The Technology of Molded Multichip Modules

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In the past several years, multichip modules (MCMs) have become cost effective in many high-volume applications, including wireless technologies, telecommunications, workstations, and consumer products. One reason for this success is the development of low-cost and highly reliable packaging techniques. We discuss a packaging technique that permits us to offer customers multichip-module packages that are identical in outline to single-chip semiconductors, and conform to the standards of board assembly manufacturers. Molded MCM packages externally appear to be identical to single-chip packages, but they have a quite different internal structure, which can be ceramic, silicon, or organic laminate-based. MCMs consist of multiple-mounted and interconnected devices that offer integration advantages not available in other packaging technologies. This paper describes the characteristics of AT&T's MCMs, and the technology of molding these structures. This molding technology offers higher reliability, higher yield, and lower cost to manufacture.

Introduction

The increased sophistication of semiconductors has certainly been responsible for the introduction of exciting new products to the marketplace. At the same time, improvements in semiconductor manufacturing technology have lowered costs to a point at which mass-produced consumer products are now feasible that previously would have been too costly.

Industries that depend heavily on semiconductors include automobiles, consumer electronics, telecommunications, and all segments of the computer industry, including main frames, mid-range workstations, and personal computers.

Semiconductors are packaged in one of two ways; hermetic, or non hermetic. Hermetic methods are used for extremely high-reliability applications, including many military and aerospace applications. The most notable disadvantage of this packaging approach is the cost. Such devices are very expensive.

Mass-produced semiconductors are typically packaged by using a transfer-molding process[1] to encapsulate them in an epoxy novalac molding compound, a type of epoxy used in manufacturing integrated circuits. The transfer-molding process preheats the compound, then transfers softened compound under pressure into the mold, where the compound adheres to a leadframe structure in the mold. This process is low in cost, since many devices can be encapsulated at once and the material is inexpensive. As semiconductor passivation, or protective-coating technology, and molding compounds have improved, plastic packages have become increasingly reliable. Thus, plastic packaging has become an extremely important part of the semiconductor industry, contributing to increased component reliability and lower-product costs.

Multichip Modules

The increase in semiconductor sophistication has resulted in the development of silicon devices with upwards of 300 input/outputs (I/Os). Also, a new type of device, known as a multichip module (MCM), has evolved that incorporates multiple

devices on an interconnect fabric. This technology results in modules with much higher-performance characteristics than packages with single-silicon chips. Multichip modules can employ fabrics, or substrates, based on ceramic, silicon, or organic laminates, such as glass-epoxy, polyimide, or triazine. An example of an AT&T MCM is shown in Figure 1b.

Multichip modules were initially packaged in hermetic packages, which increased their reliability, but also increased their cost. Making multichip modules more attractive to mass-market manufacturers involved three basic factors:

- The package format had to correspond to industry standards concerning lead counts, form factors, and printed-circuit board assembly,
- Modules had to be manufactured in high volumes, using low-cost packaging materials, and
- The manufacturing process had to have a high yield, since any defective end products would contain expensive non-reusable active devices.

AT&T's Transfer-Molding Process. AT&T has developed a high-volume MCM technology that deposits multiple layers of conductors on a ceramic substrate.[2] This process is known as MCM-D (deposited) technology. To achieve the goals previously mentioned, AT&T has developed a high-volume plastic packaging technology, in which an entire circuit with multiple devices is packaged in a standard format, using a transfer-molding process. The outside of the package is identical to a single-chip package, but has an internal structure that is considerably different.

The package differences have created numerous challenges in the manufacturing process, and have pushed the technology of packaging materials to new levels. Through the evolution of the MCM plastic-packaging technology, AT&T demonstrated the reliability of these components and developed a road map for MCM packaging materials in the future. AT&T's techniques for the transfer-molding process also focus on maximizing yield and on the quality of the molded parts.

Package Characteristics. In a typical single-chip package, the leadframe has what is known as a die "paddle." This is a support for the die which, in turn, is wire-bonded, using small gold wire, to the fingers of the package leads. Bonding takes place at multiple sites on any given leadframe strip. Leadframe strips are handled in batch form, and are serially fed through processing steps, including die bonding and wire bonding. During molding, multiple strips are placed into a transfer mold. Thus, a single processing cycle results in the encapsulation of multiple silicon devices.

In the leadframe structure that AT&T has adopted for our MCM technology, the internal section of the leadframe has an inner lead configuration (no paddle) that uses high-temperature soldering techniques to attach the leadframe directly to the bonding pads of a circuit. The circuit can include a number of active devices. (See Figure 1b.) AT&T's MCM-circuit substrates were initially ceramic based, but other materials, such as silicon and organic laminates, are now being incorporated as the interconnect medium.

Having such a substrate allows not only for the incorporation of multiple devices, but for differences in the package performance, most notably improved thermal dissipation. A single-chip leadframe conducts heat out of the package in two ways:

- Conduction through the fine wirebonds and the epoxy-molding compound to the lead fingers. The lead fingers travel to the exterior of the package, and are soldered to a printed circuit board.
- Conduction through the epoxy molding compound to the package surface, where heat is removed by air convection.

Benefits of MCM Substrates. AT&T's molded-MCM package contains a ceramic that has a fairly high thermal conductivity. This package spreads heat away from the silicon to the package leads, which are soldered to conductor pads on the film circuit. This spreading capability greatly lowers the thermal resistance of AT&T's MCM
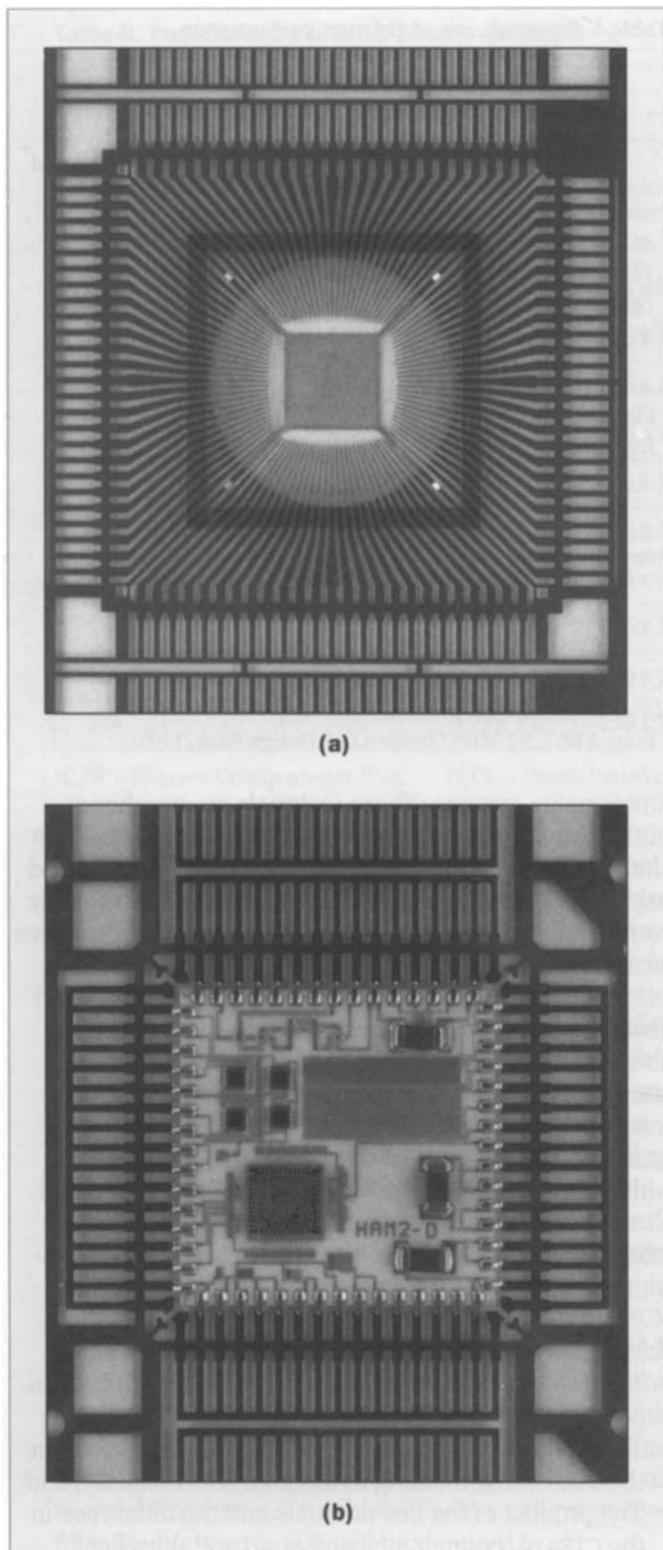
(a)

(b)

Figure 1. In (a), the square "paddle" of a single-chip package is shown in the center of this leadframe, and this paddle has room for only one device. In (b), the leadframe structure AT&T has adopted for its MCM technology is shown. The internal section of the leadframe has an inner lead configuration (no paddle) that uses high-temperature soldering techniques to attach the leadframe directly to the bonding pads of a film circuit. The circuit can include a number of active devices. AT&T's MCM-circuit substrates were initially ceramic based, but other materials, such as silicon and organic laminates, are now being incorporated as the interconnect medium.

packages, and makes them at least 20% superior to conventional single-chip packages with "paddle" leadframes. Table I shows the relative thermal performance of molded MCM-D packages versus conventional single-chip packages. These values have been calculated using finite element simulations.[3]

Further thermal enhancements of this technology also have been developed. In order to improve the thermal conduction of the heat from a silicon chip to the surface of the package, AT&T has developed a technique of molding metallic "heat posts," copper slug heat sinks, into the MCM package. The heat post is attached to the ceramic directly opposite to where the silicon is attached. The "heat post" extends to the surface of the package and provides superior thermal performance when forced air is used for heat removal. Multiple heat posts can be used when more than one chip is present.

The design of the heat posts is critical in maintaining the reliability of the MCM's incorporating them. Temperature-cycling tests provide a major criteria in establishing reliability. These tests require packages to withstand multiple temperature cycles without packaging cracking, device cracking, or device failure. The materials subject to failure include substrates, such as the alumina Al_2O_3 of the MCM circuit substrate. This material has a coefficient of thermal expansion (CTE) of six parts per million, per degree of centigrade (ppm°C), while the molding compound has a CTE near 17 ppm°C. A material for the post has been chosen whose CTE matches that of the molding compound. Further, the cross-sectional geometry of the heat post is such that it will allow for stress relief of the molding compound during temperature excursions. This particular structure will not compromise the reliability of the package. Table II shows the characteristics of the molded MCM-D packages that are

presently in production. Package outlines, which conform to the metric standards and are under development, are reported in Table III.

Material Requirements

The evolution of molding compounds over the past few years has resulted in materials that have excellent characteristics for encapsulating semiconductors. The trends for molding-compound properties include low stress, low levels of impurities, low-moisture absorption, low viscosity at molding temperatures, high-adhesive properties, and resistance to cracking at soldering temperatures.

Because of the fact that there are larger silicon devices (up to .5" × .5") now being considered for plastic packaging, and there is a growing need for low-profile packages with thin cross-sections, molding-compound manufacturers are racing to develop extremely "low-stress" materials. Such materials apply a minimum stress to the silicon, due to differential expansion rates, and must be able to withstand the thermomechanical stresses developed in the plastic themselves.

Low-Stress Molding. As a result, low-stress molding compound technology has been developed to minimize stress by loading the material with low CTE fillers, and by introducing low-stress agents to minimize the flexural modulus, or stiffness, of the material. Multichip modules with a large internal substrate are a particular concern. Experience has taught us that, as the package and substrate size increase, there is a greater risk that the stresses in a package will grow and cause the package to crack during temperature cycling. Table IV is representative of material properties of today's state-of-the-art molding compounds, and indicates the direction of compounds needed to evolve for use in large MCM applications. The table will be discussed in detail elsewhere.

Also, plastic packages are permeable to moisture. Therefore, surface-mount packaging techniques have resulted in other complications, including the well-known "popcorn effect." This is the result of the plastic package absorbing moisture and collecting it at an interface that has delaminated, such as the die paddle. During high-temperature soldering of the package to a printed circuit board, this moisture may turn into steam, which results in the package bulging or even cracking.

To combat these problems, molding-compound manufacturers have developed new resin systems, called solder resistant, based on biphenyl and higher-

Table I. Comparisons of thermal performance.

Thermal Resistance of Molded MCMs Vs. Conventional Molded Packages			
	MCMs	Thermal resistance (per °C/W)	Conventional* molded package
Plastic leaded chip carriers	68	32.3 45.0	28%
	84	30.5 43.0	29%
	100	25.1 40.0	37%
	124	24.7 NA	
Plastic quad flat packs	132	32.1 42.0	23%
	164	29.0 40.0	27%
	196	24.1 NA	
	244	23.1 NA	

Assumptions:
   Natural convection
   1 chip 0.76 X 0.76 centimeter (cm)
   Printed wiring board thermal conductivity = .032 W/cm °C

°C/W = Degrees Centigrade/Watt
NA = Package size not available
* From AT&T .9 CMOS Standard Cell Design Book, 1/90

functionality epoxies. These materials are tougher at high temperatures, and have lower-moisture absorption characteristics, lower modulii at high temperatures, and improved adhesion. Thus, there is a plethora of molding compound alternatives. Table IV summarizes the choices available for molding compounds.

Some of the critical parameters for MCM materials include the coefficient of expansion of the material above and below the glass-transition temperature (the temperature at which the glass softens to the consistency of rubber), the flex modulus, and the glass-transition temperature. Since the stresses generated within MCMs are due to mismatches in CTEs, the materials of choice for large MCMs (that is MCMs with large internal substrates) must have low CTEs and high glass-transition temperatures.

There are three stress values that must be considered:

- The product of the CTE below the glass-transition temperature and the flex modulus,
- The product of the flex modulus and the difference in the CTEs of the molding compound and substrate, and
- The product of the flex modulus and the difference in the CTEs of the molding compound and the silicon.

Table II. Post-molded multichip module packages

I/O pins	Lead type		Package footprint (in.)	Package size (in.)	Usable circuit area (in.)	Thermal parameters			
	PLCC (J-lead) (mils)	PQFP (gull wing) (mils)				Natural convection		Forced convection	
						Thermal resistance (°C/W)	Maximum power (W)	Thermal resistance (°C/W)	Maximum power (W)
68	50	-	0.99 x 0.99	0.95 x 0.95	0.70 x 0.70	32.3	1.9	24.0	2.5
84	50	-	1.19 x 1.19	1.15 x 1.15	0.90 x 0.90	30.5	2.0	18.6	3.2
100	50	-	1.39 x 1.39	1.35 x 1.35	1.10 x 1.10	25.1	2.4	16.4	3.7
100	-	50	1.48 x 1.48	1.35 x 1.35	1.10 x 1.10	-	-	-	-
124	50	-	1.69 x 1.69	1.65 x 1.65	1.40 x 1.40	24.7	2.4	15.4	3.9
124	-	50	1.78 x 1.78	1.65 x 1.65	1.40 x 1.40	-	-	-	-
132	-	25	1.08 x 1.08	0.95 x 0.95	0.70 x 0.70	32.1	1.9	24.0	2.5
164	-	25	1.38 x 1.38	1.15 x 1.15	0.90 x 0.90	29.0	2.1	18.6	3.2
196	-	25	1.48 x 1.48	1.35 x 1.35	1.10 x 1.10	24.1	2.5	15.8	3.8
244	-	25	1.78 x 1.78	1.65 x 1.65	1.40 x 1.40	23.1	2.6	14.3	4.2

°C/W = Degrees Centigrade per Watt   PLCC = Plastic leaded chip carriers   PQFP = Plastic quad flat packs

The goal in low-stress molding compounds is to lower these stress levels. Yet, many of the new surface-mount compounds appearing on the market are designed to resist cracking during infrared reflow, a process of using infrared heat to solder devices to the circuit board. As mentioned, these compounds are designed for greater toughness at high temperatures, to absorb less moisture, and sometimes to have a lower flex modulus at high temperatures. These surface-mount compounds don't necessarily have lower "stress" values than standard "low-stress" compounds. Therefore, selection of a molding compound for an MCM must be carefully done.

The last column in Table IV lists the properties that will be required in molding compounds in future MCM applications. The projected CTE properties, which will be required in molding compounds in future MCM applications, will either be in the high or low end of the range, depending on whether the substrate is ceramic or silicon. For MCM-L (laminate) applications, similar materials will be required. These materials will have very good adhesion characteristics and matching coefficients of thermal expansion. To achieve the low-CTE properties, filler loadings up to 90% will be required.

Stress Analysis. It is well known that the zero stress point of a package becomes locked in at the molding temperature. The higher the mismatch in CTEs, and the lower the glass-transition temperature, the more stress will be generated in the package. This is due to the high-molding temperature and subsequent temperature excursions. Also, the higher the ambient temperature, and the higher the CTE above the glass-transition temperature, the greater the strain or expansion of the molding compound at these high temperatures.

To assist in determining what stress properties are required for molding compounds for MCMs, we have performed a stress analysis of our present largest MCM package. This is the 244-I/O plastic quad flat pack (PQFP), a standard-sized body package that has a 1.5-inch internal ceramic and a plastic body size of 1.65 inches.

A finite element analysis of the molded structure was performed using the ANSYS[3] computer simulation program for stress analysis. (ANSYS is a registered trademark of the Swanson Engineering Co.) The properties of the present compound were used to evaluate stress distributions. As the material properties for the molding compound are nonlinear, effective material

Table III. MCM package outlines that conform to metric standards.

Package Roadmap (Metric Packages)		
Package body size	Lead count	Lead pitch
14 mm X 20 mm +	64	1.00 mm
14 mm X 20 mm +	80	0.80 mm
14 mm X 20 mm +	100	0.65 mm
28 mm X 28 mm +*	108	1.00 mm
28 mm X 28 mm +*	128	0.80 mm
28 mm X 28 mm +*	160	0.65 mm
28 mm X 28 mm +*	208	0.50 mm
32 mm X 32 mm *	240	0.50 mm
40 mm X 40 mm *	304	0.50 mm

Package Roadmap (BGA) **		
Package body size	Number of I/Os	Solder ball pitch
17 mm X 17 mm	169	1.27 mm
25 mm X 25 mm	100	.100 inch
27 mm X 27 mm	252	1.00 mm
40 mm X 40 mm	400	1.00 mm
50 mm X 50 mm	620	1.00 mm

+ 2.80 mm-thick quad flat pack (QFP) and 1.40 mm-thick thin QFP
* With and without molded carrier ring (MCR)
** Package types will evolve with standards

properties were used so that a linear elastic analysis could be performed. For this analysis, three properties were required:
- α - the coefficient of linear expansion,
- E- the modulus, and
- v - the poisson's ratio.

An effective coefficient of expansion was chosen, based on the requirement that the total strain imposed for the temperature drop must be equivalent to the actual strain experienced by a test specimen as measured by thermomechanical analysis (TMA). Over the temperature range from 170 C to -40 C , α_e=21.4 ppm°C. The poisson's ratio (the measurement in the differences of a property in an orthogonal, or perpendicular, direction) was taken from the literature to be .35. An effective modulus was calculated by using a method developed by Sullivan[5].

We studied the maximum shear-stress calculations of the package and found stresses up to 13,500 psi.

The highest stress occurs at the corner of the ceramic. There is a clear increase in stress at the thinner side of the package, when the package has a nonsymmetric substrate. Here, the principal stresses are up to 7000 psi, and the package with the offset ceramic will clearly have a higher tendency to have a crack initiated at the package surface. The maximum principal stress and the maximum principal strain are around .006 inch per inch (in/in). This is somewhat less than the measured value of .007 in/in for both tensile and flex tests.

In evaluating the stresses in larger packages with a ceramic size of 1.5 inches × 3.0 inches, we found stresses that are no higher than in the previous case. Also, it should be noted that the stresses no longer increase with larger substrate sizes, but are redistributed.

The above stresses are lower than the critical values reported by molding-compound vendors, but are within 10% of those values. These packages have been

Table IV. Choices available for molding compounds

	Present Low Stress	Present Lower Stress	Solder Resistant Type 1	Solder Resistant Type 2	Future
$\alpha 1 \times 10\text{-}5$ (in/in/°C)	1.5-1.9	1.2-1.4	1.4-1.6	1.2-1.4	.3-.8
$\alpha 2 \times 10\text{-}5$ (in/in/°C)	6.0-7.0	6.0-7.0	6.0-7.0	5.0-6.0	3.0-6.0
Tg (°C)	150-170	160-180	180-195	150-160	180-220
Flex Mod. (kg/mm²)	1100-1300	1000-1200	1100-1300	1700-1900	1500-1800
Stress (AVG) ($\alpha \times E$)	2040	1430	1800	2340	1900
Stress(AVG) $(\alpha - \alpha_s)E$	1680	1100	1440	1800	400
Stress(AVG) $(\alpha - \alpha_c)E$	1320	770	1080	1260	80

temperature-cycled over 1000 cycles without failures and, therefore, the stress results seem correct. Lower-stress materials will provide an even larger margin for post-molded MCM packages. Post-molded packages with silicon substrates will have higher stress levels and, therefore, much care will be required in selecting a molding compound for packages with large silicon substrates.

Transfer Molding Technology

Transfer molding has been used in the encapsulation of single-chip circuits for many years. Traditional production-transfer molding has involved a multicavity mold, which is driven by a single ram, or plunger. The multiple cavities are filled by long runners, channels in the mold that direct the flow of the compounds (see Figure 2). Due to geometry and the desire to manufacture as many parts per cycle as possible, common-mold designs often result in "unbalanced" configurations. In these cases, the cavities in the mold fill at different rates, and the material is at different temperatures, shear states, cure conditions and, hence, viscosities, as it enters different cavities.

Multiplunger Molding. In recent years, multi-plunger molding technology has gained widespread acceptance in the industry. This technology involves feeding a cavity with one or two small plungers, thereby eliminating the common feed runner and, hence, theoretically allowing for each cavity to fill under the same molding conditions. Multiplunger molds are typically two or four strips, as opposed to the many strips in a conventional mold. Therefore, new "rapid-cure" materials were developed to lower the cycle time and improve throughput.

These multiplunger systems do not completely cure the "balance" problems associated with conventional mold design and production processing. Specifically, most multiplunger systems are driven by either mechanical springs or hydraulic systems, which are not controlled individually. This means each ram may produce a different process profile at a given time. Also, the multiplunger systems currently available do not provide direct pressure control, and thus do not provide for applying pre-programmed "packing" profiles to the mold cavities.

What multiplunger systems do provide is the ability to apply high pressures inside the mold cavity. This produces higher-density parts than can be achieved by a conventional mold with a long runner system. Also, minipellets of the molding compound are used in these processes. These pellets are not preheated as in conventional molds. The short-runner lengths do not provide much time for heating the molding compound prior to its
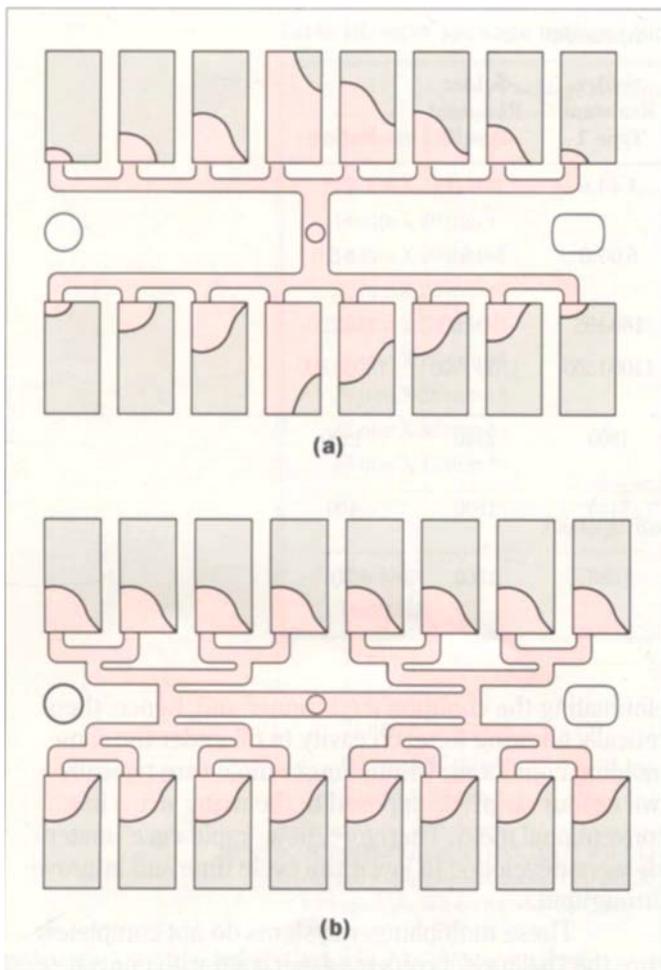
Figure 2. (a) Half of a mold with an unbalanced cavity configuration. Here, 16 cavities are filled by a single ram, but the mold geometry causes each cavity to fill at a different rate. The center cavities fill first, while the outside cavities lag behind, which produces more defective parts in the center cavities than the outside cavities. (b) A new mold design, in which a runner is designed to provide more equal temperature and shear conditions to the material being distributed among the 16 cavities.

injection into the mold cavity. Also, with large packages, more than one ram/pot combination may be required for each cavity. This creates more process-control problems than when one ram is used for each cavity. Also, as productivity is gained using rapid cure materials, the

process window may not be as wide with multiplunger molding as with conventional molding.

Thus, multiplunger molding does not solve all the engineering issues associated with mold design/process design for high-volume production. Whether multiplunger or single-ram techniques are utilized is not the issue. The heart of the molding problem is assuring that the molding compound experiences temperature and shear profiles that are within a particular window. Assuring that these profiles are controlled consistently, and with proper accuracy, will result in minimum molding defects.

AT&T's approach in MCM production molding is to concentrate on developing a mold for a given package with as wide a process window as possible. We then apply process control to achieve as uniform a process as possible. The discussion that follows addresses the design of a production mold for multichip modules.

Unbalanced Mold Systems. In an unbalanced system, the molding compound entering each cavity has unequal material properties. The important properties for filling[6] are viscosity and velocity. It is well known that the higher the product of the velocity and the viscosity, the greater the chance of wiresweep—the tendency of compounds whose viscosity is too high to push the wires together, rather than flow over them. What is not well understood is the relationship of these properties with respect to voids, or bubbles, which are a major reliability concern. What is known is that the pressure inside a mold cavity is proportional to the number and size of voids resulting in the plastic package.[7] Also, if the pressure varies, molding results will vary from cavity to cavity.

Typical unbalanced molds have been studied to determine the differences in the temperature of the molding material flowing down a long runner system and entering different cavities. The differences in temperature between the cavity closest to the cull, the point where the material enters the mold, versus the temperature of the material entering the furthest cavity, is in the range of 40°C.[6]

In order to understand the pressure profiles inside each cavity of a mold with an unbalanced runner, we built an experimental test setup. This included a capillary-pressure transducer, which was connected to a real-time, data-acquisition system. A process controller was used to control mold-filling characteristics, and a

(a)

(b)

100.0	103.5	110.5	117.5	124.5	131.5	138.5	145.5	152.5
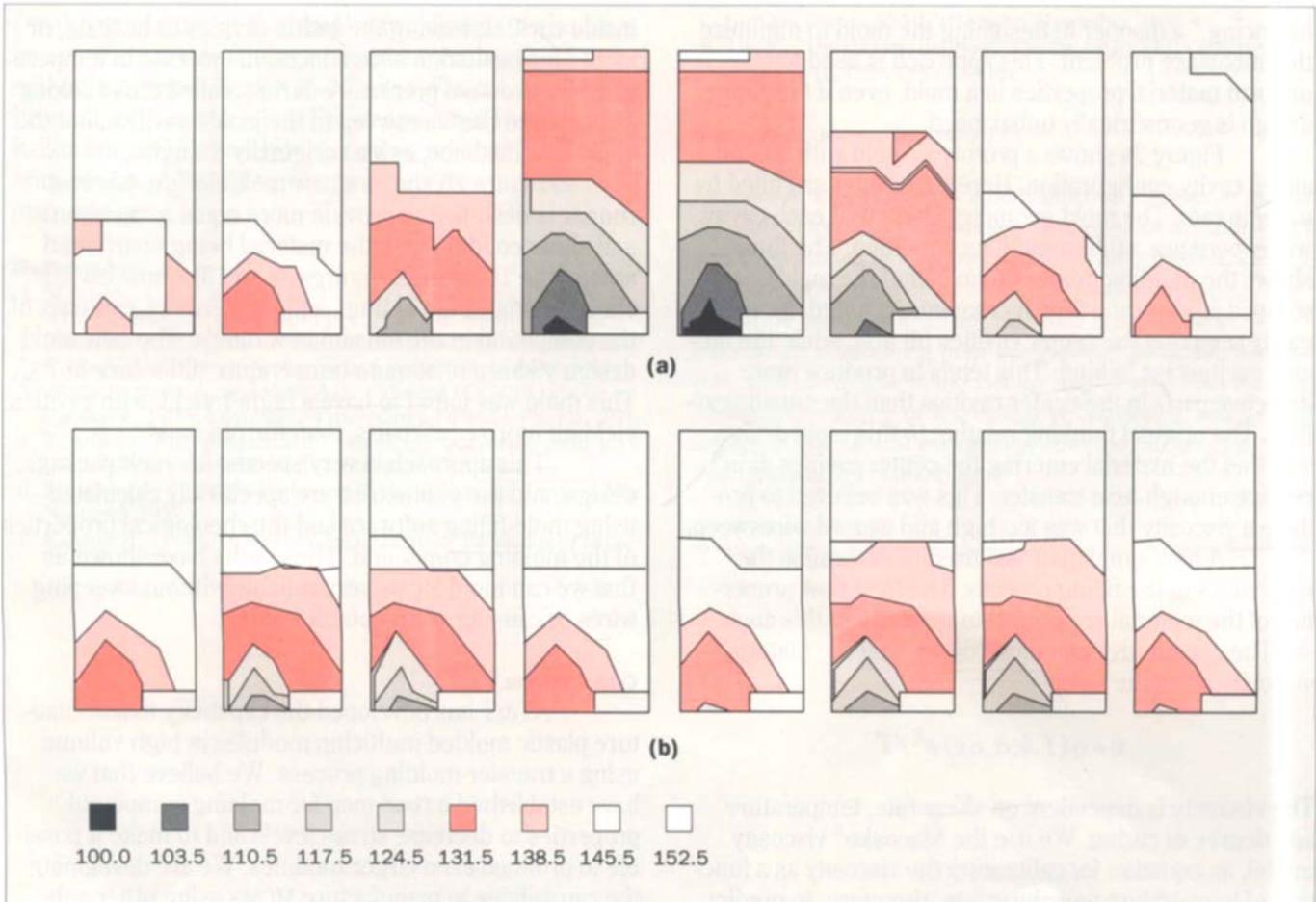
specific pressure profile was used to drive the ram. For each cavity, the data was accumulated and the pressure was measured at individual mold cavities as a function of time.

The plots clearly show a different pressure profile in each cavity. Even more importantly, the pressure is seen to drop off significantly early in the cavity farthest from the pot. It is clear that the only cavities that see the full packing profile are those closest to the cull.

We conclude that the material that travels the farthest receives the most heat transfer and, thus, will tend to cure more rapidly, particularly in the gate area. The fact that the temperature of the material is unequal as the material enters each cavity not only generates potential filling problems, but will also impact how the parts behave during the critical packing cycle. Thus,

Figure 3. These two computer-generated illustrations show isochrones—snapshots in time—and temperature contours of the compound in both the old and new molds. In (a), the cavities fill at unequal rates (as shown in Figure 2a), and this causes wide temperature variations of the compund in each cavity. In (b), the new mold design yields a maximum temperature difference of 7°C. This mold was found to have a higher yield, with cavities yielding more equal parts, than the old mold.

good tool design is critical for the manufacture of uniform and reliable plastic-molded multichip modules.

Multichip Module Mold Design

The approach that we've applied to production molding of multichip modules involves "viscosity

balancing," a manner of designing the mold to minimize the imbalance problem. This approach is used to achieve uniform material properties in a mold, even if the runner design is geometrically unbalanced.

Figure 2a shows a prototype mold with an unbalanced cavity configuration. Here, 16 cavities are filled by a single ram. The mold geometry infers that each cavity will experience a different filling condition. The figure shows the molding process (one half of the mold) stopped at a specific time increment. As noted, it can be easily seen that the center cavities fill first, while the outside cavities lag behind. This tends to produce more defective parts in the center cavities than the outside cavities. The original thinking relating to this mold design was that the material entering the center cavities didn't receive enough heat transfer. This was believed to produce a viscosity that was too high and caused wiresweep.

A flow simulation was used to determine the mechanics of the filling process. The fluid-flow properties of the material are critical to performing this analysis. The constitutive equations describing the material viscosity takes the form:

$$\eta = \eta\,(T, \dot{\gamma}, \alpha, \alpha g)\,e^{E}/T$$

The viscosity is dependent on shear rate, temperature and degree of curing. We use the Macosko[8] viscosity model, an equation for calibrating the viscosity as a function of temperature and shear rate, therefore, to predict the chemorheology of this thermosetting resin:

$$\eta = A\dot{\gamma}^{B}e^{C/T}[\alpha g/(\alpha g - \alpha)]^{D+E\alpha}$$

where

> E = activation energy
> A = viscosity factor
> B = shear factor
> C = temperature factor
> D = reactivity factor
> α = degree of conversion
> αg = gel point
> $\dot{\gamma}$ = shear rate

Using the above rheology, we found, for example, isochrones and temperature profiles at 60% of the fill level had a temperature imbalance of about 27°C between the inner and outer cavity. The simulation showed that the outside cavities actually advanced in filling beyond the

inside cavities, leaving the inside cavities to hesitate, or stop. This hesitation allowed a rapid increase in temperature and eventual premature curing, called cross-linking. This caused the wiresweep in the inside cavities, not the short flow distance, as was originally thought.

Figure 2b shows a new mold design, where a runner is designed to provide more equal temperature and shear conditions to the material being distributed among the 16 cavities. Figures 3a and 3b show isochrones, snapshots in time, and temperature contours of the compound in the old and new molds. The new mold design yields a maximum temperature difference of 7°C. This mold was found to have a higher yield, with cavities yielding more equal parts, than the old mold.

This approach is very specific for each package design, and the geometries are specifically calculated using mold-filling software and the rheological properties of the molding compound. The results have shown us that we can mold MCMs very reliably without sweeping wires or causing unacceptable voids.

Conclusions

AT&T has developed the capability to manufacture plastic molded-multichip modules in high volume using a transfer-molding process. We believe that we have established a road map for molding-compound properties to decrease stress levels and to make it possible to produce even larger modules. We are developing the capabilities to manufacture MCMs using other substrates, such as silicon and laminate-based materials, and are optimizing the materials and molding technologies for maximum product reliability and high yields.

It is clear that the production equipment available today needs to be refined to mold the complicated high I/O MCMs of the future. Better process control, better mold design, and an improved understanding of the molding process is essential in assuring a six-sigma molding process, that is, multichip modules that have 3.4 defects per million—the highest level of quality in the semiconductor device industry.

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