Abstract—Leadless ceramic chip carriers and other surface mountable components can be soldered to printed wiring boards. It is well-known, however, that temperature changes and temperature gradients can cause large strains in the solder joints. What is not widely appreciated is that the joints are not in simple shear even on a macro scale, much less on a micro scale. We consider three modes of joint deformation, characterized by the displacement of the pads (or lands) to which the solder is attached. Mode A, which is “shearlike,” is characterized by a difference in the in-plane displacements of the two pads. Mode B, associated with bending, is characterized by a change in the angle between the planes of the two pads. Mode C, which is “tensionlike,” is characterized by a difference in out-of-plane displacement of the two pads. Any given thermal change will produce a superposition of these three modes of deformation. These deformations were measured using strain gauges and holographic interferometry, two techniques which complement each other in several ways.

A strain gauge measures in-plane displacements, giving modes A and B; it measures only one part of the sample; and it is suitable for thermal chamber or power cycling. Holographic interferometry measures out-of-plane displacements, giving modes B and C; it measures every part of the sample; and it is most suitable for power cycling studies. In thermal chamber cycling, we find that above 50°C the chip carrier and the board expand as if they were independent. At lower temperatures, the considerable tractions that develop cause board carrier and the board expand as if they were independent. At lower temperatures, the considerable tractions that develop cause board bending (mode B), as well as nonlinearity in the temperature dependence of the mode A deformation. The board tends toward the chip carrier for decreasing temperature. The bending causes any given row of solder joints to have a distribution of mode C deformations, some tensile and some compressive (corner joints are in tension). When power is applied to a chip carrier mounted on a printed wiring board, the average temperature rises, causing mode A deformation similar to that in a thermal chamber. The temperature gradient through the thickness of the board, however, causes the board to bend toward the chip carrier, overcoming the effect of the traction on the joints, which is in the opposite direction. All three modes of deformation are proportional to the power. Mounting of the printed wiring board has a strong influence on modes B and C. Rigid clamping of the board decreased modes B and C deformation by a factor of two compared to that of a board with free edges.

INTRODUCTION

The advantages of surface mounted devices such as chip carriers over through-hole mounted devices such as dual in-line packages have been well documented [1]–[3]. It is expected that chip carriers will soon make large incursions into the business now dominated by dual in-line packages [4]. It is not clear, however, what fraction of these chip carriers will be leadless. Advantages of leadless carriers include lower cost, lower inductance per lead, fewer joints, greater ruggedness against handling damage, and no concern over lead stiffness and planarity. The primary disadvantage is that thermal expansion differences between carriers and substrate materials cause large strains in the joints, resulting in cracks and early failure on temperature cycling [5], [6]. The present study was undertaken to learn more about the strains resulting from temperature excursions and power cycles for a leadless ceramic chip carrier (CCC) soldered directly to a printed wiring board (PWB) using solder post technology [7].

The CCC used here had a coefficient of thermal expansion, or expansivity \( \alpha_c \) of 5.5 ppm/°C, and the PWB substrate had an expansivity \( \alpha_s \) of 17.6 ppm/°C (as measured by strain gauges and confirmed by independent results). If the two materials are not mechanically coupled and they both experience the same temperature change \( \Delta T \), their relative fractional expansion will be

\[
\frac{\Delta L_s}{L_s} - \frac{\Delta L_c}{L_c} = (\alpha_s - \alpha_c)\Delta T.
\]

This relative fractional expansion would occur if the solder in the joints between the CCC and the PWB were completely compliant. In that case, the solder post would sustain an equivalent shear strain (if only shear deformation occurs) of

\[
\Delta \varepsilon_{\text{shear}} = (\alpha_s - \alpha_c)(a/H)\Delta T
\]

where \( a \) is the in-plane distance from the solder post to the center of the carrier and \( H \) is the height of the solder post. The strain field within the solder will not be pure shear, however. Partly as a result of bending deformation and out-of-plane axial traction, regions of tensile and regions of compressive strain will exist, and the shear strain will be far from uniform [8]. Nevertheless, we can describe the overall CCC/PWB interaction by discussing and measuring the displacements and rotations of the pads (i.e., lands) to which the solder is attached.

Fig. 1 shows the three degrees of freedom considered here for the displacements and rotations of these pads. Any thermal change will cause a superposition of these modes of deformation, but they are shown individually in Fig. 1 as three different hypothetical cases. Mode A is shearlike. It is characterized by a difference in the in-plane displacement between the solder pad on the CCC and that on the PWB, normalized...
Deformation modes for a solder post. Fig. 1.

by the height of the solder post \( H \). It is measured by reading strain gauges labeled \( e_1 \) and \( e_2 \) in Fig. 1(a). The difference in in-plane displacement is given by \( \Delta a = (a/H) \Delta (e_2 - e_1) \). We avoid referring to mode A as shear because even if the deformation is pure mode A, the solder post will not, in general, be in pure shear. Mode B is associated with the bending of the PWB. Some evidence exists that the CCC also bends, and we plan to measure this effect. Here we assume that the CCC bending is negligible compared to the PWB bending. The elastic modulus of the ceramic in bending is more than ten times that of the PWB, so it seems reasonable to assume that the effective modulus of rigidity of the CCC is considerably greater than that of the PWB.

The mode B deformation of the PWB is measured by the bending angle \( \phi = a/R \), where \( R \) is the radius of curvature. The change in \( (1/R) \) can be measured by \( \Delta (e_3 - e_2)/h \), where strain gauges are required, as indicated on Fig. 1(b) and \( h \) is the thickness of the PWB. The change in the bending angle can also be measured directly using the density of fringes on a holographic interferogram.

Mode C deformation, which may be either tensile or compressive, cannot be measured with strain gauges but is readily determined within an arbitrary zero from profiles obtained from the interferograms. The zero is inferred by assuming that the CCC adjusts itself so that the algebraic sum of the mode C deformations of all the solder joints is zero.

Since a solder post is not perfectly compliant, it will exert a force on the PWB and the CCC. This force will be primarily in-plane, and directed "radially," that is, toward (or away from) the center of the CCC as seen from above. If such a force were applied at the midplane of the PWB, it would produce no bending, but since it is applied at the surface, it produces a bending moment equal to the force times half the thickness of the PWB. The bending changes the angle between the top and bottom solder pads, thereby changing the stress field within the solder. The board bends away from the carrier for increasing temperature and toward the carrier for decreasing temperature.

If the solder joints were in a circle rather than a square array, the radial symmetry would cause them all to have the same deformations, at least to first order. In a square array, the corner joints are subjected to more mode A deformation (by roughly a factor of 1.4) than the joints in the middle of each side. The bending of the board also causes a straight line row of joints to have a nonuniform distribution of mode C deformations. At low temperatures, for example, the corner joints will be in tension, whereas the joints in the middle of the sides will be in compression.

Previous work [9]-[11] seems to have concentrated on mode A deformations, ignoring modes B and C, and generally assumes that mode A is linear with temperature. Recently, other deformation modes have been considered [12]-[14]. We have measured modes A and B in 1) a thermal cycling chamber where \( T \) is varied between -20°C and +125°C, and 2) room ambient with power dissipated inside the CCC. In the second condition, we were able to use holographic interferometry to measure out-of-plane displacements, from which deformation modes B and C could be calculated.

**Strain Gauges**

**EXPERIMENTAL**

Fig. 2 shows how the three identical strain gauges were arranged. One each was glued to the bottom of the (0.65 in X 0.65 in) CCC, the top of the PWB, and the bottom of the PWB, and all three were aligned to read strain in the same direction. The CCC and PWB are described by Stafford [15]. The active area of each gauge was 0.0625 in X 0.0625 in, and the gauges were centered within the carrier land pattern. The gauges were attached with a two-part epoxy using standard procedures [16]. The epoxy was cured under clamping force for 45 min at 90°C. Copper access wires (0.02Ω) were soldered to gauges 1 and 2 and fed out through the corners so as not to interfere with the solder posts. The wires were soldered to the

1. Gauge type CEA-06-062UW-350, Micro-Measurements Division, Measurements Group (MMD/MG), Raleigh, NC.
2. M Bond AE/15 epoxy, MMD/MG.
Fig. 2. Arrangement of strain gauges.

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gauge with 96Sn/4Ag eutectic, which melts at 221°C [17]. Solder was applied [7] to the pads of the CCC using 0.040-in 60 Sn/40Pb solder spheres (solidus 183°C, liquidus 190°C) [19]. The gauges were coated with a moisture retardant,3 and the CCC was reflow soldered to the PWB with a final standoff height of 0.023 in. Three external leadwires (27 in long, 0.13 Ω) were attached to each gauge, and the gauge resistances were measured with an automatically sequencing Wheatstone bridge4 with a precision of 1 ppm of length change. Readings were converted to expansion values by use of an “apparent strain” calibration curve5 supplied with each set of gauges.

The thermal cycling chamber6 (12 in X 12 in X 12 in) had forced convection and a rate of temperature change as high as 9°C/min for increasing temperature and 6°C/min for decreasing temperature. Total cycle time was 115 min. Temperature was measured with iron-constantan thermocouples taped to the PWB.

In the strain gauge studies, power dissipation in the chip was simulated with a 40-Ω Ta2N thin-film resistor on a ceramic substrate glued inside the CCC. A Kovar lid was glued on top of the CCC, slightly tilted to allow egress of the resistor leads.

Holographic Interferometry

The holographic interferometer used in this study for making the out-of-plane thermal displacement measurements is shown schematically in Fig. 3. For convenience and improved

3 M-Coat A, MMD/MG.
4 V/E 220A data logging system, MMD/MG.
5 This curve gives the apparent strain of a gauge when mounted on a standard reference material (in this case 1018 steel) as a function of temperature. The expansion of the unknown at any temperature is the gauge reading minus the apparent strain plus the expansion of 1018 steel. For strain differences such as those used in ∆θ and ∆φ, these corrections cancel out.
6 Model SK3101, Associated Environmental Systems, Lawrence, MA.
the elementary vector expression

\[ n \lambda = \mathbf{k} \cdot \mathbf{d}. \]  

(3)

Here \( n \) is the fringe number and \( \lambda \) is the wavelength of coherent light illuminating the surface. Moreover, \( \mathbf{d} \) is the mechanical displacement vector at the point on the surface being observed, and \( \mathbf{k} \) is the sensitivity vector \((\mathbf{i}_2 - \mathbf{i}_1)\) where \( \mathbf{i}_1 \) and \( \mathbf{i}_2 \) are unit vectors along the directions of illumination and observation, respectively. The angle \( 2 \theta \) between \( \mathbf{i}_2 \) and \( \mathbf{i}_1 \) at each point in the surface can readily be established. In the present study the essentially planar test surface is intentionally oriented so as to be normal to the bisector of this angle. Consequently, since the interferometer sensitivity vector \( \mathbf{k} \) also lies in the direction of the angle bisector, the interferometer senses only the out-of-plane component of displacement \( \mathbf{d} \). In this case (3) becomes

\[ n \lambda = 2d \cos \theta. \]  

(4)

For the present arrangement \( \theta \sim 9^\circ \) and \( \lambda = 0.633 \mu \text{m} \) so that each dark fringe represents a change in elevation of only \( \sim 0.32 \mu \text{m} \) or \( 12.6 \times 10^{-8} \text{ in} \).

**Interferometer Test Program**

These tests were run on a 55-mm \( \times \) 95-mm circuit board module with a single centrally mounted primary chip carrier. The standoff height was 0.008 in. In place of the chip, the chip carrier contained a 1.5-kΩ thin-film resistor, which was instrumented with a thermocouple to monitor the temperature when the resistor was powered up to simulate operation of the module. The assembly was spray painted white to improve reflectivity. The module was first mounted by firmly affixing the chip carrier lid to a vertical glass plate, and a series of double exposure holographic interferograms of the back of the module were recorded for successively greater levels of power dissipation. In this mounting configuration, the circuit board is supported solely by the solder posts connecting it to the chip carrier and is otherwise free to deform at will.

In actual practice, such a board would be supported at its edges. In order to evaluate the effect of the support, a second series of tests was conducted on the same module with vertical rigid clamping along its longer sides. It is reasonable to expect that the edge clamping would impose considerable constraint on the response. This experiment produced a second very different set of double exposure holographic interferograms.

**RESULTS**

**Thermal Chamber Cycling**

The sample board was cycled four times between \(-20 \text{ and } +125^\circ \text{C}\). Fig. 4 shows the strain gauge results for the second cycle. After the first cycle, the data repeated well from one cycle to the next.\(^7\) A data point was taken every 2 min over the 2-h cycle duration. Corrections have not been made for effects such as transient temperature gradients, which may account for some of the hysteresis observed. The overall expansivity (end-to-end of the curve) for \( e_1 \) is 6.6 ppm/°C, which is probably within experimental error of that measured (also using strain gauges, from \( 24^\circ \text{C} \) to \( 100^\circ \text{C} \)) on an unmounted CCC, 5.5 ppm/°C. The overall expansivity for \( e_2 \) is 16.9 ppm/°C, and for \( e_3 \) it is 22.2 ppm/°C. Clearly, considerable bending occurs, since \( \Delta e_2 \) and \( \Delta e_3 \) are unequal.

As described in Fig. 1, we can convert the strain gauge readings \( e_1, e_2, \) and \( e_3 \), to equivalent deformation angle changes, \( \Delta \theta \) and \( \Delta \phi \). Since these angles depend on differences of strain gauge readings, many of the experimental errors cancel. These results are independent of the manufacturer's "apparent strain" curve and the assumed curve for expansion of the reference material. This analysis requires the assumption that the strains in the PWB and CCC are uniform and isotropic (in the plane) in the region under the CCC. It also requires defining an effective radius \( a \), which we take as that radius which gives a circle of area equal to the CCC area. That is, \( \pi a^2 = (0.65 \text{ in})^2 \), or \( a = 0.3667 \text{ in} \). To make room for the strain gauges, in these studies the standoff height \( H \) was increased from the usual 0.008 in to 0.023 in. The PWB thickness of the assembly was 0.058 in. We express the angles \( \Delta \theta \) and \( \Delta \phi \) in milliradians (mrad), where, e.g., 10 mrad corresponds to an angle of \( 0.57^\circ \), or in the case of \( \theta \) to an equivalent shear of one percent.

Fig. 5 shows deformation modes A and B as calculated from the data of Fig. 4. The hysteresis is more pronounced in mode A than in mode B. Also included on the plot of mode B is a scale for the equivalent center deflection, which (for a spherical deformation) is \( \alpha^2/(2R) \). In both plots, the zero (or reference state) and the signs are arbitrarily chosen so that the deformations are zero at \( 125^\circ \text{C} \) and positive for lower temperatures. Probably the ideal reference state would be that at the moment of joining (the solder freezes at \( 183^\circ \text{C} \)). Because we have no data at that temperature, we use \( 125^\circ \text{C} \) as a reference temperature since that is as close as we can come. On the mode A curve, a reference line is given to indicate the slope that would be observed if the solder were fully compliant. It is based on strain gauge measurements (24°C-100°C) of the expansion coefficients. That is, \( \alpha dT = 12.1 \text{ ppm/}^\circ \text{C} \times 0.3667 \text{ in}/0.023 \text{ in}, \) or 0.19 mrad/°C.

From Fig. 5(a), we see considerable hysteresis in the mode

\(^7\) Some additional curing of the strain gauges took place on the first cycle, since the upper temperature (125°C) exceeded the original cure temperature (90°C).
A deformation. This may be partially due to the time required for solder creep. It may also be due to transient temperature gradients or perhaps work hardening. For increasing temperature, we see a slope change around 50°C, above which the slope corresponds to that of the line of perfect compliance. Below 50°C, the slope is about half that value. For decreasing temperature, the curve is almost linear, again showing considerable hysteresis.

Fig. 5(b) shows that mode B deformation is nonlinear with temperature. For temperatures above 50°C, the bending angle $\phi$ is almost independent of temperature, indicating very little coupling; i.e., the solder is yielding to absorb most of the expansion difference. This is especially true of the increasing-temperature data. Below 50°C, $\phi$ is dependent on temperature, indicating a steadily increasing traction applied by the solder to the PWB as the temperature is decreased. The average slope is about $-0.06 \text{ mrad/°C}$. The direction of the bending of the PWB is toward the CCC for decreasing temperature.

**Deformations Induced by Power Dissipation in the CCC**

The same board was evaluated for modes A and B deformation induced by power dissipation in the CCC in room temperature air. The board was mounted vertically by setting its bottom edge in soft clay. The raw strain gauge readings were corrected for the temperature rise associated with each location and power level, using thermal resistance measurements by Deighan [20]. The maximum temperature rise at the hottest gauge ($\varepsilon_1$) was 36°C. The fractional expansions after this correction are shown in Fig. 6. All points are within 10 ppm of the straight lines, which gives an indication of the signal-to-noise ratio of the strain gauge results.

In this situation, the top surface of the PWB expanded more than the bottom ($\varepsilon_2 > \varepsilon_3$), indicating a bend towards the CCC for increasing power. This was a surprising result but is understandable in terms of Deighan's measurements, which showed a sizable (up to 14°C) temperature gradient across the thickness of the PWB under the CCC. Evidently, the bending caused by this gradient overcomes the bending due to the overall temperature increase, which is in the opposite direction. The slopes of the curves are 222, 329, and 238 ppm/W for $\varepsilon_1$, $\varepsilon_2$, and $\varepsilon_3$. The mode A and B deformations are therefore also proportional to the power $P$. Their slopes are

- for mode A: $d\phi/dP = 1.71 \text{ mrad/W}$
- for mode B: $d\phi/dP = 0.575 \text{ mrad/W}$.

Comparing the first of these with $d\phi/dT$ (Fig. 5(a)), we see that 1 W provides the same mode A deformation as an overall temperature increase of 9°C. Comparing the second, $d\phi/dP$ with the low-temperature slope $d\phi/dT$ (Fig. 5(b)), we see that 1 W provides the same mode B deformation as an overall temperature decrease of 10°C. Note that if the ambient increases during power-up, the two bending effects (mode B) will be at least partially compensating. This is quite likely to happen if there are nearby components dissipating power. Also note that power cycling is fundamentally different from thermal chamber cycling, since they produce mode A deformation in the same direction, but mode B in opposite directions. Thus it seems impossible to simulate power cycling fully with some equivalent temperature cycling.

**Results from Holographic Interferometry**

Holographic interferometry requires that the test object be mounted to minimize all rigid body movements unrelated to the applied loading. This requires a firm restraint against vibration or rocking and is usually accomplished using robust fixtures. In the present study, we used two modes of mounting, one in which the CCC was firmly mounted and the PWB allowed to deform at will. In the other, the PWB was firmly clamped along two edges and the CCC allowed to move. These two mounting modes, referred to as “center mount” and “edge clamped,” respectively, represent lower and upper bounds on the restraint likely to be experienced by such assemblies in actual service.

In the first series of holographic experiments, the center mount mode was used. Fig. 7 shows the resulting interferometric fringe fields for four power levels between 0.06 and 1.08 W. The PWB is oriented with the CCC on its opposite
side, so the CCC is not visible. However, its outline is indicated by the square line pattern in the center of the figure.

**Outside the CCC Land Pattern Area (Center Mounted Sample)**

The interferometric fringe fields shown in Fig. 7 represent “isoelevation” or contour lines. They consistently exhibit a symmetry about a line running parallel to the lower right to upper left diagonal of the CCC square and are roughly centered about the CCC itself. This means that the PWB curls about the CCC diagonal as it heats up. In each case, as the power was increased, the fringe density also increased, but with little change in the form of the pattern. That is, the PWB simply curled more in the same way. Also some small top-to-bottom asymmetry exists, possibly associated with thermal convection. The board was mounted with its plane surface vertical. The last interferogram in Fig. 7 is also somewhat complicated by the appearance of a secondary Moiré fringe pattern, which is not evaluated in the present analysis and should be ignored.

**Inside the CCC Land Pattern (Center Mounted Sample)**

Inside the CCC land patterns on Fig. 7, the fringes are somewhat between square and circular but generally closer to circular. By gently depressing the PWB and observing the direction of motion of the fringes in real time, it was ascertained that the PWB bends toward the CCC when the power is applied. This agrees with the strain gauge result and strengthens the conclusion that the inward bending caused by the temperature gradient through the board dominates the outward bending caused by the in-plane tractions from the solder posts. At 1.08 W about ten fringes occur between the solder posts and the center, indicating a center deflection of $1.3 \times 10^{-4}$ in. The radius of curvature at the center is found by plotting $Z$ versus $r^2$ where $Z$ is the out-of-plane deflection and $r$ is the in-plane distance from the center. The radius of curvature is $R = 0.5d(r^2)/dz$. A typical plot is shown in Fig. 8. Reasonable linearity is indicative of a spherical deformation. Eight such plots were made for each power level, taking profiles along the diagonals and the axes. The mean of the eight values $R$ is taken as an average radius of curvature, from which we can infer a bending angle (mode B) at the solder posts of $\Delta \phi = a/R$. This plot is shown in Fig. 9, labeled center mount. It is above the line obtained from the strain gauge measurement by a factor of 1.5. It has no noticeable curvature. The factor of 1.5 may be attributable to the large difference (a factor of 2.9) in the standoff heights. It is reassuring, however, that the two measurements are in the same direction and are of the same order of magnitude.

**At the Solder Pads**

Our primary interest here is what happens at the solder pads. We would like to know the local topographical gradient in order to measure directly the mode B deformation (bending angle) at each solder pad. This can be done by recording the location of two or three fringes along the gradient direction in the vicinity of each pad. Fig. 10 is a plot of the slopes obtained this way along the four sides of the CCC powered at 0.61 W. The bending angle is lowest in the corners. For a spherical deformation, one would expect the behavior shown in the dotted line. This curve is based on $R = 684$ in, as determined from the $Z$ versus $r^2$ plot. It is about the same magnitude as the measured individual values, but it erroneously predicts the greatest bend in the corners. This demon-
strates the value of the holographic technique (which measures
the bend angle at each location) over the strain gauge tech-
nique, which approximates the bending indirectly by measur-
ing the radius of curvature at the center.

The holographic technique is also extremely useful in its
ability to measure a profile along each row of solder pads,
from which we can obtain the mode C deformation. Fig. 11 is
a three-dimensional plot of these profiles for a carrier dissipat-
ing 1.08 W. The vertical dimension has an arbitrary zero, how-
ever, and in addition the chip carrier undergoes an unknown
overall tilt. To allow for this tilt, we find the plane which best
fits the four corners and lower it until it gives a net sum of
zero extension for all the joints. Such a plane is shown in Fig.
11. Finally, the deviation of the profile from this plane is
plotted in Fig. 12. The corner joints are clearly in tension, and
the joints in the middle of the sides are in compression. This
is the direction expected from a measurement of $R$ at the
center. The amplitude of this distribution, however, is less
(by a factor of two) than that expected from a spherical
model. The equivalent tensile strain is indicated by a scale in
Fig. 12, where the vertical displacements have been divided by
the height of the solder post, 0.008 in. Clearly, a significant
amount of tension exists in the corners.

Edge Clamped Mounting Tests

A second series of tests was run on the same assembly using
the edge clamped mounting mode in order to evaluate the
effects of the mounting on the deformation field around the
CCC. The interferograms from these tests at power levels
from 0 to 2.43 W are shown in Fig. 13. Here the diagonal
fringe symmetry has been replaced by a left-right symmetry
about the vertical centerline of the PWB, demonstrating the
powerful influence of the vertical edge restraint on the overall
mode of deformation. As before, the PWB has bent towards
the CCC at its center, and again the deformation increased
with increasing power (while preserving the general shape of
the fringe pattern) but now at a far lower rate. Notice that the
fringe field inside the CCC land pattern is rather similar to
that of the earlier center mount case (Fig. 7), except that for
any given power there were far more fringes for the earlier
series. The bending angle $\Delta \phi = \phi / R$ is also plotted in Fig. 9.
The bending in the present case (edge clamped) is less than
half that of the center mount case, and this bending is not
truly proportional to the power being dissipated. This shows
how important the actual conditions of mounting can be, even
though the clamped edges are more than ten PWB thicknesses
away from the region of interest.

The bending of the edge clamped case was measured indi-
vidually at each pad location and found to be lowest in the
corners, as before. It is plotted on Fig. 10. The extensional strain at the solder posts was also measured. After being corrected for the tilt, the extensional strain was plotted on Fig. 12. It has the same character but is much smaller than the extension or strain in the case of the center mount board.

The information from Figs. 7 and 13 can be visualized more readily in the three-dimensional plots of Fig. 14, made by estimating the out-of-plane displacements on a grid of 21 × 21 nodes in the plane. The scale of nodes was chosen such that each row of solder joints falls exactly on a row of nodes, as indicated by the heavy lines in the figure. The vertical scale is the same for both plots, but we chose a much larger power level for the clamped edges case than for the center mount case. This provided enough deflection to visualize easily the deformation pattern of the clamped edges case. The deflection scale is approximately proportional to the power, so similar plots for other power levels can be generated readily.

CONCLUSION

The deformations caused by temperature and power cycling of surface mounted chip carriers are a complicated mixture of modes A, B, and C. Holographic interferometry is an excellent technique for measuring out-of-plane deflections caused by power dissipation. This permits determination of modes B and C at any solder joint. A strain gauge measures strain at one area only, but strain gauge readings can be used to infer average mode A and B deformations at the solder joints, and strain gauges are well suited for thermal chamber cycling as well as power cycling. Thus the two techniques are nicely complementary.

Mode A deformation angles up to 0.02 rad, mode B deformation angles up to 0.005 rad, and mode C deformations up to 0.5 percent are observed during typical tests. The mode A deformation caused by 1 W of power dissipation is equivalent to the mode A deformation caused by a temperature increase of 9°C. The bending (mode B) caused by 1 W is equivalent to the bending caused by a temperature decrease of 10°C. Since the deformation modes A and B are well coupled, power cycling cannot be fully simulated by thermal chamber cycling. In service, both deformations occur, but the relative proportion depends on the application. The solder exerts the largest forces on the pads at low temperatures, and the mode A and C deformations are greatest in the corner pads.

The type of mounting is clearly important. For example, edge clamping of the PWB was found to decrease the bending
and tension at the solder joints by at least a factor of two. Field conditions of constraint will probably fall between the conditions studied here.

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