this consideration, the rigid pad can be regarded as a reasonable simplification for qualitative performance evaluations and the most important of all, it alleviates the complexity in the calculations of contact between needle and pad. All degrees of freedom were constrained at the resin boundary of the needle. The probing test was simulated through quasi-static vertical pad overdrive distance of $30 \mu\text{m}$. Surface-to-surface contact was followed in the contact calculation between needle and pad.

3. Optimization

The optimal design is targeted at a quality factor that has major influences on the quality characteristic of the objective. The scrub length, denoted as δ , was therefore chosen in this work as the quality factor. The Taguchi method [11-13] applies fractional factorial experimental designs, called orthogonal arrays, to reduce the number of experiments and meanwhile obtaining statistically meaningful results. The selection of a suitable orthogonal array depends on the number of control factors and their levels. The goal of the Taguchi

method is to find out the optimal and robust product or process characteristic that has a minimized sensitivity to noise.

In this work, the eight selected control factors concerning the geometry of the probing needle and their levels are listed in Table 1. These control factors include (A) round or flat tips, (B) needle diameter, (C) beam length, (D) taper length, (E) knee diameter, (F) shooting angle, (G) tip length, and (H) tip diameter. All control factors have three levels expects for the tip shape, which has two levels. Underlined levels in the table represent original geometrical design parameters of the needle. The levels were selected within a reasonable design range of an actual product.

Table 1: Control factors and levels

Factor	Description	Level 1	Level 2	Level 3
A	Tip shape	<u>Round</u>	Flat	---
B	Probe diameter (μm)	150	<u>160</u>	170
C	Beam length (μm)	<u>2500</u>	3300	4100
D	Taper length (μm)	1000	<u>1200</u>	1800
E	Knee diameter (μm)	80	<u>100</u>	120
F	Shooting angle ($^\circ$)	<u>7</u>	9	11
G	Tip length (μm)	450	<u>950</u>	1450
H	Tip diameter (μm)	25	<u>30</u>	35

According to the numbers of control factors and their levels listed in Table 1, the $L_{18}(2^1 \times 3^7)$ orthogonal array was employed in the main experiment to minimize δ . The smaller-the-better signal-to-noise (S/N) ratio, defined as

$$S/N = -10 \log \frac{\sum_{i=1}^r y_i^2}{r} \quad (1)$$

was therefore chosen to meet the purpose. In the equation, y_i is the i -th measurement data of δ and r is the number of measurements. Since a numerical analysis does not generate data variations or experimental errors, we have $r = 1$, and therefore $S/N = -10 \log \delta^2$.

The main experiment is aimed at obtaining the optimal design. For the main experiment, an $L_{18}(2^1 \times 3^7)$ orthogonal array presented in Table 2 was implemented. Table 3 and Fig. 5 show responses of control factors calculated from the results

presented in Table 2. In the table, the response for level i of factor j is defined as the average of δ of factor j at level i . The effect denotes the difference between maximum and minimum S/N responses of a control factor at different levels.

Table 2: Main experiment

Exp.	Factors and levels								$\delta (\mu\text{m})$	S/N
	A	B	C	D	E	F	G	H		
1	1	1	1	1	1	1	1	1	12.0	-21.58
2	1	1	2	2	2	2	2	2	23.7	-27.49
3	1	1	3	3	3	3	3	3	37.0	-31.36
4	1	2	1	1	2	2	3	3	42.4	-32.55
5	1	2	2	2	3	3	1	1	10.7	-20.59
6	1	2	3	3	1	1	2	2	15.6	-23.86
7	1	3	1	2	1	3	2	3	33.2	-30.42
8	1	3	2	3	2	1	3	1	30.5	-29.69
9	1	3	3	1	3	2	1	2	8.5	-18.59
10	2	1	1	3	3	2	2	1	30.6	-29.71
11	2	1	2	1	1	3	3	2	66.9	-36.51
12	2	1	3	2	2	1	1	3	8.1	-18.17
13	2	2	1	2	3	1	3	2	59.2	-35.45
14	2	2	2	3	1	2	1	3	13.3	-22.48
15	2	2	3	1	2	3	2	1	21.2	-26.53
16	2	3	1	3	2	3	1	2	16.8	-24.51
17	2	3	2	2	3	1	2	3	21.5	-26.65
18	2	3	3	1	1	2	3	1	60.3	-35.61
S/N average										-27.32

According to the results, the optimal design that leads to the minimum δ has the combination of (A) round tip, (B) probe diameter at 160 μm , (C) beam length at 4100 μm , (D) taper length at 1800 μm , (E) knee diameter at 100 μm , (F) shooting angle at 7° , (G) tip length at 450 μm , and (H) tip diameter at 35 μm . Moreover, for the factors and levels proposed in this study, the tip length (G) has the greatest effect on δ while beam length (C) and shooting angle (F) are the runners up but with much smaller effects. The probe diameter (B), tip diameter (H), and taper length (D) all show insignificant effects on δ . We note that the probing needle movement is a combination of beam deformation and tip rotation. The optimization results indicate that δ is chiefly governed by the tip rotation, *i.e.*, a longer tip length leads to greater δ under a constant overdrive distance. On the other hand, tip rotation, and hence δ , becomes smaller when the beam is more compliant, or with a longer beam length.

We need to emphasize, however, that the optimization procedure applied in this study characterizes the optimal set and ranking of control

Table 3: Responses and ranks of control factors

	A	B	C	D	E	F	G	H
Level 1	-26.24	-27.47	-29.04	-27.07	-28.41	-25.90	-20.99	-27.28
Level 2	-28.40	-26.91	-27.23	-27.95	-26.49	-27.74	-27.45	-27.73
Level 3	---	-27.58	-25.69	-26.94	-27.06	-28.32	-33.53	-26.94
Effect	2.16	0.67	3.35	1.02	1.92	2.42	12.54	0.80
Rank	4	8	2	6	5	3	1	7

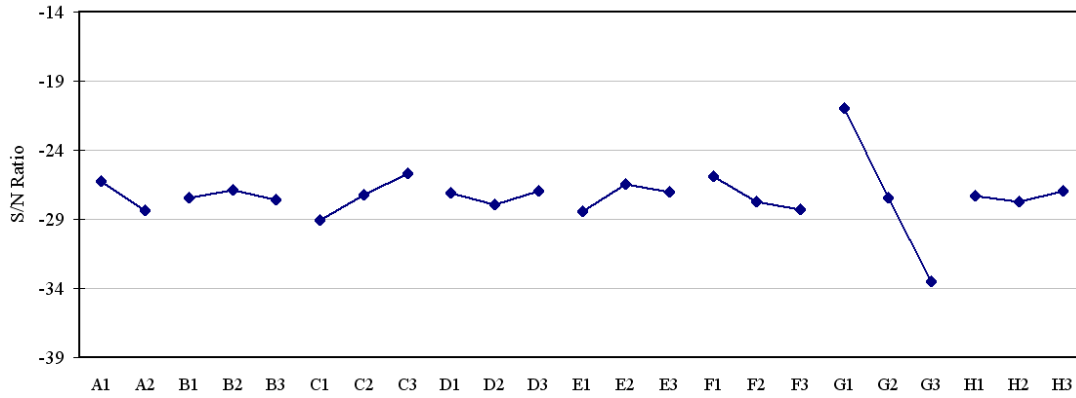


Fig. 5: Factor response diagram

factors only for the levels proposed in Table 1. When the levels are varied, the optimal set of control factors and ranking do not necessarily maintain.

4. Conclusion

The Taguchi method with the $L_{18} (2^1 \times 3^7)$ orthogonal array was employed in this work to obtain an optimal geometrical design of the probing needle based on the minimization of the scrub length the needle travels in a wafer-level probing test procedure. We considered eight geometrical factors of the needle, including tip shape, needle diameter, beam length, taper length, knee diameter, shooting angle, tip length, and tip diameter.

The optimal design that leads to the minimum scrub length has the combination of round tip, probe diameter at 160 μm , beam length at 4100 μm , taper length at 1800 μm , knee diameter at 180 μm , shooting angle at 7°, tip length at 450 μm , and tip diameter at 35 μm . For the factors and levels proposed in this study, the tip length has the greatest effect on the scrub length while beam length and shooting angle are the runners up but with much smaller effects. The probe diameter, tip diameter, and taper length all show insignificant effects on the scrub length.

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