A HIGH PERFORMANCE QUARTZ PACKAGE FOR MILLIMETER-WAVE APPLICATIONS

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ABSTRACT

A high performance quartz package has been developed for millimeter-wave applications. When integrated with a 50-ohm through-line, the 0.25-inch long package was measured with an insertion loss less than 1.2 dB and a return loss better than 15 dB up to 35 GHz.

I. INTRODUCTION

MMIC packages are generally used to protect the MMIC chips from hazardous environment and stresses, and to provide a user-friendly interface. A well designed package protects a MMIC chip from a number of environmental factors that are potentially damaging. These include moisture, EM radiation, pollutants, and corrosive chemicals. In addition, the package protects the chip from mechanical damages, such as accidental scraping of the chip or pull on the bond wires.

The current technology for packaging of GaAs MMICs has not kept pace with the development of the chips themselves. While GaAs MMICs can operate at frequencies in excess of 40 GHz [1,2,3], packaging is limited to performance below 30 GHz[4,5,6], requiring a downgrading of the performance level of the device. As an effort to address the issue, we present in this paper a design of millimeter-wave package which results in a state-of-the-art performance from DC to 35 GHz. When integrated with a 50-ohm thru-line, the package has been measured with an insertion loss less than 1.2 dB and return loss better than 15 dB up to 35 GHz.

II. DESIGN

Figure 1 depicts a schematic design of the millimeter-wave MMIC package. The design consists of a gold-plated Kovar base, a 5-mil quartz substrate with both RF and DC patterns printed on it, a quartz ring as the walls, and a top cover (not shown). The choice of Kovar material for the base is mainly because of its good match in the thermal expansion coefficient. with the GaAs MMIC and quartz substrate. The selection of substrate materials involves the considerations of the thickness, dielectric constant, and transmission loss. The substrate thickness is designed to have a good match with the MMIC chips in the package. Since the typical MMIC thickness is 4 to 5 mils, a substrate thickness of 5 mils is chosen. A low dielectric constant is preferred because it will make the package electrically small and easier to achieve broadband performance. The low dielectric-constant substrate will also relax the tolerance of the circuit dimensions and results in a high yield design. In addition, the Q factor of a 50-ohm microstrip line on a low dielectric substrate is higher than that on a high dielectric substrate. Based on the above considerations, we have selected a 5-mil quartz substrate for the low-loss package design. In a previous study[7], we found that the insertion loss of a 50-ohm microstrip line on 5-mil substrate is about 0.06 dB/mm at Ka-band frequencies.

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The RF feed-thru design is crucial to the package performance. The feed-thru structure consists of a section of transmission line outside the package, in the package wall, and inside the package. In addition, we include a coplanar RF probe pattern for ease of testing, as shown in Figure 2. The transmission lines are called, from left to right, conductor-backed coplanar waveguide, microstrip, shielded stripline, and shielded microstrip, respectively. To minimize the reflection across the 40-GHz bandwidth, we have to maintain good 50-ohm impedance match between the transmission lines. To this end, we calculate the 50-ohm line dimensions of all the lines using a spectral domain technique[8]. To minimize the through loss, the line sections are kept as short as practical. The shorter line length will also reduce the sensitivity of reflection on the manufacturing tolerances. Finally, the step junctions between the line sections are compensated by 45-degree corners.

Plated through vias on the side wall are used to provide proper grounding for electromagnetic shielding. However, it forms a nice cavity inside the package for resonance. Considering the effective electric wall, we estimated that a resonant-free

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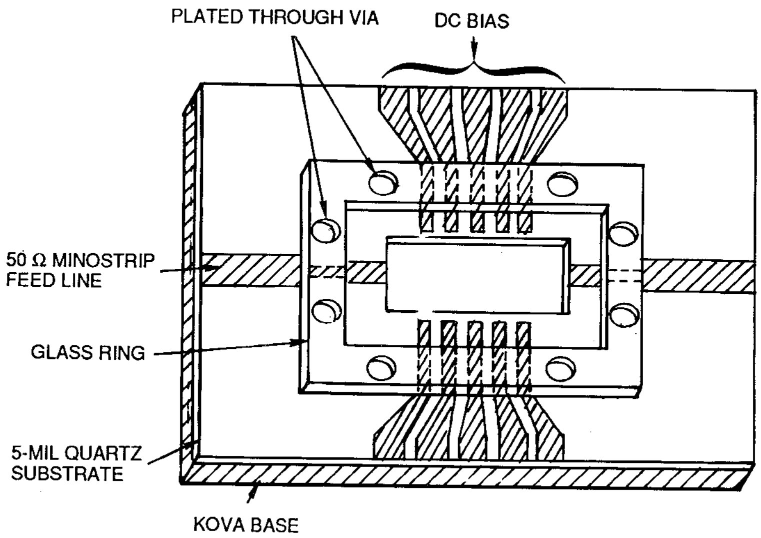

Figure 1 A schematic design of the MMIC package.

package below 40 GHz requires an interior dimension smaller than 0.15 inch by 0.15 inch.

III. FABRICATION

Figure 3 shows the flow diagram for the fabrication process of the quartz package. The quartz substrate was first polished to obtain a mirror-like smooth surface. The polished substrate was then metallized with 4-μm thick gold using a thick-film process. The designed conductive pattern was then defined by thin-film photolithographic and etching processes. Unlike the conventional thick-film screen printing process, this combined thin-film/thick-film process is able to provide the line resolution required for the high-frequency performance.

After defining the conductive pattern, we form the quartz wall and the cut-outs on the substrate by a laser trimming process. The quartz wall and the substrate were then laminated together by a glass seal process employing a closed TCE-matched glass material. The process began with printing the glass seal material on the mating surfaces, followed by burn-out, sintering, and preseal. The quartz wall and substrate were then put together carefully and placed in a furnace. The

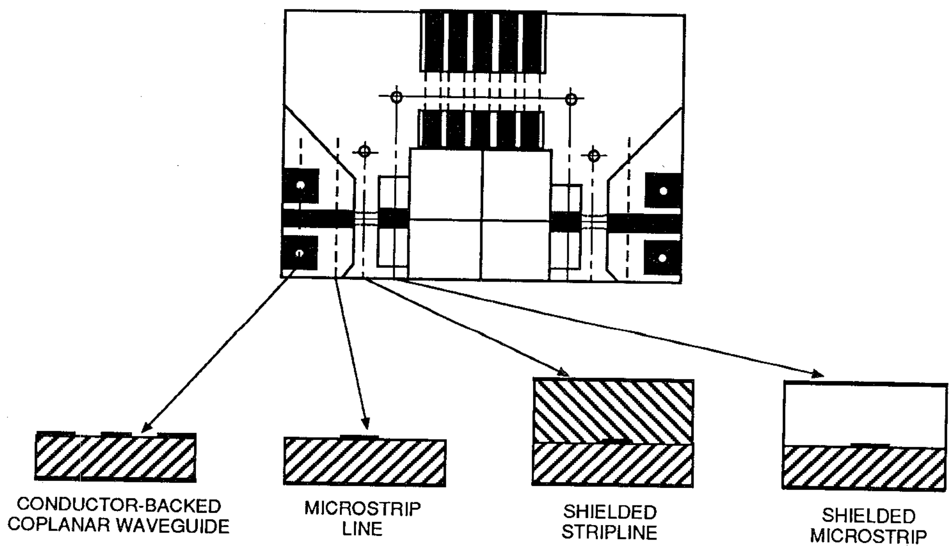

Figure 2 RF feedthrough structure of the MMIC package.

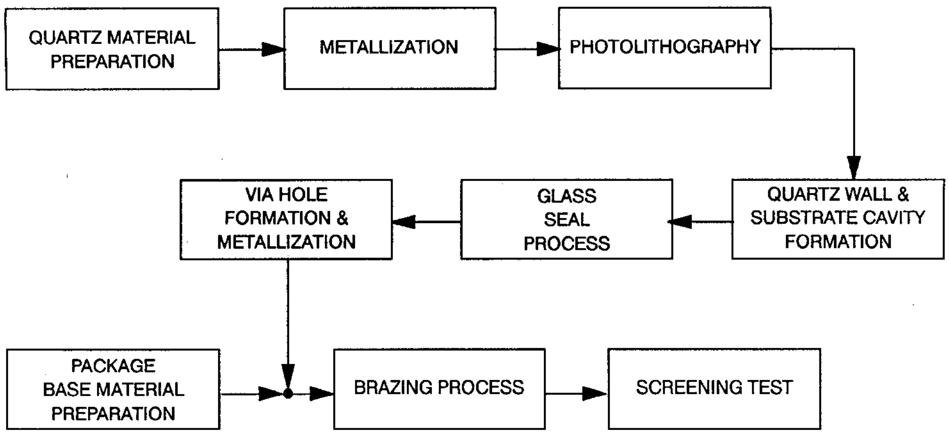

Figure 3 Fabrication flow diagram for the quartz package.

final sealing took about one hour with the furnace temperature slowly increased to 500 C for about 10 minutes.

There are two via hole requirements. One requirement is to connect the top cover with the base through the wall to form a cavity for EMI shielding from low frequency noise. The other is to ground the CPW probe pads for RF probing requirement. The via holes were formed by a laser drilling process, followed by thick-film metallization and via fillets.

The final step of the package fabrication is to attach the Kovar base to the ground plane of the quartz substrate through brazing process with a high temperature soft solder.

IV. MEASUREMENT RESULTS

Figure 4 is a photograph of a complete package with two RF feedthroughs and ten DC feedthroughs. For characterization purposes, the package contains a 50-ohm microstrip line of 0.15 inch long. Notice that two CPW probe pads are fabricated on the signal path for ease of testing with a probe station. With precision on-wafer calibration standards, the test system can be calibrated with the references defined at the probe tips. For a well maintained probe station and HP8510B system, the measurement can be repeated for better than 40 dB up to 40 GHz. Repeating the probe placement and measurement for a through line results in a typical plot shown in Figure 5. It reveals a contact repeatability better than 35 dB up to 40 GHz.

The quartz package was characterized using such a test system. The measured return loss and insertion loss are summarized in Figure 6. For the complete test structure, including two RF feedthroughs integrated with a 50-ohm line, the measured return loss is better than 15 dB up to 38 GHz. The insertion loss is less than 1.2 dB up to 35 GHz. Assuming the package to be symmetrical, the return loss and insertion loss for each RF feedthrough port can be estimated to be 21 dB and 0.4 dB, respectively. To our knowledge, this result is the best ever reported for millimeter-wave applications.

Compared to the theoretical value, the measured insertion loss is about five times higher. This is mainly due to the gold quality and surface roughness from the thick-film fabrication process. The obvious roll-off at the high frequency end is due to the low-Q resonator formed by the vias, which resonates at about 44 GHz. Metallizing the cavity wall will eliminate the problem of early roll-off.

V. CONCLUSIONS

We have designed, fabricated, and tested an advanced millimeter-wave package. The package consists of a gold-plated Kovar base, a 5-mil quartz substrate, a quartz ring, and a top cover. The measurement shows that for each RF feedthrough port, the return loss is better than 21 dB and the insertion loss less than 0.4 dB from DC to 35 GHz.

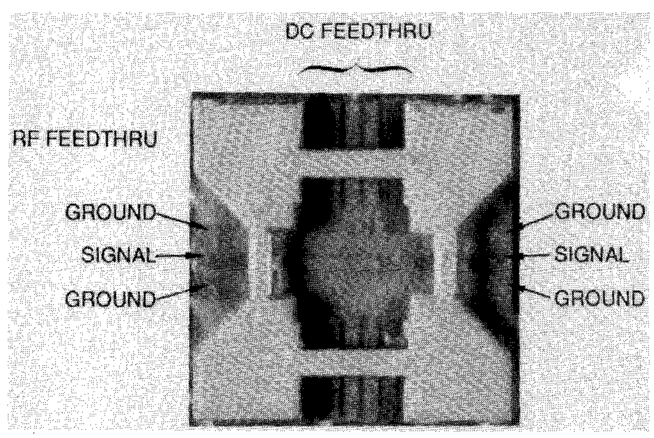

Figure 4 Photograph of a completed quartz package.

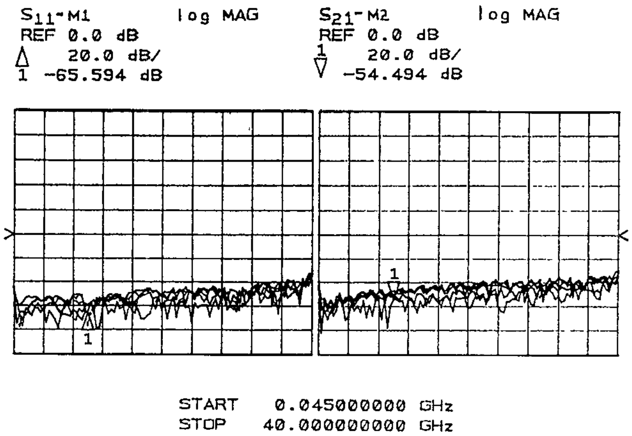

Figure 5 Measurements showing the probe placement contact.

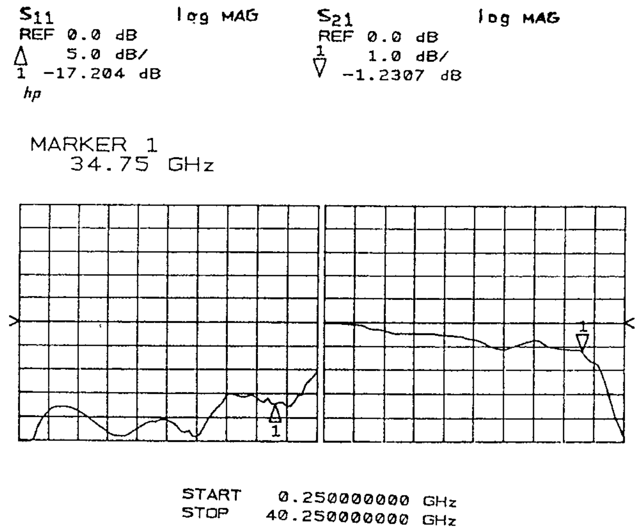

Figure 6 Measured return loss and insertion loss of the quartz package.

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