LOW-COST PACKAGE TECHNOLOGY FOR ADVANCED MMIC APPLICATIONS*

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ABSTRACT

Availability of MMICs along with expanded applications for microwave components, places increasing demands on performance and cost of package technology. We report progress in meeting these demands with metal-injection molding (MIM) of metal-matrix composites for advanced microwave packaging technology. We present our experiences in developing this technology, including dimensional control, plating, hermeticity, and cost. Electrical performance of packaged multi-chip amplifiers operating 2-20 GHz is also described.

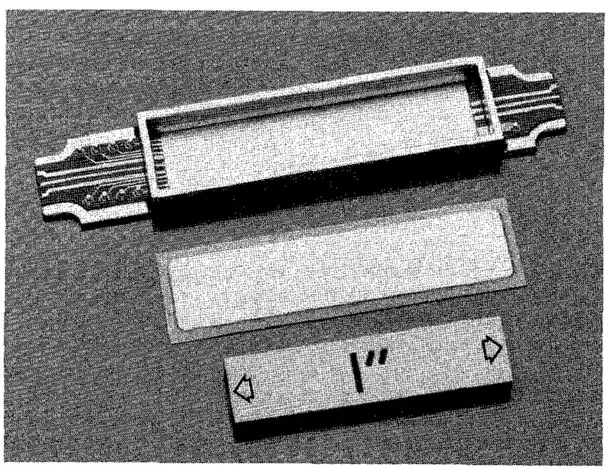

Figure 1:
Photograph of package. This particular design is approximately 2" long, 0.35" wide and 0.15" high. The shell is metal injection molded of W-Cu as one piece including slots in the ends into which the metallized alumina feedthrus are brazed. The lid is a standard-design step lid.

The increasing availability of MMICs along with other advances in microwave and millimeter-wave technology, coupled with expanding applications, present new performance and cost challenges for package technology, which must advance in parallel. Packages for microwave modules must be low cost, smaller and more precise, incorporate more complex electrical feedthrus with better microwave performance, as well as provide compatible thermal expansion, good heat removal, and environmental protection. Packages also need to be compatible with high-volume (automated) assembly, sealing and testing.

We are evaluating various materials and fabrication methods to develop a generic precision package technology suitable for both single-chip and multi-chip modules.

Our design objectives for these packages are

1) low cost and manufacturability in volume
2) high dimensional precision for repeatable assembly and characteristics
3) small size and light weight
4) high thermal conductivity, $\geq$200 W/^{o}C-m to accommodate high power circuits
5) a thermal expansion coefficient of $\approx 6 \times 10^{-6}/^oC$ to match GaAs and alumina or aluminum nitride substrates, allowing them to be directly bonded to the package floor
6) planar stripline/microstrip compatible feedthrus

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7) good microwave performance to 20 GHz: feedthru loss $\leq$0.4 dB per feedthru, return loss $\geq$15 dB ($\leq$1.4:1 VSWR) for the total package with a 50 ohm thru line; input-output isolation $\geq$60 dB

8) good shielding against electromagnetic interference or coupling

9) environmental integrity (temperature, humidity, shock, vibration) to meet MIL-STD 883

10) compatibility with high volume, automated assembly (chip bonding, wire bonding, sealing) and testing

This paper reports our experiences with one approach to meeting these goals, namely using metal injection molding (MIM) of tungsten-copper (W-Cu) to make the shells for packages as shown in Figure 1. So far, we have made about 300 such package shells.

THE MIM PROCESS

The process of metal injection molding has recently emerged as a promising packaging technique (Figure 2)(1)-(3). It begins with a feedstock of fine metal powders (about 10 μm diameter or less) that are

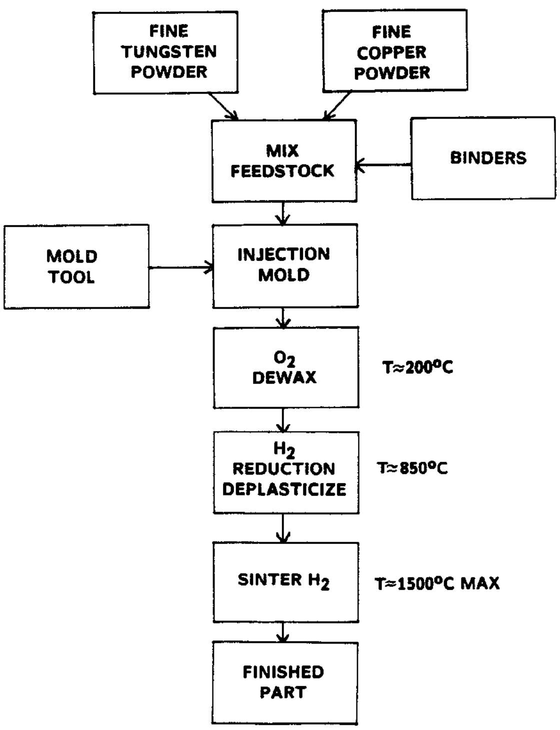

Figure 2:
Flow chart for MIM process with typical temperatures for W-Cu.

mixed with binders (waxes and other polymers). This mixture is then injection molded using methods and equipment like those used in the plastics industry. The as-molded or "green" part then undergoes chemical or thermal processes to remove the binders, and high temperature sintering of the metal particles into a dense solid part. During these processes the "green" part shrinks typically 20%. Thus the mold dimensions must be properly compensated.

BENEFITS OF MIM

MIM is well suited to small metal parts like electronic packages and has several attractive features. The first is low cost, even for small quantities or prototype runs. Prototype tooling can be inexpensive compared to other manufacturing methods. In large quantities (10,000) the per unit cost is expected to be a few dollars for a package shell (without feedthrus, lid, or plating). Furthermore, turn-around time can be rapid, both for the initial design and for design changes.

MIM also has the ability to produce complex parts as one piece and at net shape. We have been using the package shell shown in Figure 1 directly as produced by MIM, without added machining.

The MIM process is applicable to a variety of advanced materials, including nonmetals as well as metals. Our initial packages are made with W-Cu, but we are interested in less dense materials, including Mo-Cu and several proprietary combinations. Moreover, it is relatively fast and easy to vary the composition to adjust its physical properties according to requirements (of particular interest would be thermal expansion coefficient and thermal conductivity).

MATERIALS SELECTION

The initial material we chose for evaluation was tungsten-copper ($\approx$85%W/15%Cu) metal-matrix composite. This is compared to other candidate materials in Fig. 3. W-Cu was chosen on the basis of a thermal coefficient of expansion (TCE) matched to GaAs, high thermal conductivity, adequate mechanical properties, and reasonable availability of material and maturity of technology. The primary disadvantage is its high density ($\approx$15 gm/cm^3).

Metal-matrix materials such as W-Cu are not alloys, but "micro-composites", a bonded mixture of the constituents on a μm scale. For this materials system, a network of W particles is filled in with Cu. As a result, a high thermal conductivity, near that of pure metals like Cu or Al, is retained.

Several other advanced metal-matrix materials appear promising for electronic packages and are expected to be compatible with MIM, but are still in early development, such as Al/Si, Al/SiC, Al/AlN, and Cu/Al_2O_3. One reason for interest in these materials is that they are considerably less dense than W-Cu, leading to a lighter weight package.

MATERIAL	AVAILABILITY & EXPERIENCE BASE	TCE	THERMAL CONDUCTIVITY	DENSITY (PACKAGE WEIGHT)
W-Cu	FAIR	EXCELLENT	EXCELLENT	POOR
Mo-Cu	POOR	EXCELLENT	EXCELLENT	FAIR
Al-Si Al-SiC Al-AlN	POOR	FAIR	EXCELLENT	EXCELLENT
KOVAR	EXCELLENT	EXCELLENT	POOR	FAIR

Figure 3:
Comparison of candidate package materials.

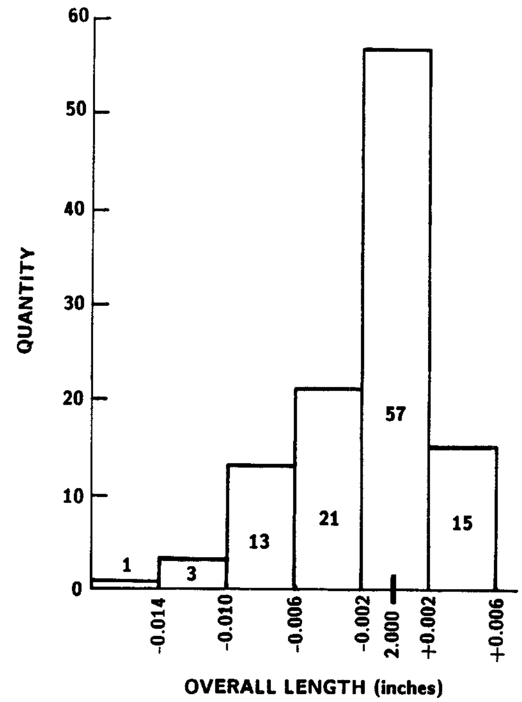

Figure 4:
Distribution of a representative package dimension (overall length) for a lot of 110 packages.

PACKAGE DESIGN

Our package technology development is meant to be generic and widely applicable to microwave and millimeter-wave components. A typical package design shown in Figure 1 is fairly representative of what is required for advanced MMIC applications. Several features of this design are worth noting.

The package size (approximately 2" x 0.35" x 0.15" outside dimensions) is large enough to accommodate a variety of chip configurations. The side walls and floor were made thin (0.030"), to reduce weight and to maximize the internal space for circuitry.

The completed package has two feedthrus, combination RF/dc/low frequency, located at the two narrow ends to allow side-by-side placement of packages for implementing arrays (one or two dimensional). The feedthrus are co-fired ceramic with metallized leads; the RF signal lines are a coplanar/stripline configuration. At present we install the feedthrus by Au/Ge brazing after the package and the feedthru metallization are Ni and Au plated.

DIMENSIONAL CONTROL

Results from several lots show that dimensions can be held within a tolerance of ±0.001"/1" or about 0.1% with reasonable yield. Typical results are shown in Figure 4. Flatness of the floor of the internal cavity and of the package base is within 0.001"/1".

These close tolerances are critical for maintaining accurate assembly of internal parts and external interfacing. Flatness is important for chip bonding and a good thermal interface to the heat sink.

The results we have achieved indicate that "secondary operations" such as machining or grinding will not be needed, keeping package cost low.

The area of the molding gate (where the feedstock enters the mold) can result in a nonflat surface, so should be located in a noncritical area. For the package of Figure 1, it is along one side at the bottom.

PLATING

Plating W-Cu requires more care than most previous package materials. We have developed a proprietary technique that has been 100% successful for plating the W-Cu MIM packages, using ≈ 175 μ" electroless boron nickel and ≈ 200 μ" electrolytic gold. The plated packages are solderable with both Au/Ge and Au/Sn.

HERMETICITY

Metal injection molded parts typically are 96% or more of theoretical density and do not exhibit interconnected porosity in walls as thin as 0.010", so we do not expect hermeticity problems from the package shell. Leak tests on open packages with feedthrus installed have shown He leak rates of $<1 \times 10^{-8}$ cm^3/s.

LID SEALING

Several approaches for lid sealing are being evaluated, including resistance seam sealing and laser welding.

ELECTRICAL PERFORMANCE

The electrical performance of a complete package was evaluated using a 3-MMIC-chip amplifier (Figure 5). The MMIC chips and interconnecting substrates, as well as all other components, were mounted directly to the package floor using conductive epoxy.

The amplifier module's gain is 30 ±2 dB from 2-18 GHz. The slight drop in gain above 18 GHz corresponds to the behavior expected based on the characteristics of the individual MMIC ICs. Return loss for both input and output is better than 10 dB from 2-20 GHz. No significant lid effect was observed.

CONCLUSION

This is the first demonstration of the use of metal injection molding for precision packaging. The results point to a promising future potential for MIM fabrication as a generic packaging technique for advanced microwave and millimeter-wave systems.

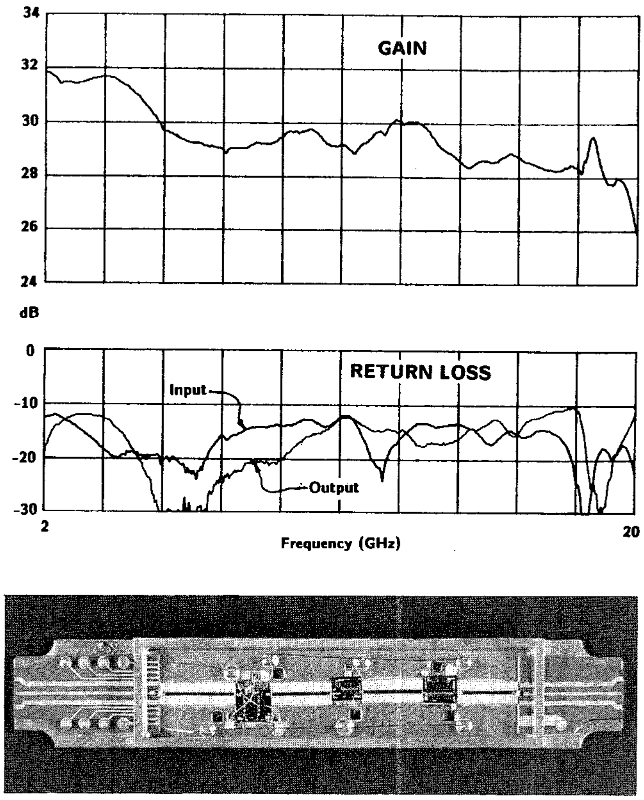

Figure 5:
Photograph and electrical performance of a 3-MMIC-chip amplifier assembled into a completed package with feedthrus.

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