High Frequency, Low Loss, Additively Manufactured Hermetic Package

Tim Smith, Bill Rhyne, Robert Reid and Christopher Hatfield

Cubic-Nuvotronics

2305 Presidential Drive

Durham, NC 27703 USA

Abstract

This paper presents the development of a new type of hermetic cavity package for mmWave RF MMICs. The package features an all copper additively manufactured construction for optimal thermal performance as well as low loss air coax RF signal routing with a critical ceramic feedthrough to isolate the internals of the package from the external environment. With a simulated thermal resistance of 1 C/W, from die backside to package lid, and RF insertion loss of less than 0.5dB from 0-80Ghz, this package can support high power as well as high frequency MMICS. With no polymers in the construction of the package true hermetic performance is expected, making this package a high reliability option as well.

For this paper two die were selected for demo packages. These die do not have surface mountable packages offered on the market. The die selected are the CMD247 30-40GHz Low Phase Noise Amplifier from Qorvo and the CHA2080-98F 71-86GHz Low Noise Amplifier from United Monolithic Semiconductors. RF insertion loss as well as environmental reliability will be demonstrated with these devices. The additive manufacturing process used is the proprietary PolyStrata® process developed by Nuvotronics. With the development of 14” panel substrate manufacturing line utilizing a mask-less process, fabrication process can support both high-volume, and high-customization without incurring prohibitive tooling costs.

Key words

Hermetic Package, Millimeter-Wave, System in Package, Cavity Package,

I. Introduction

Semiconductor design and process technologies have made considerable advances in capabilities at millimeter wave (mmWave) frequencies and rapidly increasing through sub-THz towards THz frequencies. Packaging and module integration technologies have not kept pace and can limit integration and use of those devices in systems. High frequency bare die from 40GHz up to 100GHz are readily available from manufactures and distributors but surface mount ready packages supporting these devices are not available, forcing system architects to make difficult choices between size, weight, performance and cost. For systems where RF performance or reliability has been a priority there was little choice other than the “gold-brick” package, which offers superior environmental protection and reliability, as well high thermal conductivity for power applications. This approach importantly offers minimal RF losses but are large, heavy, and expensive to build. The “gold-brick” package with connectorized I/Os is not conducive to surface mount assembly lines that are essential for reducing complex electronic system cost points.

Conventional plastic packaging with metal lead frames offer low cost packaging solutions but are limited in RF and thermal performance. The plastic material also allows moisture ingress into the internal cavity which in turn can cause reliability problems through corrosion or dendritic growth [1].

Ceramic packages have been used for decades to provide high performance, high reliability surface mount packages, with some companies even offering solutions up to 60GHz. These packages can be hermetically sealed for environmental reliability and use thin or thick film patterning with multilayer lamination or firing with vias to provide an electrical path to the next level interconnects. Approaches using glass as the interposer offer the promise of higher frequency operation due to the improved accuracy and technologies for patterning glass and creating through glass vias [2]. In this case [2], the transition from PCB to glass has an insertion loss of 1.4dB and the vertical transition through the glass has an insertion loss of 0.4 dB at 40 GHz.

There is also a substantial effort focused on developing antenna in package (AiP) solutions. This has largely been driven by the use of mmWave bands in 5G networks [3]. Much of this uses conventional packaging technology and is not hermetic. Automotive radar applications are also pushing this technology forward and glass-based approaches are also being developed for these applications [4]. An insertion loss of 0.6dB was reported in the passband of 76-81 GHz [4].

II. Technology Development

This development discussed in this paper is a key addition to the PolyStrata® manufacturing process. The PolyStrata® process is a batch additive metal manufacturing process developed more than 10 years ago and has been discussed in many previously published papers [5,6]. This technology has been demonstrated at D-band and G-band showing it's high frequency capabilities [7,8]. The PolyStrata® process is illustrated in Figure 1. The process is compatible with existing interconnect technologies such as solder, conductive epoxy, wire bond, and flip chip. The proven RF performance makes the technology a perfect fit to replacing plastic lead frame, LTCC and even organic boards as a package substrate for mmWave RFICs.

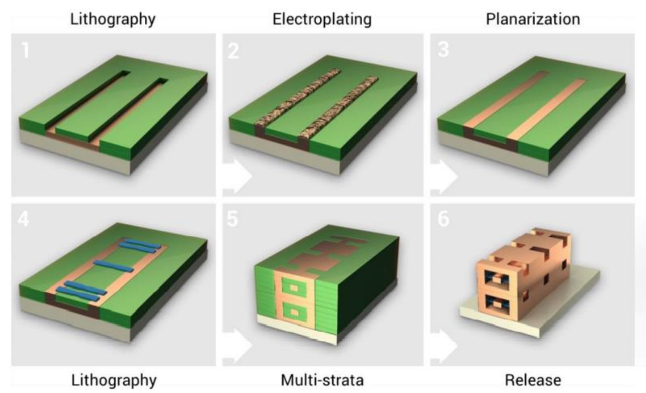

Figure 1. Basic PolyStrata® process overview.

Cubic-Nuvotronics has developed a patented (US Patent No. US10319654B1, 2017) hermetic feedthrough using a small ceramic chip, environmentally sealing the PolyStrata® Air Coax transmission line. Enabling a cavity package substrate to be designed that can be lidded and sealed using traditional approaches. The package base material is copper providing 400W/m-K of isotropic thermal conduction allowing for low thermal resistance paths through the package base and lid. This permits the package to dissipate heat through the lid by attaching a heat sink directly to the package, with simulated thermal resistances as low as 1 C/W. Packages developed also support ultra broad band with insertion loss of less than 0.4dB easily achievable to frequencies 90Ghz and above. Figure 2 shows the loss per mm of a PolyStrata® coaxial transmission line at D-Band.

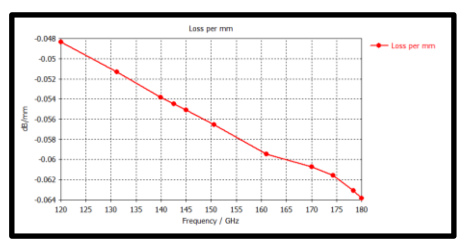

Figure 2. Loss of a PolyStrata® coaxial transmission line.

Figure 3 shows how during the transition from the PCB board to the PolyStrata® rectangular coax lines, the signal line passes through a ceramic hermetic feedthrough. The orange color features are the copper of the PolyStrata® package as well as the board metal. The center conductor of the coax passes through a via in the ceramic, shown in white, and down to a landing pad on the board. The metal through the via and around the sides of the ceramic is plated as part of the formation of the copper on that layer of the build. Initial demonstration of the fabrication of this feature and leak testing has passed fine leak MIL-STD-883 TM1014. Figure 4 is an SEM image of a cross-section of the tested device which shows how the plated copper forms well around the edges of the feedthrough which is important for eliminating any potential leak path.

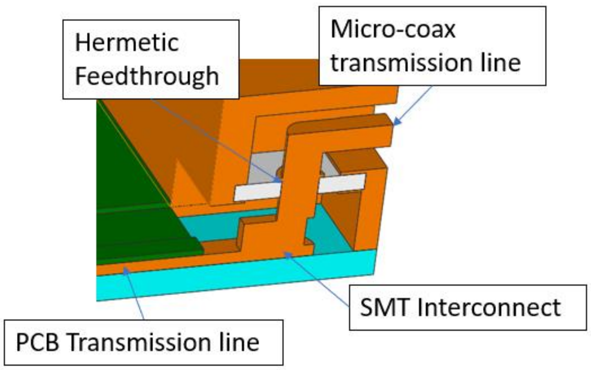

Figure 3: Cross-sectional view of micro hermetic feedthrough concept.

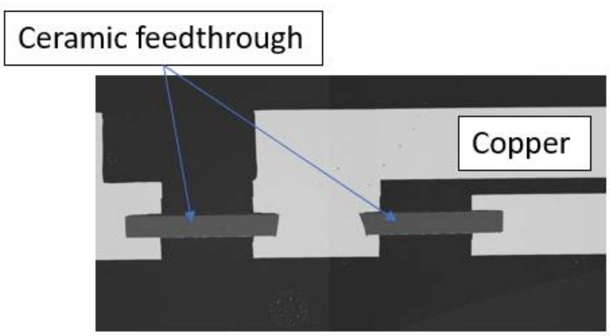

Figure 4: SEM cross-section of hermetic feedthrough fabrication demonstration unit.

III. Package Design

A standard structure was developed that could support a broad range of RFIC's typically found in the market but do not have packaging options offered. These usually are lower volume wire bondable type millimeter wave devices above 40Ghz. This package can support high power GaN or GaAs MMICs as well and InP or SiGe devices which require the lowest loss RF interconnection and high thermal conductivity provided by the all copper construction. Figure 5 shows the basic components to the package substrate design that are all monolithically fabricated on wafer. All that needs to be done at this point is die attach, wire bond and lid attach. These steps can all be run in an automated fashion at wafer level in high volume. Figure 6 is an image of the completed 8-inch wafer with the developed prototype packages. This substrate size contains more than 400 units on a wafer, demonstrating the batch fabrication capability of this technology. The PolyStrata® manufacturing technology is currently implementing an increase in substrate size to 14-inch panels which will effectively quadruple batch quantity.

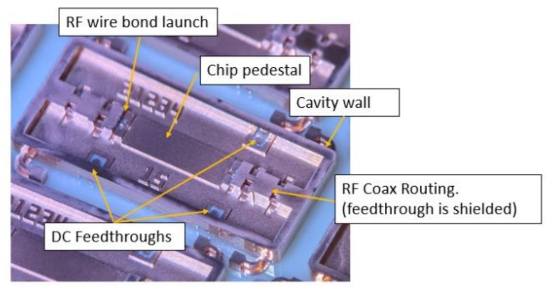

Figure 5: Microscopic image of a PolyStrata® Package substrate designed to support a 30-40Ghz GaN device with better than 0.32dB Insertion Loss and 20db Return Loss.

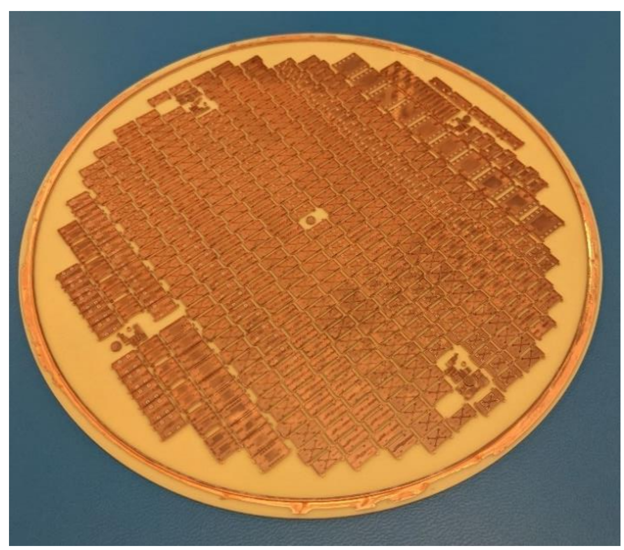

Figure 6: Photograph of fabricated wafer of various prototype package designs.

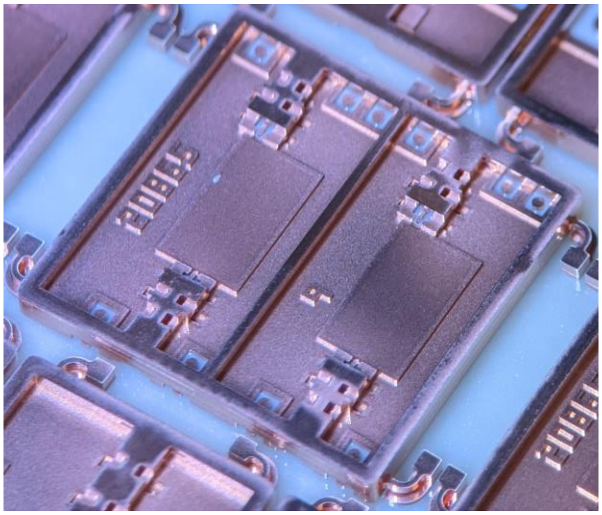

Figure 7: Microscopic image of example package substrate supporting two die with solid metal wall creating separate cavities. Package size is 8x7.5mm.

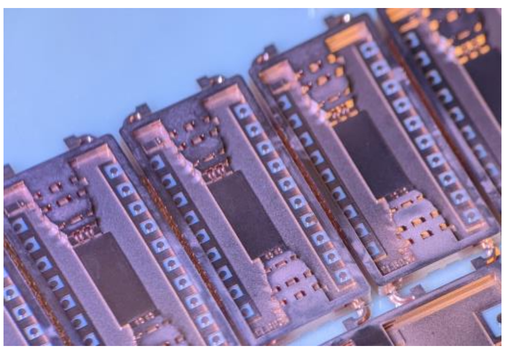

Figure 8: Microscopic image of PolyStrata® Package substrate supporting differential RF I/O's and a high number of DC control lines.

Figures 7 and 8 show example packages. Figure 7 shows a package capable of supporting two die in a compartmentalized substrate and Figure 8 shows a package that can support a number of I/O’s and control lines. Because the package is built using the PolyStrata® technology the RF performance of the package is unmatched. A single transition was developed that supports ultrawide band RF signal from 0-70Ghz with less than 0.12dB insertion loss and 20dB return loss. See Figure 9. Tuned solutions above 70Ghz can be implemented for the 71-86 Ghz frequency band and even higher.

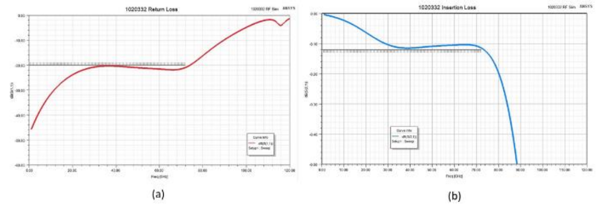

Figure 9: ANSYS Electronics Desktop simulation of return loss (a) and insertion loss (b) performance of hermetic feedthrough transition to PCB trace.

IV. Conclusion

In this paper we have demonstrated a new packaging technology using the PolyStrata® manufacturing process. These products meet stringent hermetic standards, eliminating concern of long-term reliability. They have proven RF performance building off of PolyStrata® recta-coax technology. A wide range of passive structures can be integrated in the package, including couplers and high-power combiners. These parts are batch manufactured allowing an impressive economy of scale as well as requiring minimal or no tooling for minor design changes. Most importantly the finished packages can be shipped in tape and real format and integrated on a standard pick and place line to enable a new class of high frequency systems at lower cost. This technology provides a cost-effective packaging approach to very high frequency devices, offering unmatched performance and bandwidth.

References

[1] G. Zhang, J. Li, Y. Chen, R. Wang and M. Yang, "Failure analysis for IC plastic and substrate/lead-frame package," *2014 15th International Conference on Electronic Packaging Technology*, 2014, pp. 1225-1228, doi: 10.1109/ICEPT.2014.6922864.

[2] T. Galler, T. Chaloun, K. Kröhnert, M. Schulz-Ruhtenberg and C. Waldschmidt, "Hermetically Sealed Glass Package for Highly Integrated MMICs," 2019 49th European Microwave Conference (EuMC), 2019, pp. 292-295, doi: 10.23919/EuMC.2019.8910813.

[3] Antenna in Package (AiP) Technology for 5G Growth, Curtis Zwenger and Vic Chaudhry, Chipscale Review, March-April 2020.

[4] C. Zhu, Y. Wang, Z. Duan and Y. Dai, "Design of Patch Antenna in Embedded Glass Fan Out Package for 77-GHz Automotive Radar," 2020 IEEE Asia-Pacific Microwave Conference (APMC), 2020, pp. 1066-1068, doi: 10.1109/APMC47863.2020.9331638.

[5] J. R. Reid, J. M. Oliver, K. Vanhille and D. Sherrer, "Three dimensional metal micromachining: A disruptive technology for

millimeter-wave filters," 2012 IEEE 12th Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems, 2012, pp. 17-20, doi: 10.1109/SiRF.2012.6160165.

[6] Z. Popovic et al., "Micro-fabricated micro-coaxial millimeter-wave components," 2008 33rd International Conference on Infrared, Millimeter and Terahertz Waves, 2008, pp. 1-3, doi: 10.1109/ICIMW.2008.4665595.

[7] J. W. Jordan et al., "Monolithically Fabricated 4096-Element, PolyStrata® Broadband D-band Array Demonstrator," 2019 IEEE MTT-S International Microwave Symposium (IMS), 2019, pp. 1060-1063, doi: 10.1109/MWSYM.2019.8700988.

[8] J. -M. Rollin, D. Miller, M. Urteaga, Z. M. Griffith and H. Kazemi, "A Polystrata® 820 mW G-Band Solid State Power Amplifier," 2015 IEEE Compound Semiconductor Integrated Circuit Symposium (CSICS), 2015, pp. 1-4, doi: 10.1109/CSICS.2015.7314481.