Micromachined Conformal Packages for Microwave and Millimeter-Wave Applications

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Abstract— **High frequency circuit performance is significantly influenced by its RF package configuration. This paper presents the use of Si micromachining to develop a miniature package that conforms to the circuit geometry while providing physical and electromagnetic shielding. The advantages of a conformal package, other than reduced size, are control of package resonances, the capability to isolate individual circuit elements and improve circuit performance through elimination of parasitic radiation. In addition, the use of micromachining provides reduced fabrication tolerances and most importantly lower cost.**

I. Introduction

In microwave and millimeter wave circuit applications RF packaging is becoming an important issue to address due the lack of appropriate packaging configurations for use in circuit design. Several years back, experts in the field of device and component development began to realize that packaging of such components was progressing at much slower rate than the devices themselves [1]. As a result, many problems observed in device and component performance at these frequencies are being attributed, after diagnostic testing, to the package in which they are housed. Typical problems associated with circuit packages, especially above X-band, include resonances due to the large physical geometry surrounding these circuits, cross-talk caused by parasitic radiation to neighboring circuits, and unwanted excitations that result in power leakage in the form of substrate modes. Many of these issues can be addressed by integrating the package with the circuit monolithically, which implies that the package is considered as part of the circuitry and is designed to meet performance specifications. Other desired attributes of an RF package include the capability to provide protection from hostile environments, appropriate means for heat removal, and mechanical support for components while introducing minimum performance degradation [1]. With state of the art advances in semiconductor processing techniques, silicon micromachining can offer what conventional means have not been able to provide; packages which conform to the circuit geometry, require much less space and provide superior mechanical, thermal and electrical performance.

In the past few years, the use of Si micromachining in microwave and millimeter-wave circuit applications has been extensively explored at the University of Michigan, leading to many innovations [2], [3]. Among these has been the capability to develop self-packaged circuit components which have demonstrated improved electrical performance when compared to conventionally developed components [4]. This effort (Fig. 1) has lead to the first demonstration of a monolithic conformal package that follows the path of various line geometries, and is sized in such a way that its package resonance exists well above the desired range of operating frequencies. One very important characteristic of this packaging approach is that it provides monolithic self-packaged geometries which can be integrated within more complex planar circuit arrangements. Furthermore, this package can be integrated with any uniplanar technology and can incorporate any type of transmission medium such as microstrip, coplanar waveguide, coaxial line or stripline.

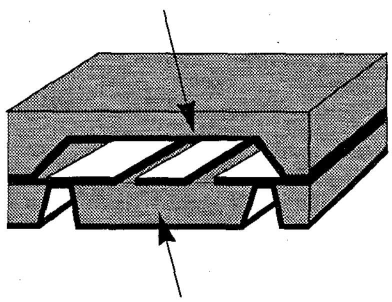
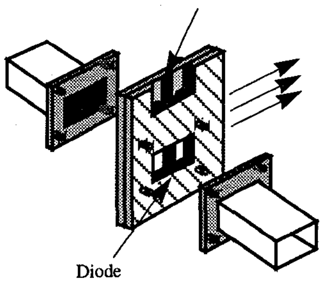
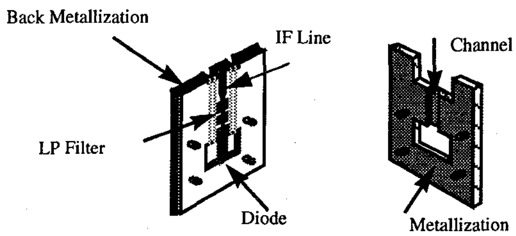


Fig. 1. Micromachined self-packaged embodiment.

The concept of conformal packaging can be applied to a very broad range of applications. One such application is the development of planar diode mounting structures for detector and mixer applications. Fig. 2 shows a schematic of a mounting structure for use with a rectangular waveguide which sends the RF signal to the diode via a probe mounted inside the waveguide. Such a mounting structure can be developed generically to accommodate both applications and can be used without requiring



(a) Waveguide to Micromachined Mount Transition



(b) Circuitry Micromachined Mount

Fig. 2. Illustration of a micromachined mounting structure used in a diode detector configuration with a waveguide system. The structure (a) is secured between two waveguide flanges where the IF signal is extracted from the self-packaged circuitry. The design layout is shown in (b) where the diode signal is extracted through lowpass filter.

waveguide alterations. In this arrangement only the probe is exposed to the RF excitation through windows etched on the substrate while the diode circuit is completely shielded from the rest of the circuitry by a package that elegantly follows the circuit path without interfering with the signal lines. The window can also provide a means for allowing printed antennas to radiate in free space or allowing access to parts of the shielded circuits for on-wafer probing or circuit control via optics.

Presented in this paper is the implementation of a self-packaged mounting structure for use with a detector diode circuit. The fabrication of the circuit along with its conformal package is presented and experimental results on circuit response are discussed. For more accurate understanding of electrical performance, the mounting structure is measured using on-wafer techniques. For the mounting structure under test, the waveguide probe has been replaced by coplanar waveguide probes appropriate for on-wafer measurements.

II. Design/ Fabrication Approach

To demonstrate the flexibility offered by micromachining, the mounting structure shown in Fig. 3 is developed with both longitudinal shielding as well as cross cavity shielding. The cross-cavity junction implemented in the shielding allows for incorporation of commercial diodes or other input paths to the existing circuit. The passive circuitry in this mount consists of an input matching network a diode mounting region, and a lowpass filter output. At the diode placement location, a cross-cavity is formed in both the upper and lower cavity regions and is designed to operate under cut-off as discussed earlier. For the embodiment presented here, the lower cavity dimensions form a sub-

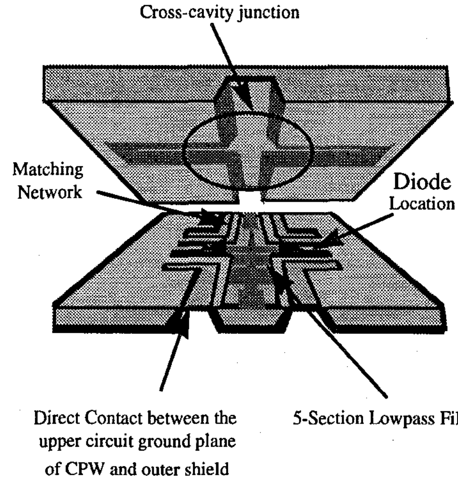


Fig. 3. Illustration of a mount implemented using micromachining that provides conformal self-packaging to various paths within a detector circuit.

strate-filled waveguide which has the dominant effect on the package resonance. The dimensions of the shield (height of 350 μm and average width of 817 μm) are chosen so that the package dominant resonance is about 54 GHz.

The self-packaged configuration discussed here was developed using wet chemical etching techniques on a two silicon-wafer system. On the circuit wafer, high resistivity silicon is removed to form channels along the lower surface which create a substrate-filled cavity underneath the actual planar circuit. The upper wafer has low resistivity silicon and provides all the upper cavities to the circuitry.

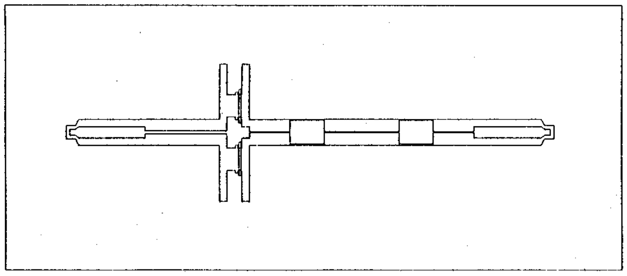


Fig. 4. Passive circuit design layout.

After metallization of the cavity regions, these wafers are brought into contact to form the shielded geometry shown in Fig. 1. The shielded cavities that exist above and below the circuit configuration are fabricated so that they provide continuous direct contact to equalize the ground planes of the circuit and the shielding regions. This is necessary to minimize the leakage of power into the substrate due to excitation of substrate or parallel plate modes.

III. RESULTS AND CONCLUSIONS

The characterization of the mounting structure is done on an Alessi Probe station using an HP 8510B Network Analyzer and Cascade Microtech GSG probes in order to de-embed the circuit response using a TRL calibration technique. Fig. 5 the layout configurations of the circuit while Fig. 5 shows a photograph of the mounting structure where the open window area represents the location that is used to probe the individual circuits. Inside the upper area is the conformal package similar to the illustration in Fig. 3.

For successful use of this structure as a detector mount, it is important to develop an appropriate matching network which will allow the diodes to receive most of the RF power. Typical designs [5] require a lowpass filter in addition to the matching network to pass the modulated output signal. In this case, a 5-section lowpass filter has been used which provides a 3 dB point at 19 GHz. Fig. 6 shows the measured response compared to theoretical results based on finite-difference time domain technique of this filter with a 50 ohm input and output match.

When off the shelf diodes are used, low bias currents on the microampere level provide input impedances on the order of kilo-ohms. In the mounting structure under study, however, the planar lines are limited to about 100 ohms given the high dielectric constant of silicon, $e_r = 11.7$, and thickness of 350 μm.To circumvent this problem, resistors are placed in parallel with the diode to make the matching easier and also to provide a wider bandwidth. For the example mounting structure, two shunt (224 ohm each) thin film resistors were placed in parallel to the diode location in the cross-cavity junction which is matched to a quarter-wave section of 70 ohm line at the center frequency of 21 GHz. Fig. 7 shows measured results of the passive circuit where the return loss of the circuit provides the best match at around 22 GHz. This shift in frequency occurs because open-end parasitic effects were not included in the design. Preliminary measurements of a similar mounting configuration without the shunt resistors gave a system responsivity of about 1800 V/W at 21 GHz for a bias cur-

Probe Window ⟶

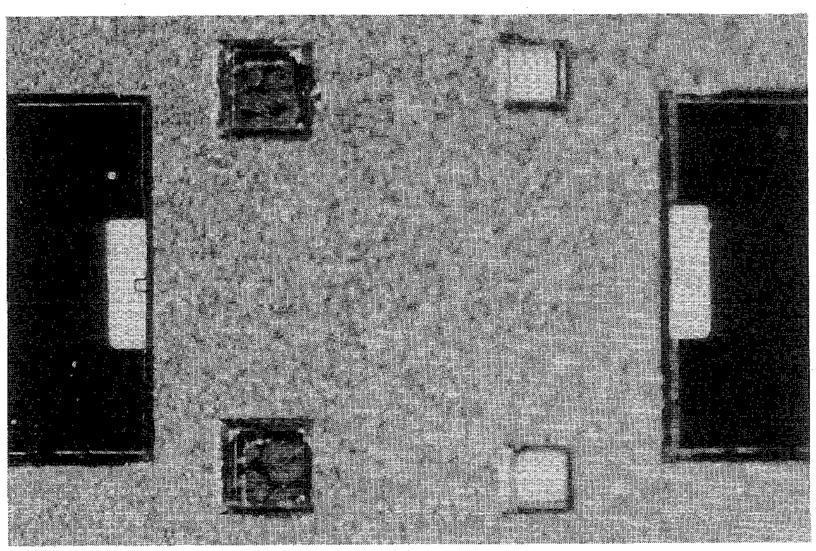


Fig. 5. Photograph of the probe window used for probing the circuit.

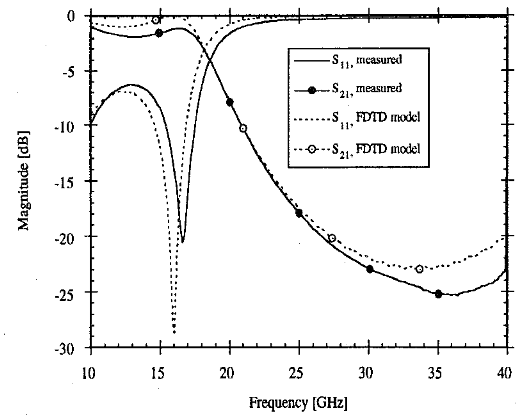


Fig. 6. Measured and theoretical results of the 5 section stepped impedance lowpass filter.

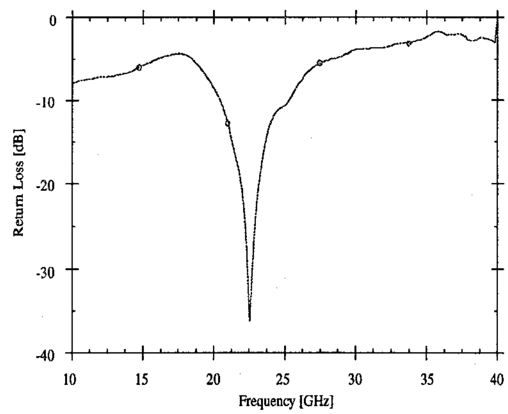


Fig. 7. Circuit response of the passive mounting structure.

rent of 20 μA, using Hewlett Packard HSCH 8320 Schottky barrier diodes. Detailed results for a variety of mounting configurations will be presented at the conference.

IV. ACKNOWLEDGMENTS

This work was supported by the Army Research Office and the Office of Naval Research. The authors would like to thank Dr. Gabriel Rebeiz and Mr. Thomas Weller for there technical discussions and Dr. Nihad Dib for theoretical data.

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