
# Coplanarity analysis and control of spring probe heads for wafer testing

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The applications of wafer-level chip scale package (WLCSP) and micro chip scale package (MicroCSP) technologies have grown significantly in recent years, particularly as consumer electronics have driven down the size of devices. The tight pitch requirements of device leads become one of challenges in device manufacturing. As traditional IC packages have pitches >0.4mm, many WLCSP devices boast pitches of ≤0.4mm. The trend away from singulated package test toward wafer-level test requires new equipment investment, including probe heads and related contactors, to match the mechanical and electrical performance requirements of the device in wafer testing.

Many WLCSP tests employ conventional front-end contact techniques, either cantilever needles or "vertical probe cards," based on buckling beam technology. Both techniques have limitations in performance. Cantilever cards are incapable of RF testing that is required in final test of WLCSP devices. Difficulties in maintenance and complexity in repair result in high tooling costs for these types of probe cards. Another major limitation with a cantilever card is a result of its structure, which is suitable only for low pin count devices testing 1-3 devices in parallel. Vertical probe cards with short signal paths are more reliable in making contact and offer better RF performance. The typical weakness of these techniques is their lack of compliance. The WLCSP bump structure usually requires significant compliance for reliable contact when employing high parallelism testing.

As an alternative contactor technology, spring probe heads have grown in popularity in wafer testing because of their advantages over cantilever needle and buckling beam technologies. Spring probe heads provide increased compliance as well as the benefit of field serviceability through individual contactor design structure. Tip coplanarity is a frequently raised concern when utilizing a spring probe head in wafer testing. This paper offers an analysis of tip coplanarity analysis and proposes approaches to ensure optimal design and performance of a spring probe head.

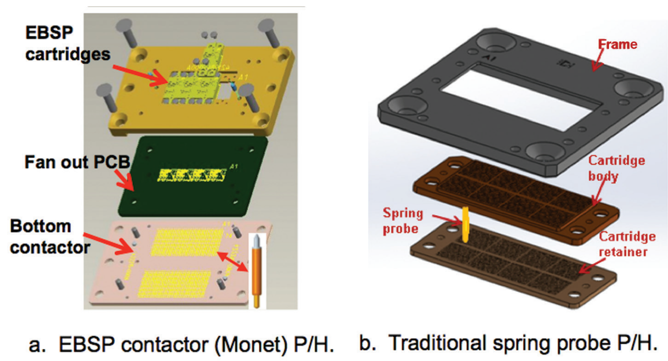



**Figure 1:** Typical structures of spring probe heads.

## Basic structure of a spring probe head

Typical WLCSP probe head and spring probe contactors are presented in **Figure 1**. Embedded Barrel Spring Probe (EBSP) contactor probe head (P/H) is a new contactor technology developed by Smiths Connectors. With the specific spring probe structures, EBSP P/Hs are typically used for small pitch (≤0.3mm) applications.

Traditional spring probe are used in contactors for >0.3mm pitch applications. The traditional spring probe may be used in <0.3mm pitch P/Hs, but it is discouraged as its RF performance deteriorates in such applications. This deterioration is due to the additional length (>5mm) required to provide enough compliance in a small diameter (<0.25mm) probe.

As shown in **Figure 1**, the spring probe head structures are completely different from those of traditional cantilever needles and vertical probe cards. The compliance of a spring probe contact tip on device balls/pads is driven from compression of the spring, while other techniques depend on compliance of the signal beam.

Spring probes consist of four components while other contactors have one contacting component. Generally, wafer or WLCSP testing set ups require very tight control on contactor tip coplanarity. The unique structure of spring probes with multiple components requires additional considerations in probe head structure, manufacturing processes, and material selection to control the tip coplanarity and ensure adherence to technical specifications of the wafer tester probe header.

## Determining spring probe head tip coplanarity

It is well known that the function of the interconnect is to provide reliable connection with enough probe tip compliance (or travel) to absorb the flatness tolerances of wafer balls/pads and other related components in probe head structures. The state of spring probes inside the probe head body is described in **Figure 2a**. The "free" state refers to the spring probe head placed on the board at free state. When the spring probe head is mounted on a test board or space transformer (fan-out PCB), the bottom plunger is compressed to achieve the "preloaded" state. The spring force is applied on the board. The wafer ball/pad

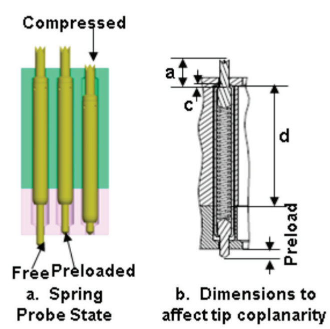



**Figure 2:** Spring probe state and dimensions that affect coplanarity.

contacts and compresses the spring probe tip or crown down to testing condition in the "compressed" state.

As shown in **Figure 2b**, the tip coplanarity of the spring probe head is primarily determined by a couple of factors: 1) The accumulated tolerances of the dimensions, a, c, and d, and 2) The bowing (or warpage) generated by preloading of the spring probes. The dimension tolerances are controlled by manufacturing processes of the top plunger and probe body. At the current machining capability, the plunger tolerance is ~ +/-20µm (dimension "a" in **Figure 2b**) and counter bore depth tolerance of +/- 25µm (dimension "d" in **Figure 2b**). The probe head body bowing is dependent on the preload force of spring probe, pitch, quantity of spring probes, and body material. The tip coplanarity of a probe head can be calculated with this formula:

$$H = \Delta a + \Delta c + \Delta d + \delta$$

Where:

H = tip coplanarity of whole probe array;

$\Delta a$ = top plunger neck tolerance, ~ +/-0.02mm;

$\Delta c$ = barrel crimping thickness tolerance, negligible;

$\Delta d$ = counter bore depth tolerance, ~ +/-0.025mm, and

$\delta$ = cartridge bowing due to preload.

As an example, **Figure 3** shows coplanarity of a 10 WLCSP site spring probe head (0.4mm pitch, ~ 200 pins/site). For the worst case scenario, the maximum coplanarity is ~ 200µm. Dimension tolerance contributes ~50% and probe head bowing about 50%. This probe head uses traditional spring probes with top side compliance ~ 350µm. Although spring probe compliance can withstand the tip coplanarity variation, wafer testing set ups cannot accommodate such significant variation. Generally, it is not easy to improve tolerances of structural dimensions because of manufacturing process limitations. The improvement or reduction in probe head bowing becomes a major factor in spring probe head development.

## Probe head body bowing and body material selection

As mentioned previously, the coplanarity of a spring pin probe head is primarily affected by accumulated tolerances of spring probe components and probe head bowing. The components' tolerances are determined by manufacturing processes. Probe head bowing is generated by the preload of spring pins at the test board side. Being different from cantilever and vertical probe head contactors, the compression spring of a spring probe is usually pre-compressed, or preloaded, when a probe head is mounted on the mother test board. This preload is about 20 to 30% of the total compliance with a force of 8 ~ 12gf. Under this spring force, the probe head is deformed into a bridge shape, with the middle area raised. Bowing of the probe head can contribute up to 50% of the total tip coplanarity variation of a probe head (**Figure 4**). In addition to spring preload force, the material stiffness, or flexural modulus of elasticity, significantly impacts probe head bowing as well. **Table 1** is a list of flexural moduli for different thermoplastic materials.

To compare the bowing of probe heads with different materials, structures, and pin counts, a series of finite element analyses (FEA) were performed with one 8-site probe head (PH). This is a conventional WLCSP PH (previously referred to as a socket). The structure and other parameters of this PH are listed in **Table 2**.

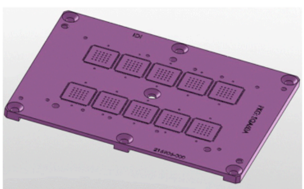
| | Material | Flexural Modulus | |
|---|---|---|---|
| | | English, kPSI | SI, Gpa |
| A | Ceramic Filled PEEK | 650 | 4,482 |
| B | MDS 100 | 1420 | 9.791 |
| C | New Thermoplastic Material | 2465 | 17 |
| D | New Ceramic material | 18853 | 130 |

**Table 1:** Spring probe head body materials.

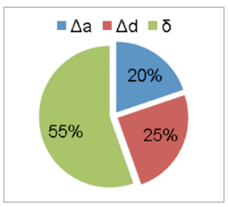
| # of sites | 8 |
|---|---|
| Pitch, mm | 0.4 |
| Pin count, per site | 137 |
| Pin count, total | 1096 |
| Preload/pin, gf | 12 |
| Total preload, kgf | 13.15 |

**Table 2:** Spring probe head example for FEA.

The FEA results on a solid model with four different materials are shown in **Figure 5**. According to basic principles of structural mechanics, the flexural modulus elasticity of the material is the primary factor that determines material bending. A higher flexural modulus material has less deformation under external force. For this particular probe head model, FEA results show the center area has the greatest bowing or deformation. Ceramic PEEK is commonly used in package test sockets and is also applied in WLCSP probe heads. With the use of Ceramic PEEK, the maximum bowing at the PH center is up to 0.26mm for this specific 8-site PH. Usually, the preload travel length of a spring probe is about 0.12mm. Under 0.26mm maximum bowing, some spring probes in the center area lose their preload, which can cause increased contact resistance (CRES) due



a. Probe head




| Item | Coplanarity, um |
|---|---|
| Δa | 40 |
| Δd | 50 |
| δ | 112 |
| H | 202 |

b. Tip coplanarity

**Figure 3:** Example of spring probe head tip coplanarity distribution.

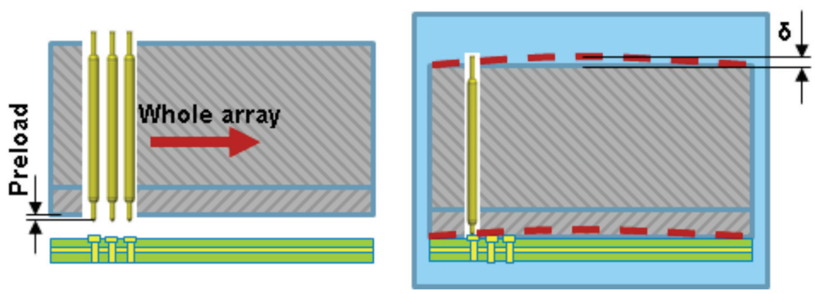



**Figure 4:** Spring probe preload and probe head bowing.

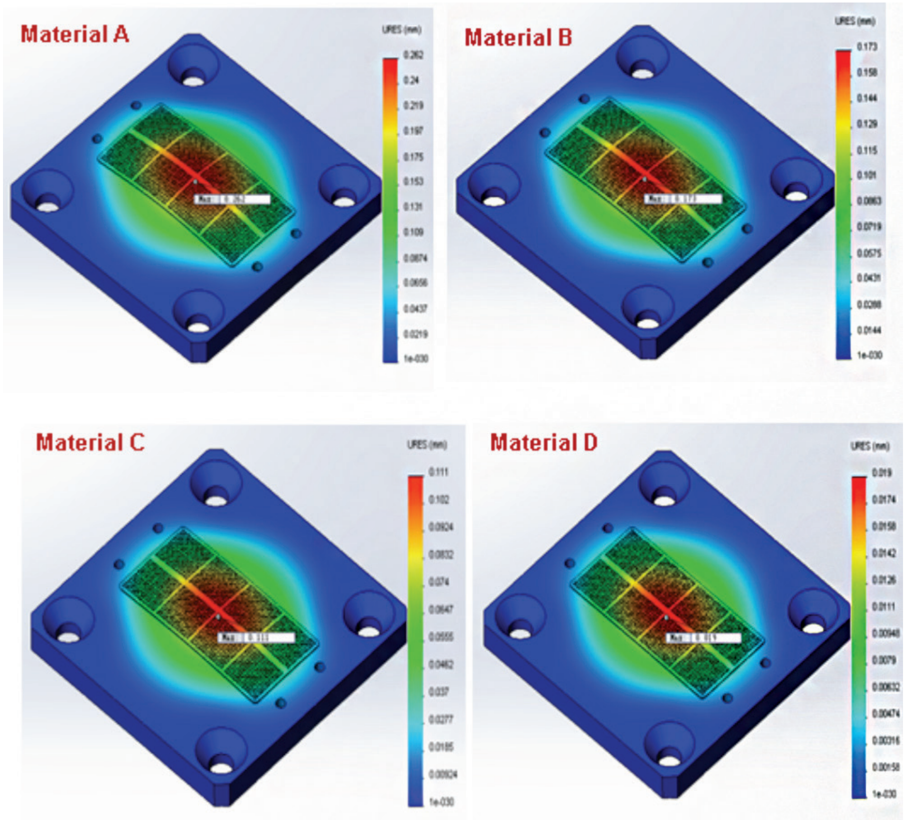



**Figure 5:** Spring probe head bowing in FEA.

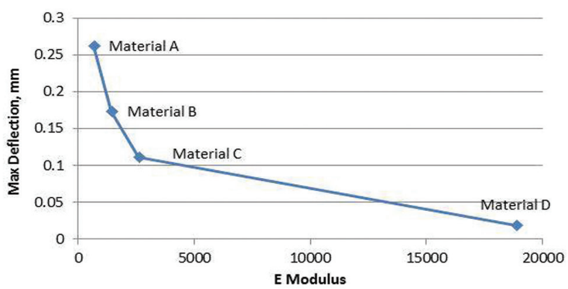



**Figure 6:** Probe head bowing vs. materials.

| Material | | PH Bowling, mm | | Co-Planarity |
|---|---|---|---|---|
| | | Max | Min | mm |
| A | Ceramic Filled PEEK | 0.261 | 0.054 | .207 |
| B | MDS 100 | 0.172 | 0.033 | .139 |
| C | New Thermoplastic Material | 0.110 | 0.020 | .090 |
| D | New Ceramic material | 0.019 | 0.016 | .003 |

**Table 3:** Coplanarity vs. probe head bowing.

to unstable contact with the test board. Therefore, this design with Ceramic PEEK may not have proper performance and should be redesigned.

Using materials with a high flexural modulus of elasticity, probe bowing can be greatly reduced as presented in **Figure 6**. With doubled flexural modulus in material B, the maximum defection is reduced to 0.173mm, which is still greater than the preload travel of a spring probe. When using material C, the flexural modulus is four times greater than Ceramic PEEK, and the maximum deflection is 0.11mm, which is less than the preload travel of typical spring probes. For material D, which has an extremely high flexural modulus, the maximum deflection is only 0.019mm and could be considered with no bowing for the PH.

Usually, tip coplanarity is the primary technical specification of a probe head in WLCSP and wafer testing. The impact of PH body bowing on tip-to-tip coplanarity of the pin array can be calculated with the formula:

$$\text{Tip coplanarity} = \text{Max Deflection} - \text{Min Deflection}$$

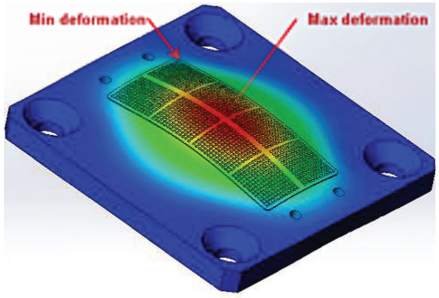



**Figure 7:** Maximum bowing in the center of the probe head center.

As shown in **Figure 7**, the maximum deflection is at the center and the minimum deflection is located at the edge of the spring probe arrays. **Table 3** lists the coplanarity values affected by PH bowing for four different PH materials. The material with higher flexural modulus has the best coplanarity if all other component tolerances are the same.

## Probe head structure on spring probe tip coplanarity

The availability of high strength thermoplastic composite materials is very limited in this industry, which may be the result of a narrow pool of manufacturers and challenges in developing high flux modulus thermo-plastic materials. Optimization of the probe head structure is another approach to reduce spring probe PH bowing and improve tip coplanarity. Among various PH structures, spring probe cartridges with frames are one commonly deployed option.

**Figure 8** presents an 8-site probe head designed with one spring probe cartridge and a stainless steel (SS) frame. The FEA simulation results, shown in **Figure 9**, indicate the cartridge with an SS frame structure can reduce maximum deflection from 0.262mm to 0.124mm—

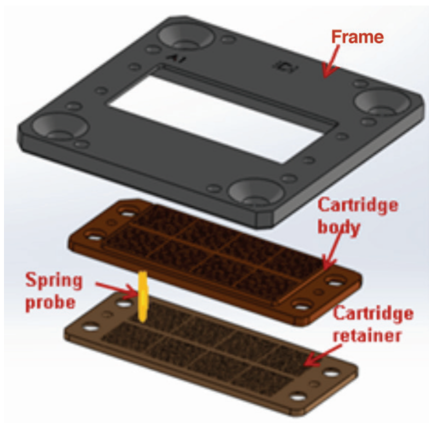



**Figure 8:** Probe head with frame.

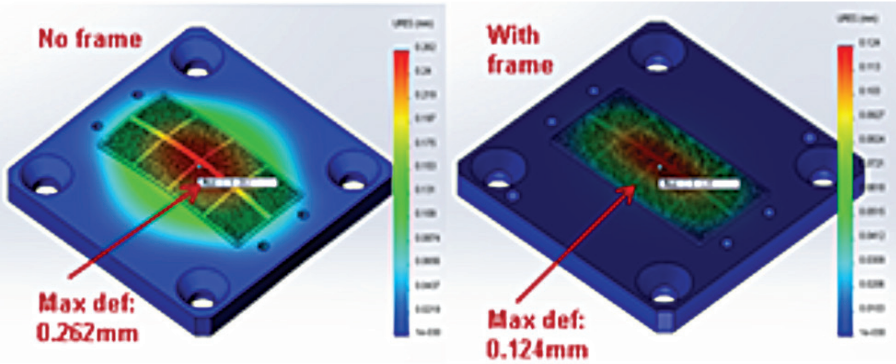
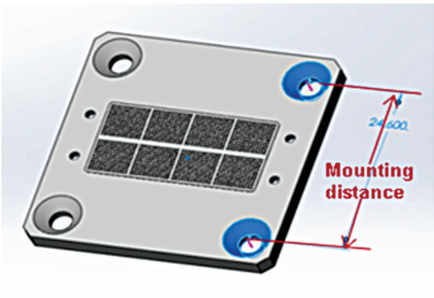



**Figure 9:** Max deflection comparison: with and without a frame.




| Mount Distance, mm | Max Deflection, mm |
|---|---|
| 44.6 | 0.329 |
| 39.6 | 0.317 |
| 34.6 | 0.301 |
| 24.6 | 0.262 |

**Figure 10:** Body bowing vs. probe head mounting location.

an improvement of over 50%. The PH bowing of this cartridge with frame design is less than the typical spring probe preload travel, and therefore, it maintains reliable contact of the probe to the test board pads for low CRES.

The mounting screws on a probe head can also affect PH bowing. Although the mounting locations of screws are primarily determined by the test board design, it is always beneficial to have the location close to the spring probe array. **Figure 10** shows an example of how mounting screw distance impacts probe head bowing. As this distance varies from 44.6mm to 24.6mm, the maximum deflection is reduced from 0.329mm to 0.262mm.

## Summary

Spring contact probes have been established as one of the major contact technologies for WLCSP device testing. In pursuit of a stable contact, the preload travel of spring contact probes against the test board can result in probe head bowing and affect contactor tip coplanarity. To minimize the impact, higher stiffness materials should be selected to reduce bowing and improve coplanarity. Enhancements in probe head design structure, such as cartridge and frame methods, can also reduce bowing significantly and ensure better coplanarity of probe head tips.

All simulation results and measurements presented in this paper are based on worst case design scenarios. Considering all design structures and manufacturing improvements, the tip coplanarity of spring probe heads can typically be controlled in the range of <80µm in WLCSP and wafer testing technical specifications.

## Biographies

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