CUSTOMIZABLE MULTICHIP MODULES FOR HIGH-G TELEMETRY APPLICATIONS

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ABSTRACT

The Microelectronics and Computer Technology Corporation (MCC) has developed a rapid turn around process for fabricating multichip modules (MCM's) called the Flexible Manufacturing of MCM's (FMM). The Army Research Lab (ARL) in co-operation with the Applied Physics Laboratory (APL), has investigated the survivability of this technology in high-g applications. Comparisons were made to other packaging technologies by constructing a 3-channel digital recorder in this and two other competing technologies.

KEY WORDS

Telemetry, multichip modules, copper-polyimide, high-g, digital recorder, and in-bore

INTRODUCTION

Telemetry for projectiles such as artillery and tank fired rounds has always been a challenging task. There is much less space available than on missiles. The available volume in a standard ARL package replacing the nose fuse of an artillery projectile is about 8 cubic inches. The space required for the battery, transmitter and antenna is 6.5 cubic inches, leaving only about 1.5 cubic inches for electronics and sensors. Available volume is much less for a kinetic energy (KE) penetrator. Typically the only space available is in the tracer well, which is about one quarter of a cubic inch. Clearly, high density packaging is required.

A possible solution to the space limitations is to use a Multi-Chip Module (MCM). This packaging technology uses unpackaged die interconnected to a substrate in which very fine traces are placed. Typically MCM substrates are made using a set of photo-masks to define the circuitry. The process is time consuming and expensive. It is also very difficult to find a vendor willing to make the small quantities used for custom telemetry systems.

The Microelectronics and Computer Technology Corporation (MCC) has developed a rapid turn around process for fabricating copper-polyimide MCM's called the Flexible Manufacturing of MCM's (FMM). The advantage of this technology is that the substrate comes with a weave of signal interconnection traces built in. Linking and cutting these traces at the appropriate locations then programs, or customizes the circuitry required for a particular application. The FMM process is perfect for the quick turn around and small quantity requirements of custom telemetry systems. Once a design is standardized, it can be transferred into a high volume manufacturing process with no re-design.

Space is not the only requirement that must be met. The environment in a gun-launched projectile is very harsh. The launch accelerations start at 10,000 g's for artillery and can reach 100,000 g's in an advanced KE penetrator. An artillery round can spin up from rest to 18,000 rpm in less than 15 milliseconds. This is the main subject of this paper: can the FMM technology survive these extreme conditions?

First the FMM process and its advantages are described. Next the high-g qualification process is covered. Finally an implementation of a digital recorder designed to capture the accelerations experienced by a projectile while it is still in the gun's bore is presented. This in-bore recorder design was duplicated with surface mount technology and another MCM technology called MCM-D to explore packaging efficiency and other design tradeoffs.

FMM TECHNOLOGY DESCRIPTION

I. MCM Rapid Prototyping Background

The generic base substrate consists of four metal and three dielectric thin film layers built up on 96% Al_2O_3 ceramic. The bottom two layers contain diagonal interwoven strips interconnected to form 4 different potential reference planes. The top two layers are used for the signal lines which are formed by a weave type routing configuration utilizing wiring segments 320 um long on each of the layers. The top metal layer also contains a "sea" of 120 um octagon shaped wirebond pads on 320 μm pitch. Details of the "sea" of bond pads and signal wiring layer are shown in Figure 1. Half of the bond pads are connected directly, through vias, to the reference planes; the other half are designed to be used as the signal wirebond pads and are used as the nodes for the custom FMM autorouter. The top metal layer is gold, so that wirebonding can be done from ICs to the bond pads. This MCM-D thin film technology produces lines of known impedance [1]. The characteristic impedance of the signal lines is approximately 50 ohms, the line resistance is 1.5 ohms/cm, and the line capacitance is 2 pF/cm.

The transmission characteristics of the signal lines have been measured using Cascade Microtech coplanar wafer probes and the -3 dB roll-off frequency was 900 MHz for a 46 mm long signal line structure, making these rapid-prototype substrates well-suited for use in mixed signal applications [2, 5].

The MCM programming procedure consists of a laser direct-write process for both subtractive and additive metallization. The subtractive, or "cutting," process is used to divide the continuous X or Y substrate-long signal wires into shorter segments at the narrow regions on the top surface, thus removing only a very small section of metallization. The additive processes are then used to rejoin, or "link," the divided segments into the design-specific nets, again by only adding small sections of metal. The semi-custom wiring grid is designed to minimize the total number of laser operations that are required to implement an MCM design, basically 1 link and 2 cuts to turn each 90 degree corner, or 1 link and 1 cut to connect to a net node or substrate bond pad. This leads to the lowest cost with the highest reliability.

MCC developed an autorouter for use with this generic pre-fabricated thin film multi-chip module technology, (A recent version autorouter for use with Windows based PCs is now available). The router has been integrated into a design tool that facilitates rapid turn-around of MCM designs. The tool routes the MCM and generates the cut and link control files used to program the substrate.

In going from prototype volumes to higher volumes, neither the chip placement nor the wiring topology is changed. Only the customization process differs, in that a photomask and an IC type photoaligner are used to pattern the top metal layer of the substrate. Thus, the performance insights gained from prototyping are directly transferable to higher production quantities[3].

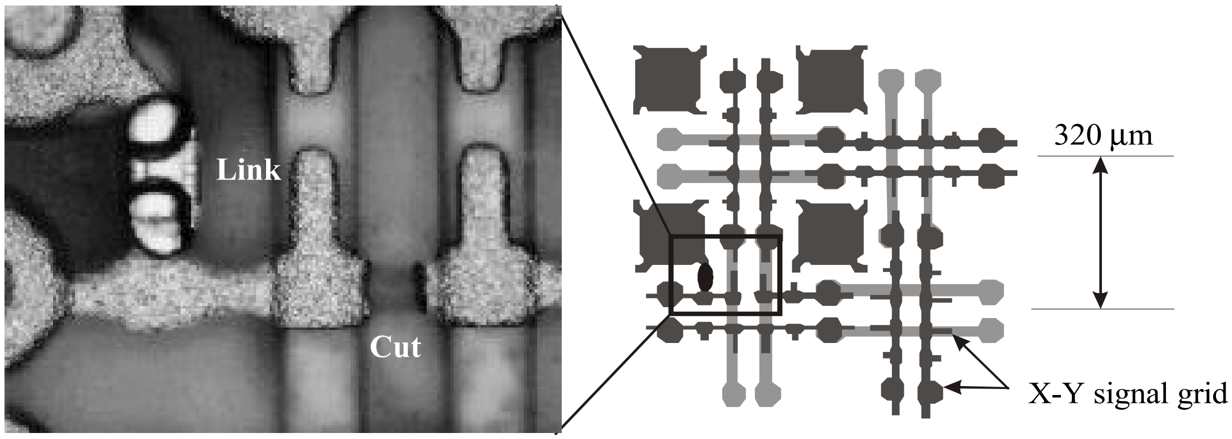

Figure 1. Micrograph (left) and schematic (right) of the MCM signal wiring layers. The layout includes a "sea" of bond pads with a 320µm period. A link and a cut are shown, connecting a signal line with a bond pad.

II. Rapid Prototype Flip Chip Development

To enable flip chip bare die assembly, rerouting from the fixed bond pad grid of the MCM wiring layer to landing pads is required. A new process was developed to perform this function without the use of photomasks[4]. This "reroute layer" process has been expanded to create solder pads for surface mount technology (SMT) devices and I/O wiring. Figure 2 is a micrograph of a substrate with an SMT capacitor attached.

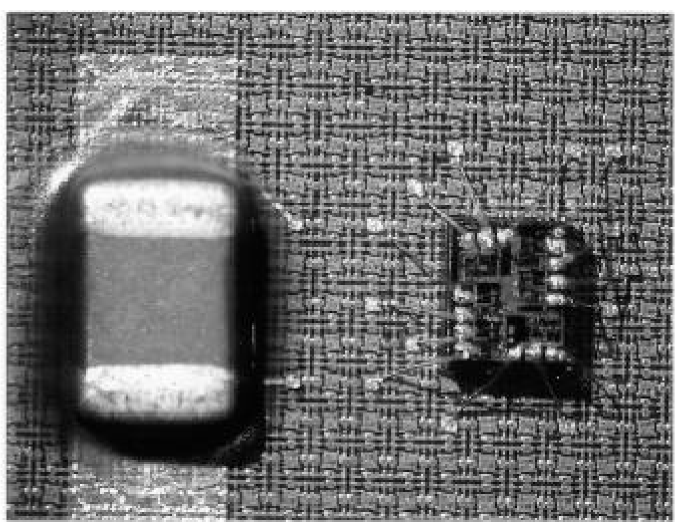

Figure 2. Micrograph of SMT capacitor attached to "reroute layer".

HIGH-G QUALIFICATION

The ARL shock table was utilized to pre-qualify the MCC FMM substrate for high-g applications up to 30,000 g's. This simulator uses elastic cords to accelerate a test item mounted to a table. This table strikes an anvil covered with a thin felt mitigator. The resulting deceleration shocks the item under test with loads of up to 30,000 g's. Figure 3 is a diagram of the simulator.

The first tests of this substrate were of a bare substrate mounted to a stainless steel plate. The purpose of these tests were to verify that the internal structures (links, cuts, vias and signal lines) of the FMM substrates would survive high-g accelerations. Failures associated with the adhesion of the ceramic MCM to the stainless steel backing plate were experienced until an adhesive with the correct properties was found. The adhesive that provided the best survivability was Torr Seal by Varian Vacuum Products. With Torr Seal the substrates survived reliably to 30,000 g's.

The next phase of the program was to test the substrate with a simple circuit consisting of a 7404 hex inverter and a capacitor. This is the same circuit as shown in Figure 2. The wirebonds were done with a ball bonder and were made with 1-mil gold wire. The wirebonds were covered in glob-top to protect them in handling. The purpose of these tests was to verify that the customized copper-polyimide interconnect, standard die bonding and wire bonding practices could survive high-g loading. The substrates were exposed to shocks of up to 30,000 g's with no die attachment or wirebond failures.

The final test discussed in this paper involved mounting the MCM (with the circuit shown in figure 2) to a printed circuit board to simulate how an MCM would actually be mounted. Torr Seal was used to adhere the substrate to the FR-4 circuit board material. 30-gage wire was soldered from the I/O pads on the substrate to pads on the circuit board. The circuit board and substrate were placed in a fixture and encapsulated in clear epoxy (EnviroTex Lite). This is similar to how circuitry is actually packaged in a projectile, the main difference being the type of encapsulant. The preferred encapsulant, Stycast 10 90-SI, is black however, and makes inspection after testing more difficult. The assembly was subjected to eight shocks ranging from 10,000 g's to 30,000 g's. No failures were observed.

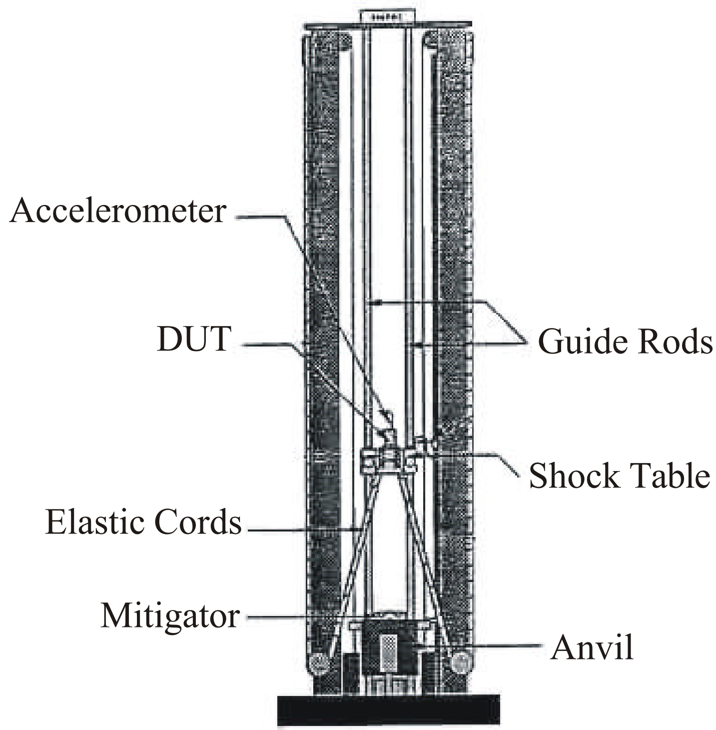

Figure 3. ARL shock table

IN-BORE DIGITAL RECORDER IMPLEMENTATION

I Circuit Description.

The final phase of this study was to implement a practical circuit in the FMM technology and compare this package to other types of packaging. A 3-channel digital recorder was chosen because it mixed analog and digital signals and was complex enough to be a challenge to implement in a small package.

The circuit design was intended to capture data while the projectile was in the bore of the gun. After the projectile clears the bore, the data will be sent back to a ground station via an analog telemetry link. The circuit accomplishes this task by digitally recording the data in memory when triggered by a g-switch. Once the data is stored, the memory is read and converted back to an analog signal. To accommodate the limited bandwidth of the transmitter, the data is read at one tenth the rate at which it was stored. Also, the data is played back in a continuous loop to enhance the probability that the data will not be lost due to an interruption of the telemetry link. Specifications for this design are 300kHz digitizing rate at 12-bit resolution and 30kHz playback rate for an effective data bandwidth of 60kHz.

The design for the circuit was generated at ARL and sent to MCC for the manufacturing of the substrates. The assembly and electrical testing of the MCM was done at APL. The MCM was returned to ARL where it was mounted to a circuit board containing the signal conditioning and power regulation. Figure 4 is a picture of the completed MCM attached to the circuit board.

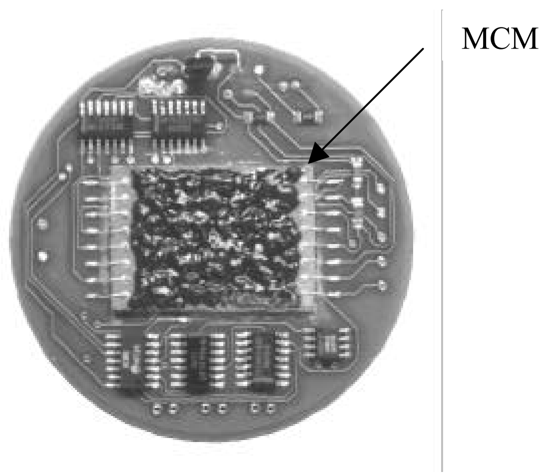

Figure 4. Completed In-bore Recorder.

II Comparisons to Other Technologies.

Two other packaging technologies were looked at to provide comparisons to the present standard packaging and to the highest density packaging available.

Surface mount technology (SMT) is presently the most common form of packaging used today. It provides a factor of 3 to 4 in packaging density over through-hole components. ARL built a copy of the in-bore recorder circuit using SMT. This circuitry included the same signal conditioning and power regulation that the MCM version used. As can be seen from Figure 5, the MCM packaged circuit provided an overall packing density gain of 4 to 1. The packaging density of the MCM itself was more than 25 times denser than SMT.

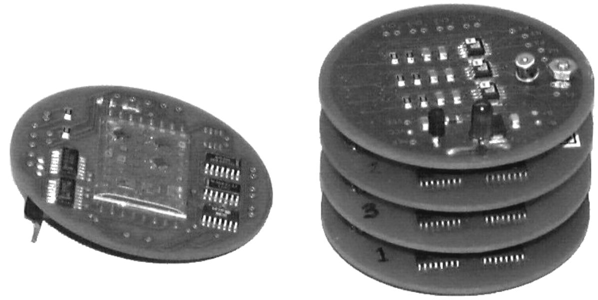

Figure 5. MCM (left) and SMT (right) versions of the in-bore recorder.

The most aggressive form of die-level packing at this time uses an interconnect technology called MCM-D in which the D stands for “deposited” dielectric and conductor layers. This technology uses the same type of thin-film technology as the FMM base substrates. The difference is that each circuit design requires a custom interconnect design. APL agreed to build an MCM-D version of the in-bore recorder. The process is still not complete but the design work is finished. The design, shown below in Figure 6, is slightly smaller than the FMM design in actual area occupied by the IC devices. The main difference is in the area taken up by the I/O pads. The FMM design incorporates solderable pads while the MCM-D design uses much smaller pads designed for wirebonding. The overall size of the MCM-D design is 1” by 0.86” and the size of the FMM design is 1.25” by 0.86”.

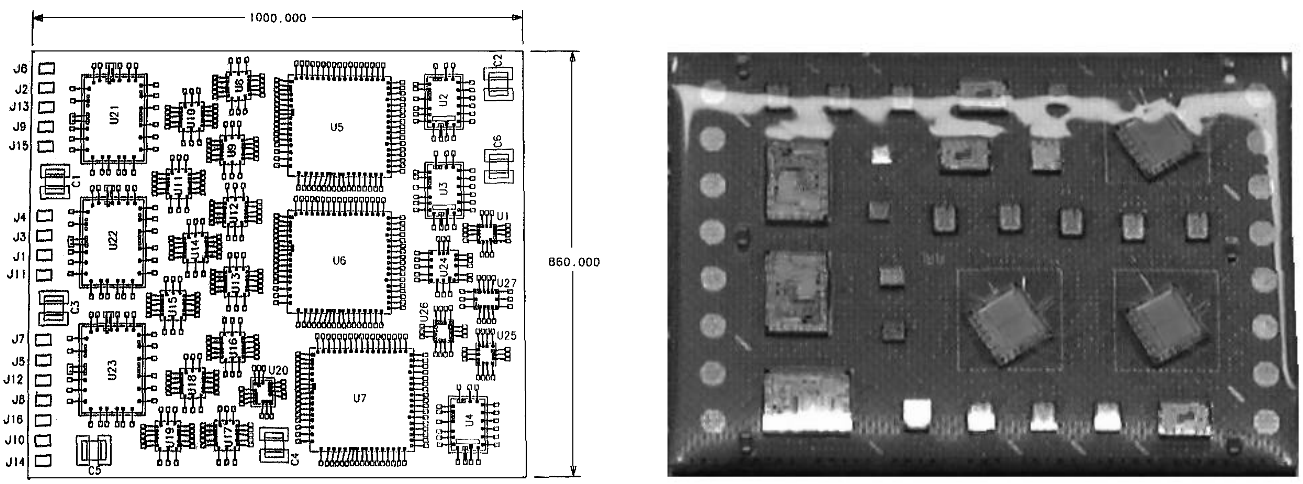

Figure 6. MCM-D (left) and FMM (right) versions of the in-bore recorder MCM. Both MCM’s are to the same scale.

MCM-D does have a small advantage in package density, but it is more time consuming to implement. The FMM process is implemented on a generic substrate that is already on hand. Typically, there is about a one week design phase and then a two to three week manufacturing phase depending on whether or not a reroute layer is required. The MCM-D process requires a minimum of eight weeks for a standard 5-layer design.

CONCLUSIONS

The MCC FMM technology is a viable solution to the requirements of modern high-g telemetry systems. Preliminary testing has shown that it can survive the harsh acceleration environment found in gun launched projectiles and can provide packaging densities approaching that of the most state-of-the-art technology available today. The quick turn around time associated with this technology makes it ideal for those tests requiring a custom design in a small package as fast as possible.

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