

Measuring board and component flatness

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The introduction of high-pitch devices has made coplanarity between components and substrates more important. The conventional standard vertical displacement from bowing and twisting over the area of a PCB has been one percent of the board diagonal, but today's design engineers may specify displacement as low as 0.30 percent. What may matter even more, however, is the flatness of an individual bond-pad region on the board. The solder balls connecting an area array device to its bond pad are not easy to handle, and the flatness of a single PCB interconnect region is not likely to be closely related to the average flatness of the entire board.

Meanwhile, concerns are growing over the flatness of new component types. Problems have already been identified, for example, with the flatness of CSPs, despite their small area. The "doming" of flip chips, in which the center of the die bows upward, is a common phenomenon.

Manufacturers are now beginning to encounter two additional factors that can degrade coplanarity. One is the higher temperatures required by lead-free processing. The highest temperatures in reflow ovens using conventional Sn/Pb solder are about 225°C, but lead-free solders usually reach temperatures around 260°C. The higher temperature tends to enhance bowing or twisting of both the board and the component.

At the same time, board materials are changing in response to the higher reflow temperatures, which are just beyond the qualification range of FR4 materials. The board materials, which can withstand 260°C, most notably teflon and polyimide, appear to have roughly the same bow and twist characteristics as FR4, but development efforts are likely to

reveal significant differences in behavior. To this must be added the probability that new molding compounds designed for the higher temperatures, and having their own responses to thermal excursions, will be used on many components.

or less than the calculated average. In addition, the profile of warpage across the individual site may have critical bearing on interconnects.

The standard manual method for measuring twist in a board is to bring three corners

warped that they are likely to cause line jams, and boards where pins will not line up with holes. But these are deviations on a scale far greater than the precision needed to ensure, for example, that a BGA and its interconnect region on the PCB both have sufficient flatness to permit interconnect bonding consistent with long-term reliability.

Using shadow moiré

It can be seen easily why pinning three corners of a board cannot achieve precision. The three corners to be pinned must be chosen with some degree of subjectivity; selecting a different set of three corners might produce different results for the same board. More important, bow and twist are three-dimensional phenomena, and the process of forcing three corners into the same horizontal plane introduces unknown stresses on the board.

The result of these very complex interactions on the unpinned corner is very difficult to predict. Measurement of the height of the unpinned corner may tell whether a board will jam or not, but it gives no information about whether a high-density device can be successfully attached to a local area of the board.

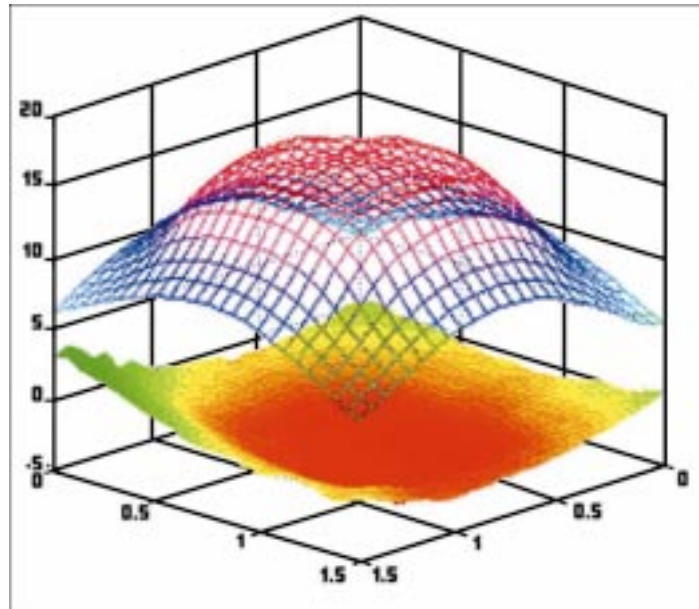


Figure 1: Flatness measurement at 225°C reflow temperature shows the height profile (top) of a BGA and the PCB bond pad region (bottom).

The production environment is experiencing tighter, less manageable pitches and new materials. So measuring the coplanarity of boards and components becomes a prudent procedure. The types of damage that can result from out-of-control planarity errors fall broadly into two categories: those defects which cause failures immediately recognizable by electrical symptoms, and those defects which introduce stresses which will become failures as the result of normal thermal cycling during use.

Conventional thinking about the flatness of the PCB—for example, that vertical deviations can be no more than one percent of the board diagonal—leads easily to a rather dangerous misconception when fine pitch and other emerging trends are involved. The misconception is that the bow or twist of a single area array device site is proportional to the area of the whole board. In reality, the displacement within a single device site may be more

of the board flat against a table surface and measure the gap between the fourth corner and the surface. This method works fairly well on a gross scale. This method identifies boards so

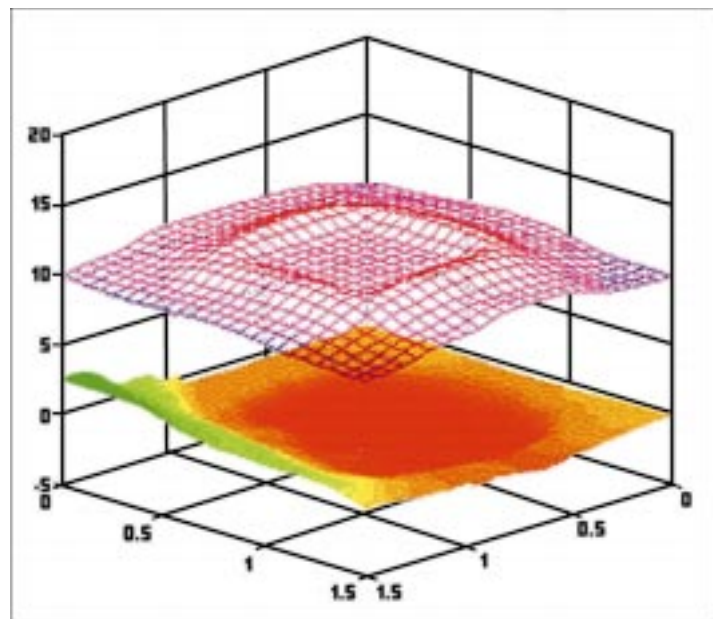


Figure 2: Pin 1 solder ball defect is visible, as the BGA and the PCB are relatively coplanar with each other at the point of solder freeze (180°C).

A more useful method is the shadow moiré technique. An optical grating having 100 lines per inch is placed above the board to be inspected. A collimated light source above the grating is aimed to strike the grating and the board at 45°. Because it has passed through the grating, the light source produces a “shadow grating” on the board. When the shadow grating is viewed by a CCD camera from directly above the board—that is, at 0°—the geometrical interference between the two gratings produces fringes that yield z-axis displacement data across the entire surface of the board.

The fringes are counted from one dark band to the next, and the change in height indicated by each fringe is equal to:

$$W = P / (\tan a + \tan b)$$

where P is the pitch of the grating (center-to-center distance between lines), a is the angle of illumination, and b is the angle of observation.

But observing and measuring fringes does not facilitate visualization of actual warpage. Three-dimension data can be displayed by robust algorithms, which convert the fringe image into an out-of-plane displacement matrix.

ment matrix.

The shadow moiré technique can be used to measure the flatness of boards and components both at room and at reflow temperature. The ability to simulate reflow temperature makes it possible to visualize and to measure bow and twist which may occur during temperature changes, and which would otherwise be impossible to measure.

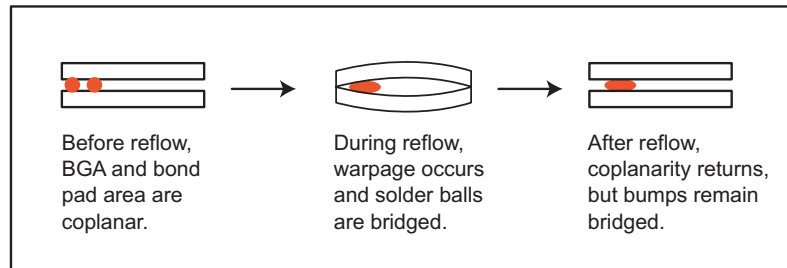


Figure 3: Warpage during reflow can lead to a permanent defect.

In many applications, an individual bond pad area and an individual component may appear to have adequate flatness at room temperature, both before and after reflow, and yet experience interconnect failures. A 40mm BGA shadow moiré having a profile at reflow temperature is shaped like a small mound. To produce this image, both the PCB (only the bond pad area) and the compo-

nent were independently subjected to the prescribed reflow profile (peak = 225°C) and their profiles were measured and plotted.

Reflow caused the BGA and the bond pad to bow in opposite directions. During reflow, this would place great stress on the solder balls. The BGA from a lot where bridging of adjacent solder bumps was occurring in the region of Pin 1 can be viewed as

much of the interconnect area, solder balls were actually being stretched, but near Pin 1 solder balls were being compressed until they made lateral contact with each other. During cooldown after reflow, the solder bumps freeze as the temperature passes through 183°C, and the bridged bumps become permanent features.

With this information, the manufacturer was able to introduce process changes, which greatly improved the mechanical behaviors of both the board and the component. In this case, optimizing the process helped to significantly reduce occurrence of the defect.

The shadow moiré technique is flexible since it can be applied either in a laboratory setting or on-line. It can measure flatness in whole boards (whether populated or not), in individual bond pads and on individual components in JEDEC trays. As higher densities, shrinking sizes, and the introduction of lead-free and bromine-free materials make interconnect precision a key element in profitability, rapid measurement of these parameters becomes more vital.

the green area at the left of the bond pad image. Since both the component and the bond pad region were flat before and after reflow, the mechanism causing bridging was a puzzle.

Imaging both items at simulated reflow temperature showed the bowing that was occurring in both the bond pad and the BGA. Maximum vertical displacement is between 0.431mm to 0.457mm. Over