NONDESTRUCTIVE ANALYSIS OF CERAMIC PACKAGES USING RESONANT FREQUENCY

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INTRODUCTION

Ceramic pin grid arrays (PGA's) are used by microprocessor suppliers for packaging high power chips in a hermetic environment. PGA's are multilayer co-fired structures with internal metal planes and vias. The combination of materials in the packages leads to differences in thermal expansion and, therefore, stress concentrations both during the fabrication of the package and during subsequent processing with the chip in place. These stresses combined with the brittle nature of the ceramic material may lead to package cracking.

The purpose of this study is to investigate a non-destructive technique to detect flaws both in incoming packages and at various stages of the assembly process. A viable method would allow increased manufacturing yield and improve reliability by detecting cracks which might eventually propagate and lead to a loss of hermeticity. It would allow testing of packages with "live" die and would be rapid and inexpensive to be useful for testing of mass produced components. Of the nondestructive evaluation techniques available, resonant frequency testing seems to be the most rapid, least expensive, and, overall, best suited to the needs of high volume manufacturing. This paper discusses practical application of the method to electronic packaging.

Previous work, by Cawley et al. [1,2], studied frequency shifts due to flaws in various components and showed that natural frequencies tend to be reduced by damage. These studies also showed that frequency shifts due to small cracks tended to be obscured by shifts due to differences in component sizes from acceptable manufacturing tolerances. Therefore, in cases where the same component is tested over time, the method may detect small flaws, but otherwise, the simple process of finding the frequency of the first vibration mode may have limited usefulness. Cawley [1] proposed a method for correcting for dimensional changes which is investigated here using the finite element method.

The fracture of brittle materials is inherently a statistical phenomenon related to the distribution of the size and location of the initial flaw population and its interaction with any imposed stress state. Any practical NDE technique will have limitations on the minimum size of detectable flaws. Determination of the maximum allowable flaw size for a given component must be addressed separately. The usefulness of resonant frequency measurements and the limitations of the technique for ceramic packaging of electronic devices are shown in this paper

TECHNIQUE

The resonant frequency of the ceramic packages was measured using a GrindoSonic™ instrument, manufactured by J.W.Lemmens, St.Louis, MO. In this technique, a light, mechanical impulse is imparted to the sample and the resulting transient vibration is detected by a piezoelectric transducer placed at a node of the vibrational mode being analyzed. The frequency of the transient vibration, also referred to as the resonant frequency, is displayed in kHz on the GrindoSonic display. The resonant frequency detected is a function of the impulse initiation site, fixturing and detection site. By varying the supports and the excitation and detection sites, the frequencies of the different vibration modes can be obtained. Finite element modeling provided information which enabled proper test set-up for each vibration mode. Frequencies were repeatable to about 1 Hz for the lowest modes.

Testing was performed on several types of PGA's and on flat ceramic plates approximately the same size as the actual packages. Flaws were simulated on test parts in two ways: slots of different sizes were cut in the plates with a diamond saw and the packages were broken in Instron testing using a ring-on-ring type fixture. Modeling was performed for cracked and uncracked plates using the general purpose finite element program ABAQUS™[3].

RESULTS-EXPERIMENTAL

Dimensional Tolerances

To confirm that the largest source of variability in the measured frequency of ceramic PGA's is manufacturing tolerances, the frequencies of the first vibration mode of 750 unassembled packages with no known cracks were measured. Five out of the ten packages with the highest and lowest frequencies were measured for exact package outer diameter (O.D.). The results of the correlation between O.D. and frequency of the first two vibration modes is shown in Figure 1. In a separate test, there was no correlation found between mechanical strength and measured frequency.

Crack Length

A group of packages was tested before and after destructive mechanical testing using a bi-axial stress configuration. Due to the package cavity, it was possible to stop the testing in time for the component to remain intact. Figure 2 shows the resonant frequency distribution before mechanical testing. Figure 3 shows the frequency distribution after mechanical testing. The cracks created by the mechanical testing caused a drop in frequency as expected, but there was an overlap between the two distributions due to dimensional tolerances. The packages were then examined using C-Scan to measure the approximate length of the cracks. Since it was possible to measure the frequencies before and after cracking, good correlation was obtained between the crack lengths, as measured by C-Scan, and the resonant frequency, as shown in Figure 4. It was possible to detect the smallest cracks measurable by C-Scan (approximately .2"). The correlation would probably be more exact between the shift in frequency and the crack area instead of length. The crack length represented in Figure 4 is strictly a two dimensional approximation from a C-Scan image.

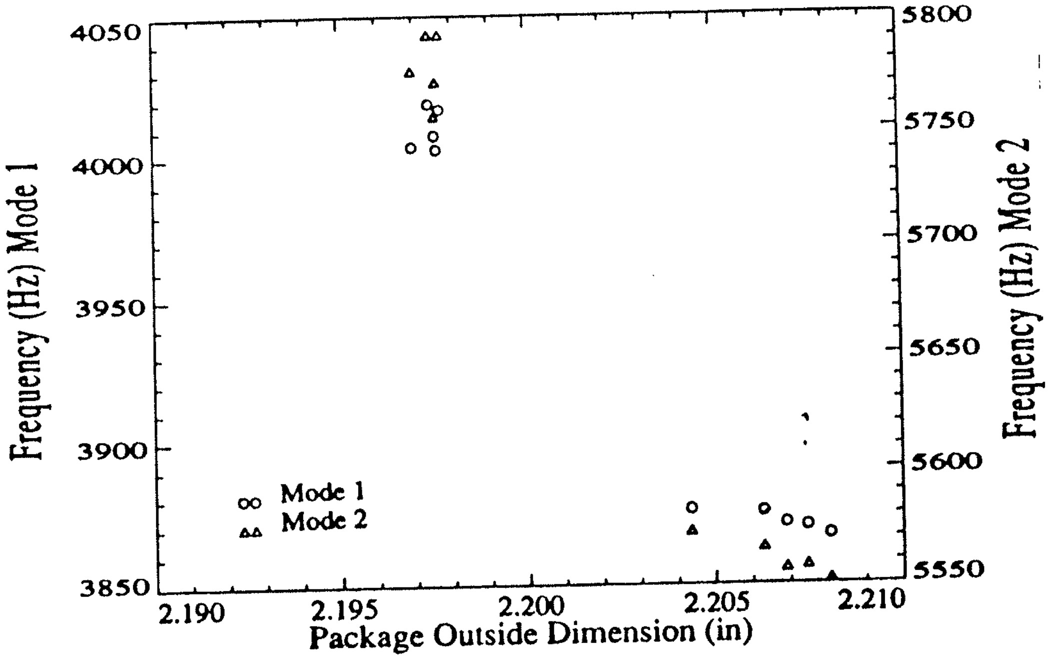

Figure 1. Correlation between package size and measured frequencies

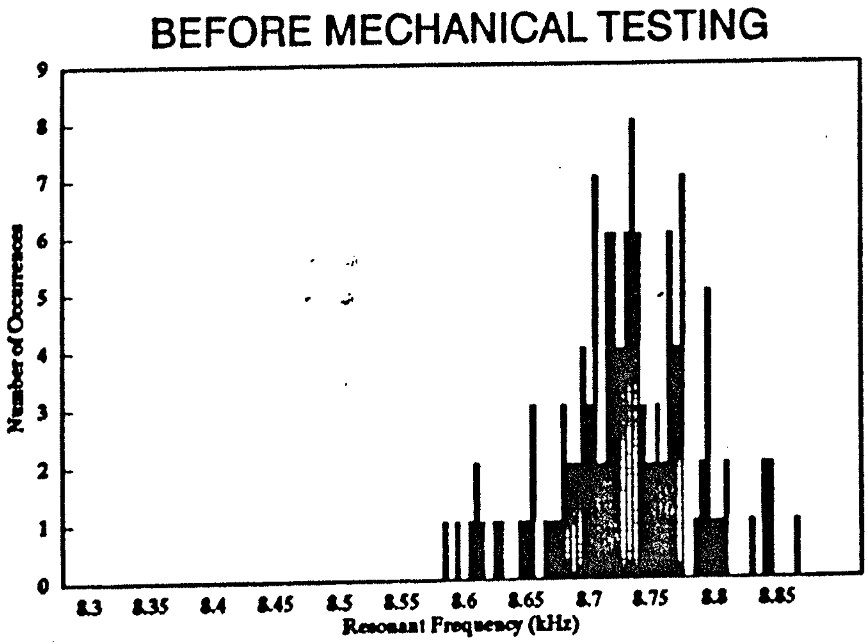

Figure 2. Resonant frequency distribution before mechanical testing.

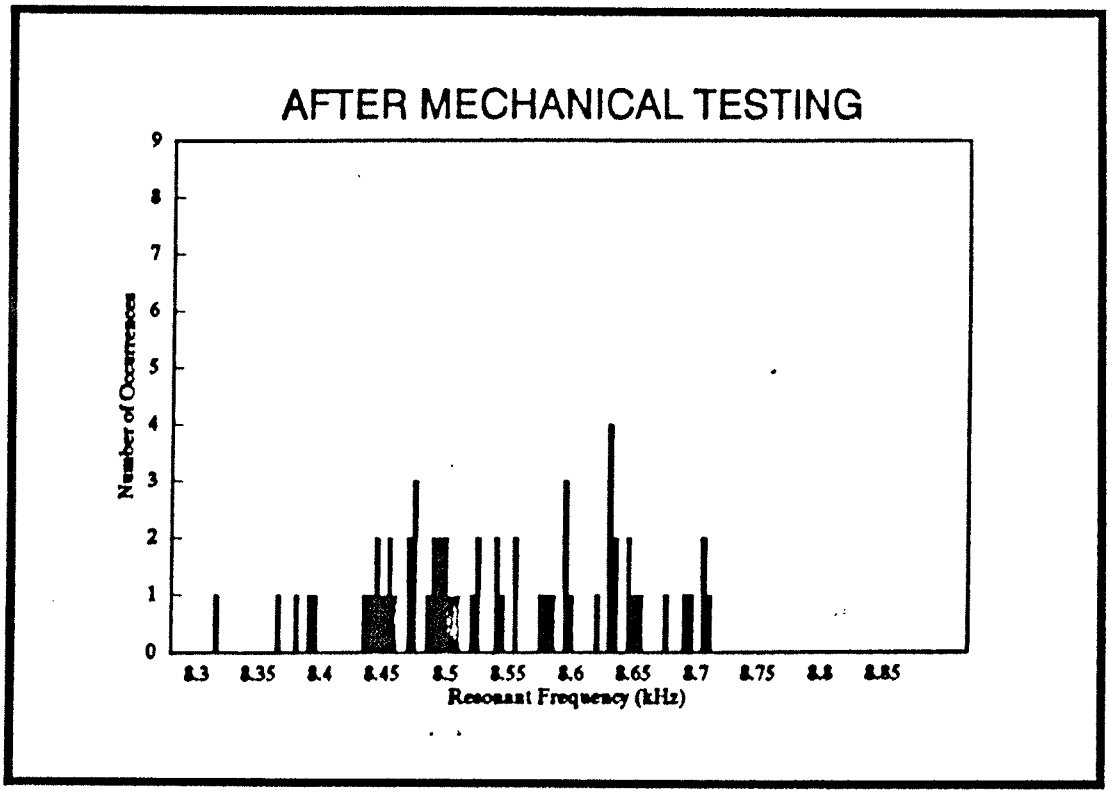

Figure 3. Resonant frequency distribution after mechanical testing.

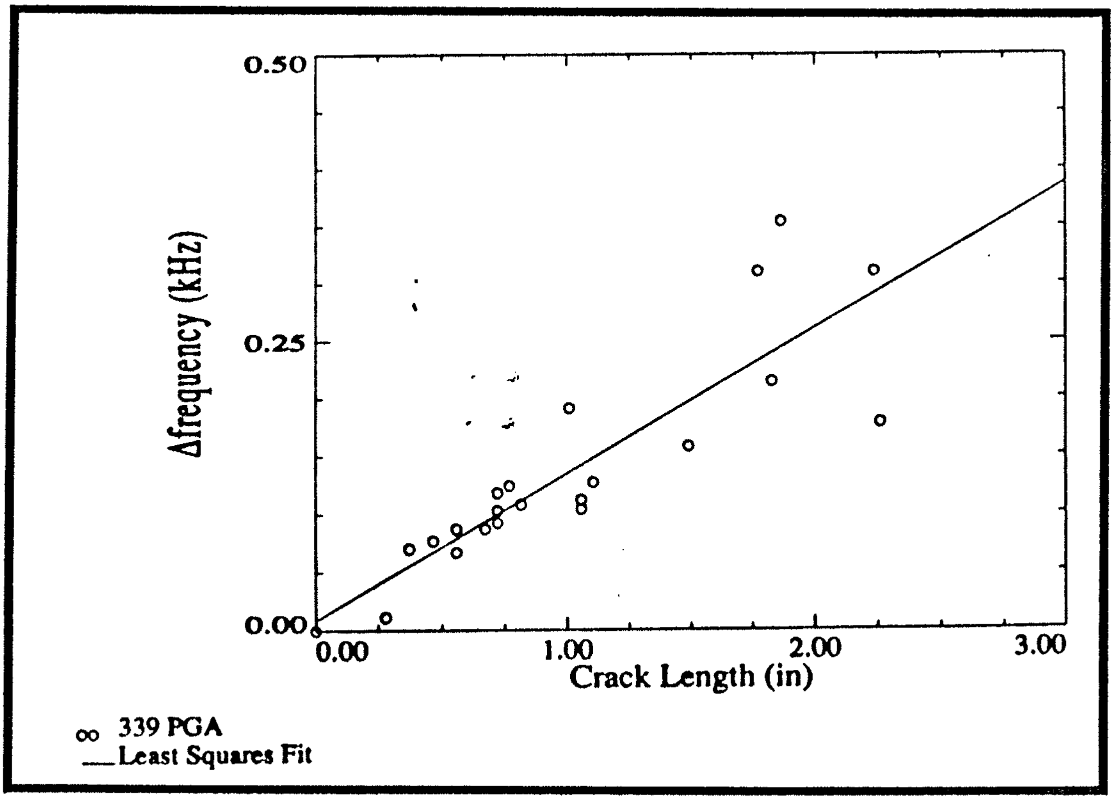

Figure 4. Frequency shift as a function of crack length-Mode III

Application

Testing was then performed on packages with live chips, i.e., packages which were part of a production lot where package cracking had been previously observed to be a problem. The resonant frequency was measured first on fully assembled packages. Testing was subsequently conducted on the same parts after each of several electrical tests, to determine whether any of the manufacturing tests damaged the packages. The resonant frequency test was the only technique known which could be used on "live" parts to detect flaws. Since the size and locations of the suspected cracks were similar to those created by the mechanical testing, it was possible to show that the flaws were not created by the electrical testing of the packages.

RESULTS-MODELING

Dimensional Tolerances

The above results from testing of actual packages showed that unless a technique could be found for adjusting for manufacturing tolerances, the usefulness of resonant frequency testing would be limited to cases where testing the same parts at different times would be practical. Therefore, it was decided to investigate the method proposed by Cawley [1] in which it was suggested that frequency changes in the different modes due to size differences follow a different pattern than those due to cracks.

Testing and finite element modeling was performed on flat plates nominally 2.4 in. square and .096 in. thick made from 90% Al_2O_3. The frequencies of the first four vibration modes were calculated and depended on material density, elastic modulus and Poisson's ratio, in addition to exact package dimensions. Results were calculated using the ABAQUS [3] finite element program with 100 plate elements. Increasing the number of elements by a factor of 4 changed the results by less than 1 Hz.

Using reasonable values of material parameters (E=43 Mpsi, Poisson's ratio=.20 and density=.000348 lb/in^3), agreement within 1% was obtained between the models and the average test results for the first two modes of 55 undamaged plates. Several plates were also tested with slots cut using a diamond saw. Again, excellent agreement was obtained between models and test using the same parameters.

The effect of varying the length and thickness of the plate on frequency is shown in Table I. Frequency changes due to tolerances for the plates are smaller than those observed for the packages in Figure 1. This is most likely due to tolerances in addition to O.D. in the package which are not present in the flat plate models. Table II gives calculated frequency shifts for plates with three sizes of cracks. The cracks were parallel with the package edge and located at .24 inches from the edge. Figure 5 shows normalized displacements due to the first four vibration modes for the plates with a slightly longer crack in order to see the effect more clearly. Also shown in Figure 6 is the frequency shift for the first four modes plotted against crack length.

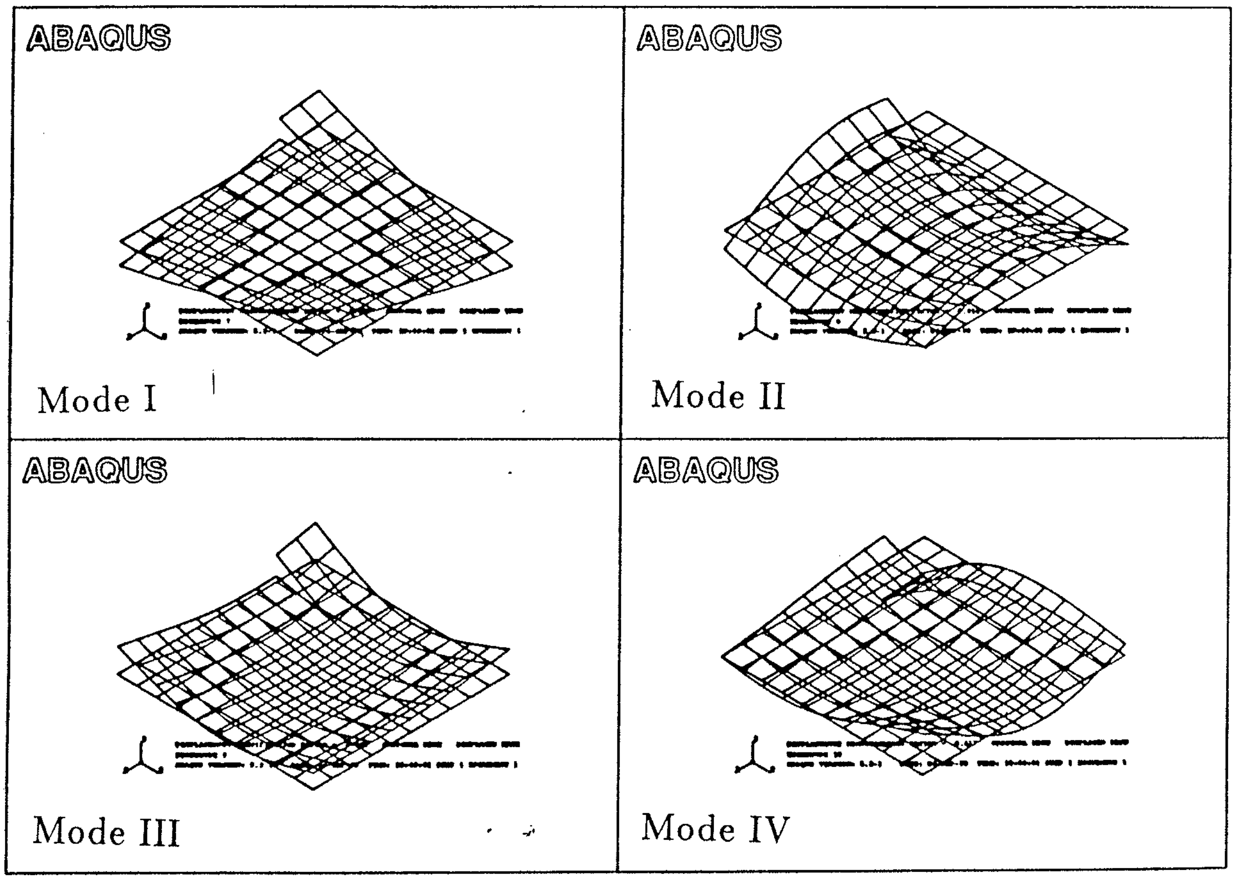

Figure 5 - Mode shapes for first 4 vibration modes of cracked plate

Frequency Shift for Models of Flat Plates
Due to Cracks

Mode	Nominal Plate 2.40” sq. x .096” Hz	5 % cut .12”		10 % Cut .24”		20 % Cut .48”	
		Δ Hz	% diff	Δ Hz	% diff	Δ Hz	% diff
I	3865.3	-4.2	.11	-19.9	.52	-102.1	.515
II	5637.9	-2.8	.05	-11.7	.21	-66.2	1.2
III	6480.9	-2.1	.03	-9.8	.15	-64.9	1.0
IV	9764.2	-20.2	.21	-115.2	1.2	-777.4	8.0

Table 1. Frequency shift from nominal due to dimensional tolerances

Frequency Shift for Models of Flat Plates
Due to Tolerances

Mode	Nominal Plate 2.40” sq. x .096” Hz	10 Mil Larger 2.41” sq.		1 Mil Thinner .095” thick	
		Δ Hz	% diff	Δ Hz	% diff
I	3865.3	-31.7	.82	-39.4	1.0
II	5637.9	-46.5	.82	-58.1	1.0
III	6480.9	-53.4	.82	-66.7	1.0
IV	9764.2	-79.6	.82	-98.7	1.0

Table 2. Frequency shift from cracks of different lengths

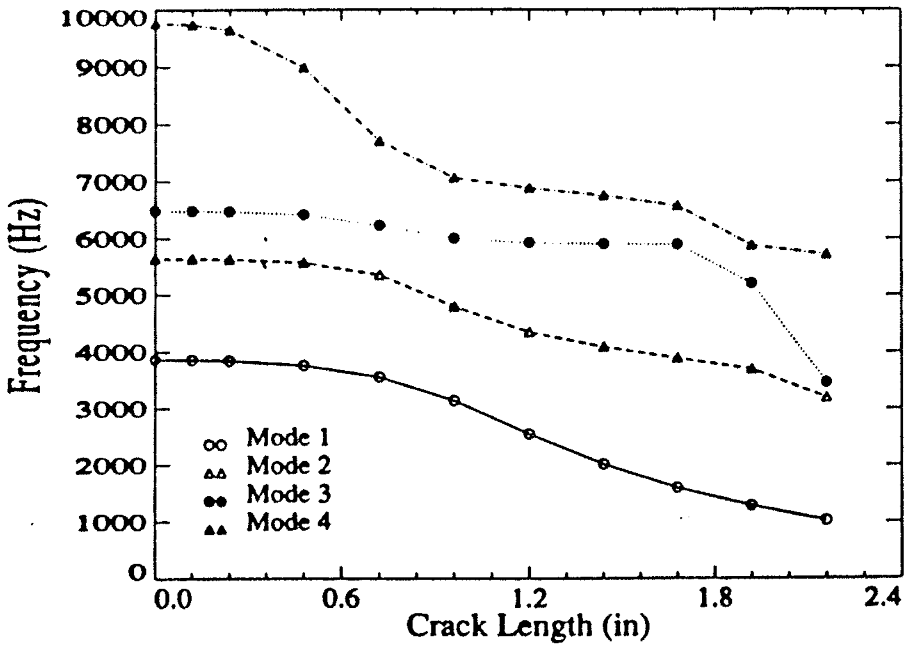

Figure 6-Model results for frequencies of plates with increasing crack length

DISCUSSION

The models of frequency shift as a function of crack length and plate size demonstrate that small cracks will be obscured by manufacturing tolerances in cases where it is not possible to test the same package before and after application of a load. For practical applications, exact measurement of sizes of large quantities of packages is not compatible with the demand for a low cost and rapid method for crack detection. Therefore, it is probable that a crack must be greater than 0.5 inches long through the entire thickness of an approximately 2 inch square package to be detected by simply measuring one frequency per package. However, the models also suggest that if the frequencies of the first four modes can be determined, and the nominal frequencies of these modes are known, shifts due to package size can be differentiated from those due to cracks and much smaller cracks can be detected.

Future work will focus on models of more realistic cracks in actual packages and on detection of small cracks using relative shifts in several vibration modes.