CONF-980550--
SAND98-0383C
SAND--98-0383C
RECEIVED
FEB 17 1998
OSTI
19980529 003

IC Chip Stress During Plastic Package Molding

D. W. Palmer, D. A. Benson, D. W. Peterson, and J. N. Sweet
Sandia National Laboratories*
Albuquerque, NM, USA
email: palmerdw@sandia.gov

Abstract

Approximately 95% of the world's integrated chips are packaged using a hot, high pressure transfer molding process. The stress created by the flow of silica powder loaded epoxy can displace the fine bonding wires and can even distort the metalization patterns under the protective chip passivation layer [1, 2]. In this study we developed a technique to measure the mechanical stress over the surface of an integrated circuit during the molding process. A CMOS test chip with 25 diffused resistor stress sensors was applied to a commercial lead frame. Both compression and shear stresses were measured at all 25 locations on the surface of the chip every 50 milliseconds during molding. These measurements have a fine time and stress resolution which should allow comparison with computer simulation of the molding process, thus allowing optimization of both the manufacturing process and mold geometry.

Introduction

The molding of IC chips in epoxy heavily loaded with silica filler has been industry's main packaging route for at least 20 years. Indeed, most semiconductor companies also see this style packaging as a high yield step. However, IC molding achieves high yield only as long as the manufacturing is done within the empirically well explored space of temperature, known molding compounds, normal package dimensions, normal I/O count and spacing, and cycle time. Private companies have performed many parametric studies involving temperature, rate, and initial molding compound chemistry to empirically minimize mechanical damage during manufacture. When some packaging parameter must change (thinner package or higher I/O count), these studies must be rerun. If the molding process could be accurately modeled, then such experiments could be minimized in favor of computer simulation [3]. Some initial success with computer modeling of the molding flow has occurred but detailed code construction is stymied by the lack of validating measurements at the IC surface during the molding process. Experience has shown that small changes in the physical mold geometry or the process timing can greatly change the maximum stress seen by the IC.

To further validation of simulation code, we developed a technique to measure the mechanical stress over the surface of an integrated circuit during the molding process. In particular, a CMOS test chip with 25 diffused resistor stress sensors was applied to a commercial lead frame [4]. The unit was then molded with an ASM FICO Model MS 100 system. The mold machine was slightly modified to allow a ribbon cable connection between the lead frame and our measurement equipment during the molding process. Both compression and shear stresses were measured at all 25 locations on the surface of the chip every 50 milliseconds during molding. The measurements in this hostile environment shed light on the molding process and are a potential path to validate computer codes describing the process in detail.

Experiment

Test Part Description.

To avoid developing a special lead frame design, these molding tests use a complex lead frame made available to Sandia from a previous industry development effort. The basic part for this testing uses an assembly test chip mounted on this lead frame to carry out tests inside the molding press. Figure 1 shows a view of the lead frame used. The frame is designed for the manufacture of four quad flat package parts with a nominal lead pitch of 0.015" and a total of 296 leads per package.

A flex cable was made for this work using Kapton backed copper that is photo etched to connect 37 of the 63 leads from one side of the lead frame to an external D style connector for the electrical measurements. Electrical noise can easily mask the low level stress signals from the assembly test chips. Shielding of the conductors to reduce sensitivity to electrical noise is provided by additional layers of Kapton and copper foil on each side of the 37 conductors. The shield layers are attached to the hood of the D connector as a means of grounding the shield during tests. The flex cable with the proper pitch and location of pre-tinned copper leads is soldered to the lead frame as shown in Figure 2. To make a test part, the four lead frame is cut to a single frame in such a way that holes for the alignment pins in the transfer press mold are maintained. The mold has steel bars that close on the part to be molded. We maintain electrical isolation of the 37 conductors in the press by the use of additional Kapton frames placed above and below the conductor region as shown in Figure 2.

In the course of testing we discovered that the forces used to close the mold were adequate to extrude the Kapton material and electrically short the conductors to the mold. To fix this, we added copper foil shims in place of the Kapton on three sides of the lead frame where the electrical isolation is not needed. The additional strength of the copper material is sufficient to support the load between the two halves of the mold and allow the remaining Kapton insulated side to survive the press operation. The choice of Kapton, flex cable adhesive and the solder for attachment of the frame to cable was made to allow the part to survive at the molding temperature of 180 to 190 °C.

DISCLAIMER

The sensor device specified to be used in this work is the Sandia ATC04 Assembly Test Chip shown in Figure 3. This chip contains 25 sensor arrays spaced over the face of a nominal 0.25" square by 0.026" thick silicon die. Each sensor has a diode with its forward biased voltage calibrated to act as a temperature sensor. In addition, four p-type and 4 n-type piezoresistors with nominal 10K ohm resistance allow the determination of the compressive and shear stress states at each of the array locations. A system of digital addressing for the specific array location and for the specific sensor element within an array is used to transfer each measurement to output lines on the die. This addressing permits a total of 225 individual electrical measurements to be made on the die.

Molding Press

The transfer molding press used in this effort is an ASM FICO Model MS 100 System. It provides a computer controlled pressing operation with a wide selection of possible operating parameters. Figure 4 shows an exterior view of the press system cabinet. The heated mold is located on a moving section in the middle of the photo. During operation the lower half of the mold slides forward to provide access to the area holding the parts to be molded. The equipment to the right is the temperature controller and pre-heater section used to introduce the plastic mold compound pellets into the ram for transfer into the mold. The area at the left houses equipment for cleaning mold surfaces and placing the new parts for assembly. The hydraulic press and electrical motors are in the cabinet below the working area. At upper center is a video monitor displaying the computer controlled setup parameters.

The lower mold platen shown in Figures 5 holds 8 frames, i.e. 8 parts are intended to be molded in each cycle of the press. One ram is provided for each part molded and compound is injected through one flow channel from the base of each ram to one mold section. In the current testing illustrated in Figure 6 we use only one of the ram and sample mold sections. Mold compound is placed in one ram cylinder and pressed into the one instrumented mold section.

The initial tests with this system used a HYSOL brand mold compound type MG52F-AM. This is a silica filled epoxy based mold compound. The pellets for this test were in the form of a 14.3 mm diameter by 17.57 mm long pellet weighing 4.8 g and came from batch 533311. The mold temperature for the test was 180 °C +- 1 °C. The plunger temperature was 180°C +- 5 °C. The mold halves were closed with a 500N/cm^2 clamping pressure prior to transferring the compound into the mold. A pellet preheat time of 5s preceded the start of the ram motion. The ram motion is programmable and starts at 8 mm/s and profiles down to 2 mm/s giving a transfer time into the mold of about 8 seconds. The ram pressure is limited by a maximum drive pressure of 80 bars.

Time dependent measurement system

The previous measurements with the ATC04 have all been made with a test system designed for single measurement sets where speed of measurement was not a concern. In the present work we seek to resolve the measurements to a time scale that would detect changes occurring as the mold compound flows over the test part. A complete measurement set of the 225 outputs from the die in about 50 milliseconds was the initially selected objective and this has been met with the system we now describe.

Computer based data acquisition in a 100+ megahertz speed Pentium class computer is sufficient to the present task. We used a National Instruments AT-MIO-16X Multi Function I/O card using AT Bus communication to do the data measurements. This board has a large number of 16 bit resolution analog measurement modes as well as digital input and output, multiple timers, internal calibration and analog output capability. To isolate and service the digital addressing lines of the ATC04 assembly test chip, we also used a 24 line parallel digital I/O interface card (Cyber Research CYRDIO24). The multi-function I/O card outputs a selected level of current to a resistor being measured. One differential voltage measurement channel determines the potential on this resistor while a second voltage measurement channel is used to determine the potential on a standard resistor in series with the resistor on the die being measured. The connections to the die resistor are in a four terminal configuration to avoid contributions due to the cables. The results are interpreted to give the die resistance value. For the diode voltage measurements, similar measurements are done but interpreted to give the forward biased potential on the diode that can be calibrated to give the local temperature on that cell of the die.

Software was written in C++ to control the measurement process. The capability to calibrate the system, acquire data in single pass, and capture data in high speed time dependent mode is included. The system sets up the I/O cards for operation, calibrates the voltage measurement system, and then runs in the selected mode. For the high speed measurements, an internal clock is set to run with microsecond resolution and is read periodically for each data sample. The I/O card is sufficiently fast that it can be used in a simple mode where a data acquisition command is issued and the resulting data is read and recorded in memory. For this work we read each of the 225 sensors on the die 10 times, construct an average of these, record the data and move on. At the end of 225 measurements the time is read from the I/O card register and recorded as well. This cycle of all locations on the ATC die and the recording of the data in system memory requires 55 milliseconds. Typically, we run this rate of sampling for a duration of 110 seconds during which the part is molded in the transfer molding press. Accuracy of the resistance measurements with this system is better than 1 part in a thousand although noise considerations will limit this resolution to a lower value in the high speed tests under some of the actual molding press conditions where electrical noise has not been completely isolated.

Results

Initial Test Results

The initial results and data analysis presented here are for the case of a cabled part in place on the press at elevated temperature, but in which the press is not operated. This background test allows us to evaluate the level of resolution available in the measurements. The results are analyzed with pi and alpha coefficients determined near room temperature. The 25 diode thermal sensors are interpreted with a single standard diode calibration curve. Temperatures and several stress parameters derived from the ATC04 resistor arrays for this baseline test are given as examples over a 110 second measurement interval in Figures 7 through 11.

The temperature measurement showed constancy in short and long time intervals. The slight calibration differences between the temperature sensing diodes show up in all these graphs as a pseudo-spread of several degrees over the chip. Relative time resolved temperature can be measured to within 1 degree with our setup as shown in Figure 8.

Figures 10 and 11 indicate the 2 MPa long term reading resolution and the ability to see 0.5 MPa changes on 1 second time scales. These temperature and stress resolutions were sufficient to see those effects needed for code comparison. Straightforward changes to the test chip would allow at least an order of magnitude improvement in resolution (see extensions below).

Measurements during Molding

Figure 12 shows the plot of 25 temperature diodes across the test chip during the molding process. Readings were initiated as the plunger began moving. At 9 seconds the molding fluid enters the IC chamber. At this point the IC uniformly drops in temperature by about 7 degrees. The temperature slowly, but uniformly, re-equilibrates to the mold temperature over the next 13 seconds as the IC cavity is completely filled by mold compound. This lowering in temperature may be due to the pressure relaxation as the compound enters the cavity, evaporation from the moving front of the compound, or to some endothermic reaction (crosslinking) that is beginning in the compound. When the cavity is full, the pressure begins rising around the IC. At this point a partial shunt of our signal occurred and the readings experience an offset and more noise. Compensating for this artifact, the temperature remains fairly constant for the rest of the 95 second process. At this point the mold was quickly opened and the part pried from the metal mold; a quick cooling and reduction in electrical noise is noted on the graph.

It is apparent that all sensors are initially at the same temperature and move together in lockstep throughout this molding cycle. The extent of the isothermal condition was not predicted. Since our test IC covered only a small part of the area being filled with mold compound, it is possible that any temperature gradient was too small to note. We had hoped that the spreading compound would have caused a noticeable temperature gradient so that the fluid front could be mapped in time. The dip in temperature when the molding compound arrives had been noticed before in tests with thermocouples, but was surprising in the 7 degree magnitude. Little local temperature fluctuations occurred.

Unlike the temperature readings, there was a difference in the stress readings taken at different spots over the IC surface during molding. Figure 13 graphs the readings from a cell at the center of the test chip and one at the corner. These voltage readings are inherently weaker than those from the diode thermometers and are more susceptible to noise. By definition the stress level was zero until the compound reached the IC cavity. At this point the readings of both shear sensors rose together. The center cell reached a higher reading than the corner by the time of complete cavity fill. Again, the readings are offset during the compaction phase due to signal shunting in the interconnections. In this case the noise induced was extreme, however, a slight increase in stress can be seen as the compaction phase of molding reached 1000 psi. At 95 seconds the press was quickly opened and the part pried out. In this free standing, post mold condition, the built-in stress of the corner cell is considerably higher than that of the center cell.

One obvious observation is that the stress reaches approximately 17 MPa, and is thus easily monitored by this test chip. A second point is that there are different readings at the different stress monitors so that local conditions are in fact being measured and not some global stress. The built-in stress seen with the corner sensor is consistent with past post-molding readings. This suggests that built-in stresses represent process / geometry induced stresses and are not much reduced or relaxed from the time of manufacture.

Future Extensions

After a few successful molding runs, this study exhausted the funding. Much new understanding could be obtained by repeating the same experiments with different molding compounds, different processing temperatures, and different mold geometries. However, when funded to perform a follow-on study, there are several straightforward improvements to be made.

Although absolute reading accuracy within 2MPa and the relative reading resolution to 0.5MPa provides better computer code validation than exists to date, it is clear that more experimental accuracy can easily be obtained. For example, the stress sensors on the test chip were not designed to provide quick, low noise measurements. They are high in resistance (10K) and thus are sensitive to noise induced in the signal lines and to current leakage effects. Lowering the sensor resistance will reduce this sensitivity, but the sensor self heating will require additions to the measurement system. These additions will switch the sensor current on only when needed to lower the heating duty cycle and avoid heating effects in the test chip.

The ATC04 test chip has a simplified layout which adds the leakage current from the wells of all resistors to any measurement made. Simple redesign where each stress sensing resistor can be independently measured (isolated) would lower the noise at 180 C considerably.

A third improvement is the chip sizing and bond pad placement of the test chip to mimic the product IC. In the above test, the test chip was only about 20% of the area of the product chip for which the leadframe and mold case were designed. Although a computer code can accommodate such a mismatch, it is important to validate the code in the region of expected use, not in a fringe area.

A fourth extension that would help validate computer codes would be the correlation of the stress data with x-ray movies of the filling of the mold chamber. By using aluminum plugs in the steel mold casing, it may be possible to image the IC with the gold bond wires. Using an x-ray die as part of the molding compound filler would allow correlation between the injection front and the stress readings.

Conclusions

Among the discoveries made with this approach:

1.A uniformity of temperature exists across the chip during molding regardless of the distribution of molding compound.

2.A small dip in the temperature of the chip occurs when the molding compound first enters the IC chamber.

3.Shear stress builds up to 20 MPa and differences over the IC surface are up to 10 MPa, even though envelop calculations suggest 2 MPa is enough shear to create adequate flow. (Noise allowed only +- 2 MPa for most measurements).

4.Possible slip and stick flow occurs along the surface.

5.Stress sensors designed for 180 C operation and lower impedance could increase accuracy and reduce noise in readings to reveal another layer of subtleties.

6.Final IC chamber pressure is reached within 10 seconds after the chamber begins filling. Compaction and initial cure take place at final pressure.

Acknowledgments

The authors would like to thank C. Alger of Intel Corpoaration for encouraging remarks that initiated this study. The experiment could not have been preformed without the molding equipment expertise of E. O'Toole and M. Donnelly at Sandia Labs.

***Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.**

References

1. Nguyen, L. T., "Wire Bond Behavior During Molding Operations of Electronic Packages," *Polymer Engineering and Science*, July 1988, Vol. 28, No.14, pp. 926 - 943.
2. Tay, A. A. O., "Simulation of Three-Dimensional Wirebond Deformation During Transfer Molding," *Proc. IEEE ECTC* May 1995, Las Vegas, Nevada, pp999-1004.
3. Kuah, T. H. *et al,* "Simulation Tool Enhances Integrated-Circuit Encapsulation", *Solid State Technology*, pp 83-89, November 1995.
4. Sweet, J. N. *et al,* "Piezoresistive Measurement and FEM Analysis of Mechanical Stresses in Plastic Quad Flat Packs," *Proc. InterPACK '97*, EEP-vol19-2, Kohala Coast, Hawaii, ASME, June 1997, pp 1731-1740.

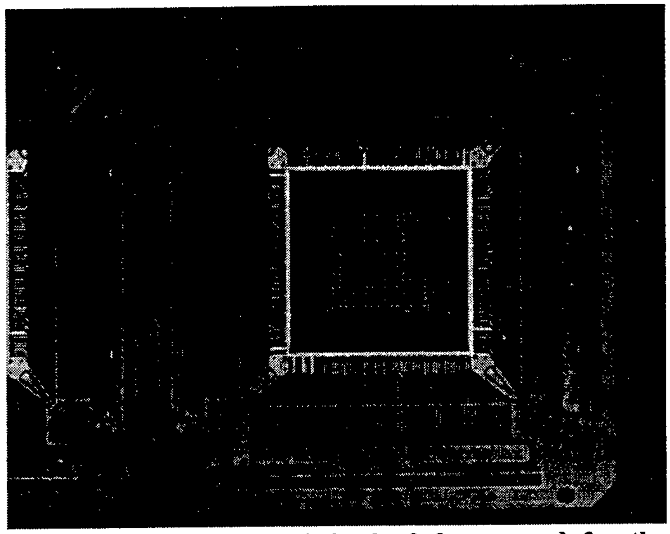

Figure 1. Photograph of the lead frame used for the transfer molding tests. The quad flat package configuration has 296 leads of which 37 are routed out of the mold with a flex cable assembly for in situ real time electrical diagnostic tests. One of the two mold gates (diagonal openings at the upper frame corners) is used to inject the mold compound for these tests

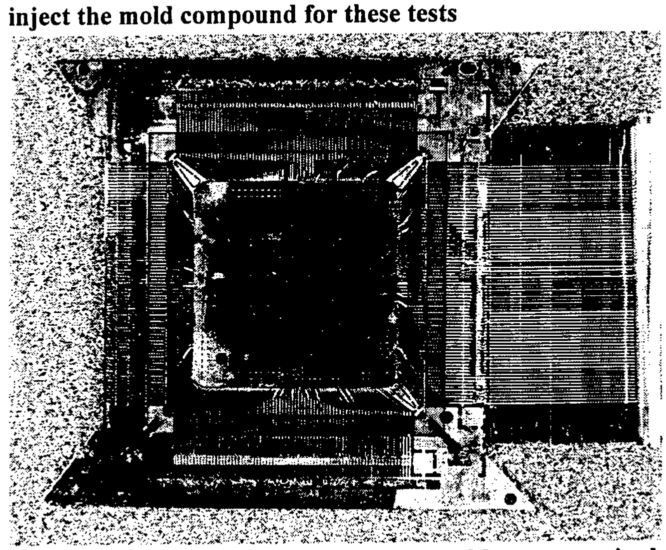

Figure 2. Lead frame showing the assembly cut to a single frame and solder attached to the flex cable. A Kapton frame insulating the leads can be seen around the part coinciding with the position of the mold edges that clamp against the part to seal the mold.

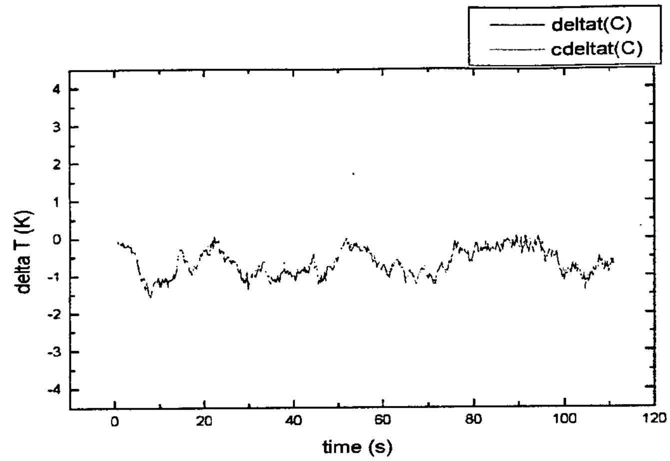

Figure 8. Expanded temperature change plot for the center and corner cell on the die as a function of time over the 110 second sample duration.

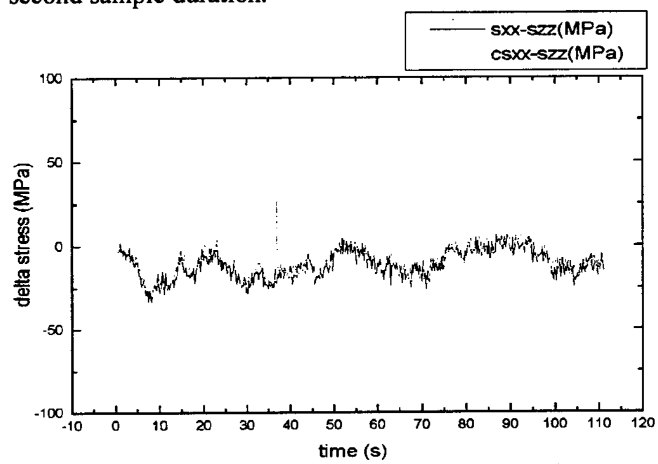

Figure 9. Baseline plot of the time dependence in the difference between the in plane and out of plane compressive stress for a center and a corner cell on the ATC04.

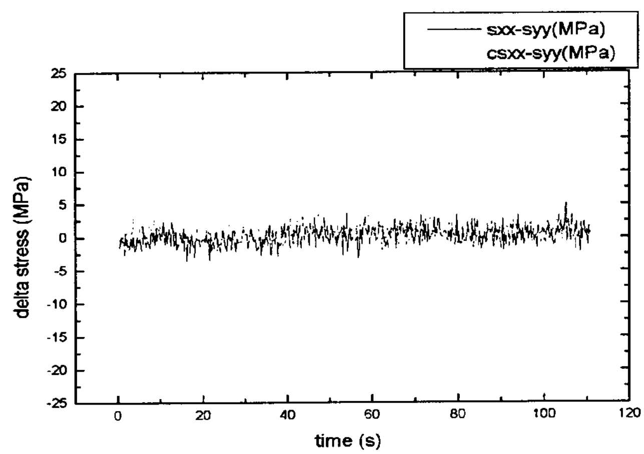

Figure 10. Baseline plot of the time dependence in the two axis in plane compressive stress difference derived from measurements for a center and corner cell on the die.

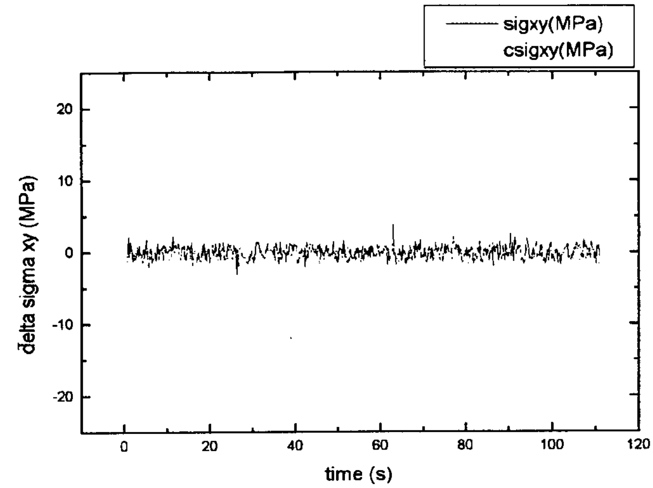

Figure 11. Baseline plot of the in plane shear stress versus time for a center and corner cells on the test die.

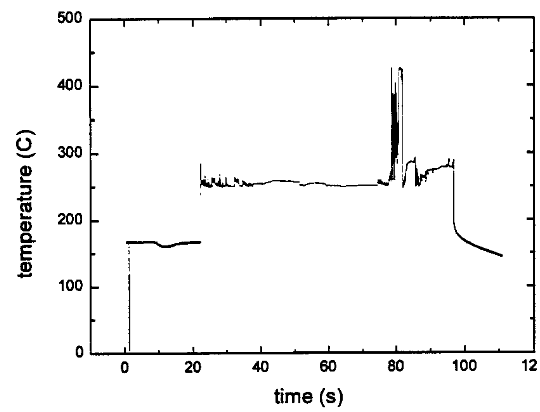

Figure 12. Temperature readings at 25 locations on the surface of the chip during molding process. Note the dip at 9 seconds during cavity fill.

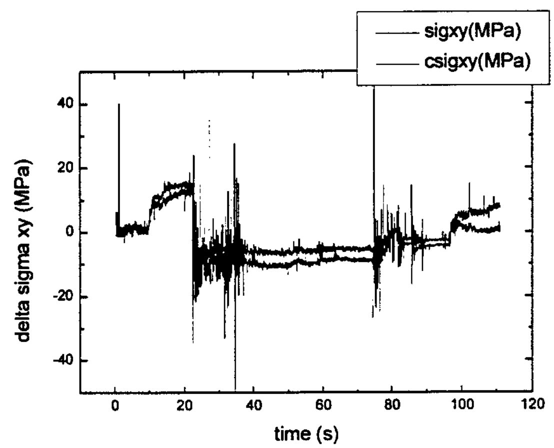

Figure 13. Shear stress measured at two points on the chip during molding. Notice high stress values and built-in residual stress at the end of the test cycle.

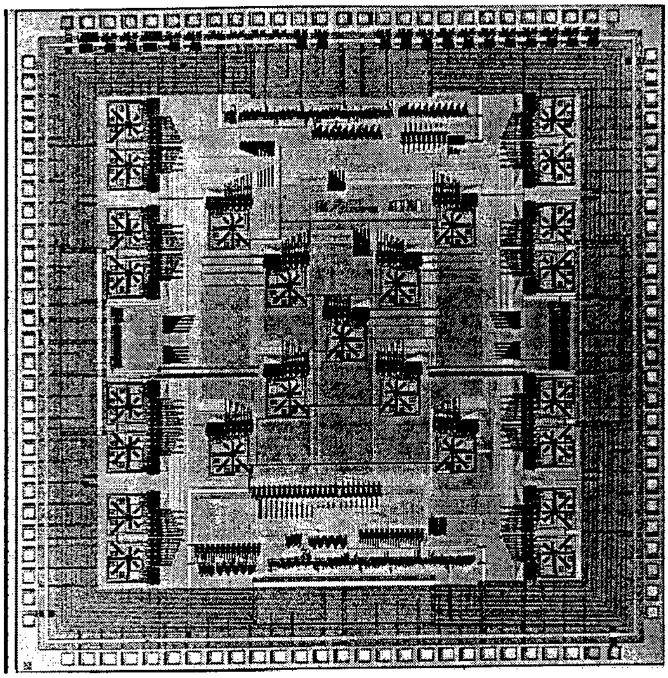

Figure 3. Photo of the Sandia ATC04 Assembly Test Chip. This die has 25 sensor cells spaced over the die area, each with temperature and stress sensors to monitor test conditions.

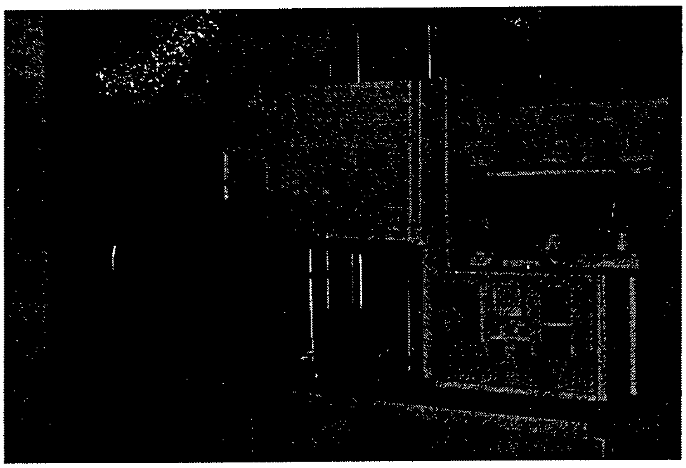

Figure 4. Photo of the Fico MS 100 transfer molding press. This press is designed to mold 8 parts at one time using 8 separate rams to drive compound into each mold section. The press is computer controlled to give a selection of mold temperatures and a programmable ram speed during the transfer of mold compound.

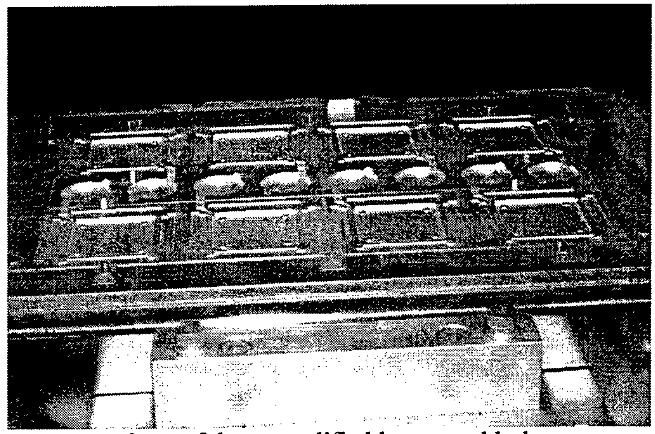

Figure 5. Photo of the unmodified lower mold platen showing the eight lead frame positions and the base of the eight ram cylinders used to heat and press the mold compound. One flow channel connects each base of the ram to each mold section to carry the mold compound to the parts during pressing.

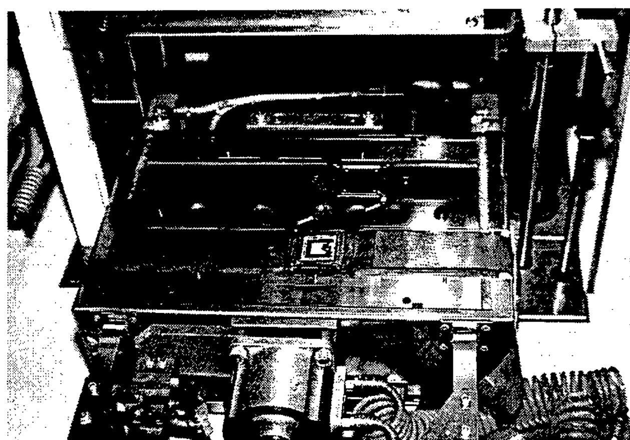

Figure 6. The lead frame and flex cable mounted in the open mold of the press system. During pressing, the lower mold platen moves back into position where it raises to seal against the upper mold platen. The flex cable allows electrical connections to be maintained while the part is pressed in the high temperature environment.

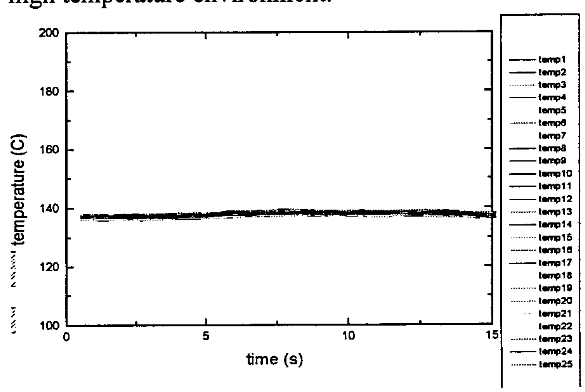

Figure 7. Temperatures for the 25 cells on the ATC04 die as a function of time. Variation in the apparent temperatures over the 110 second interval and among the different cells give an indication of the resolution available in the current testing.

M98002897

Report Number (14) SAND--98-0383C
CONF-980350--

Publ. Date (11) 199802

Sponsor Code (18) DOE/DP, XF

UC Category (19) UC-706, DOE/ER

DOE