Micromachined Micropackaged Filter Banks

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***Abstract*— A micromachined, micropackaged filter bank at X/Ku-band is presented. The filters are integrated on a silicon substrate, and the micropackaging provides high isolation between the adjacent filters in the overlapping frequency region. This technology allows for the low-cost integration of switched filter banks *on the same substrate* for satellite communication systems, base-stations, and wide-band radar applications.**

***Index Terms*—Filters, micromachining, packaging techniques.**

I. Introduction

SWITCHED filter banks are commonly used for multiband communication systems and frequency hopping radar systems where high isolation between the filter elements is a requirement. Also, compact size, reduced weight, and low material and fabrication costs are essential. The conventional design for a switched filter bank is to machine a series of channels in a metal carrier and to place individual filters inside these channels. An input and output switching network of p-i-n diodes selects the filter response (Fig. 1). The conventional design technique suffers from many drawbacks. The machined metal carrier and packaging is custom made and therefore is very expensive to produce. Furthermore, the use of separate low-loss substrates for filters combined with active semiconductor substrates for p-i-n diodes is expensive to assemble. We feel that micromachining, combined with micropackaging, is a possible solution to the cost problem.

Silicon micromachining has been used to fabricate low-loss lumped elements, filters, power dividers, and couplers [1], [2]. Monolithic micropackaging by micromachining techniques has also recently been shown to provide high isolation between planar transmission lines while still being compact and relatively simple to fabricate [3].

The purpose of this work is to demonstrate the capability of combining the low-loss characteristic obtained using membrane technology with the high isolation and compact size obtained using micropackaging. The goal is to construct a high performance X/Ku-band filter bank with high isolation between the filters.

II. Design of Micromachined Filter Banks

The micropackage is a two layer structure placed on a bottom carrier substrate. The two layers consist of a micromachined filter substrate and a top cavity substrate (Fig. 2). The filter substrate layer is a 525-μm silicon membrane wafer. The membrane is a stress compensated tri-layer of SiO_2–Si_3N_4–SiO_2 with a thickness 1.4 μm and a relative dielectric constant of about 7. Surrounding the filters are etched via grooves which prevent substrate modes from forming and most importantly, isolate the two filters. The micromachined filter substrate includes the membranes, all metal feedlines, filters, and air bridges. For future designs, this layer could also include active circuits such as p-i-n diode switches, radio frequency (RF) amplifiers, and intermediate frequency (IF) system circuitry using either flip chip technology or device integration.

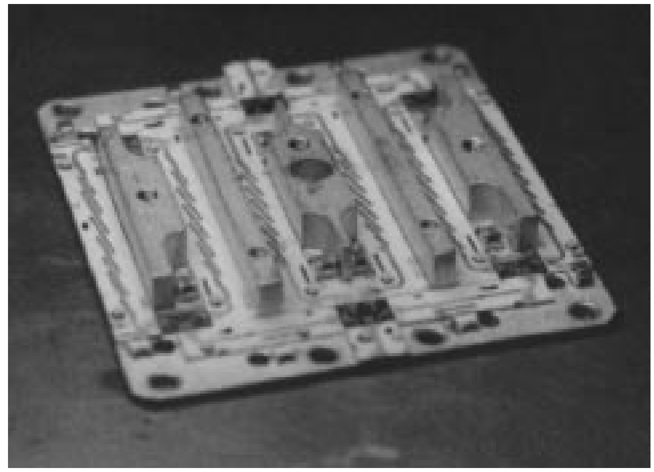

Fig. 1. Switched filter bank (courtesy of Texas Instruments).

The top cavity substrate is a micromachined wafer that surrounds the filters except for small mouse-holes for feedlines to the filters. The cavity is coated with metal (Ti–Al–Ti–Au) approximately 2 μm thick. This isolates the two filters and feed lines from each other. Alignment marks are placed on the micromachined substrate wafer to aid in the assembly of the top cavity wafer. The layers are secured to each other with a silver conductive epoxy. The package forms a rugged, compact, and lightweight structure.

The micromachined filters are based on an interdigital design shown by Matthaei *et al.* [4] and demonstrated recently by Chi *et al.* by using micromachining techniques [2]. However, the micropackaging technique applies to any shielded microstrip or stripline filter design. The feedlines for the filters are 2.4-mm-long shielded grounded coplanar waveguide lines on high-resistivity silicon ($\rho = 1200\,\Omega$-cm). The lines extend beyond the via holes of the filter and are not isolated from each other in any other way [Fig. 3(a)]. An airbridge was fabricated

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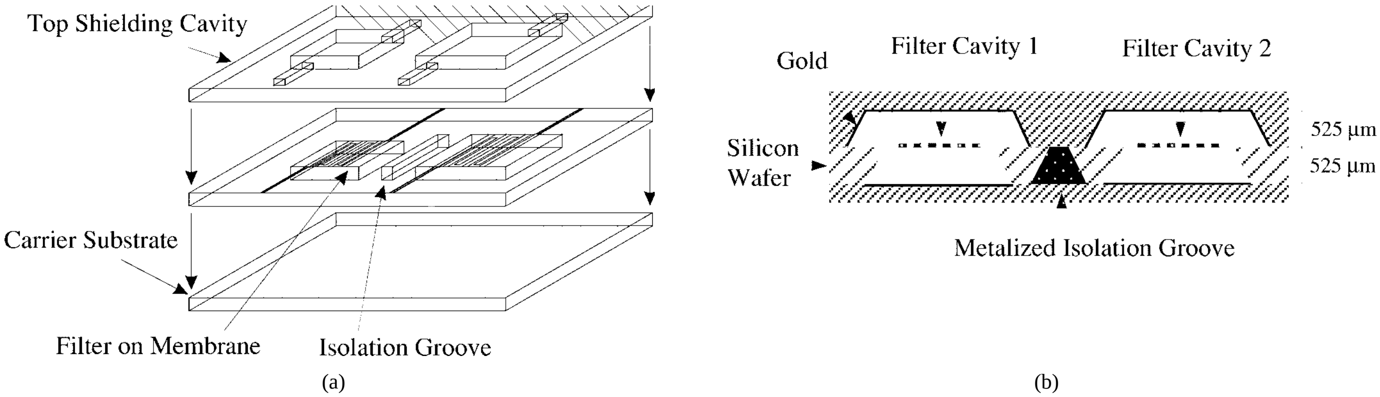

Fig. 2. Micropackaging of micromachined filter bank. (a) Isometric view. (b) Cross-section view.

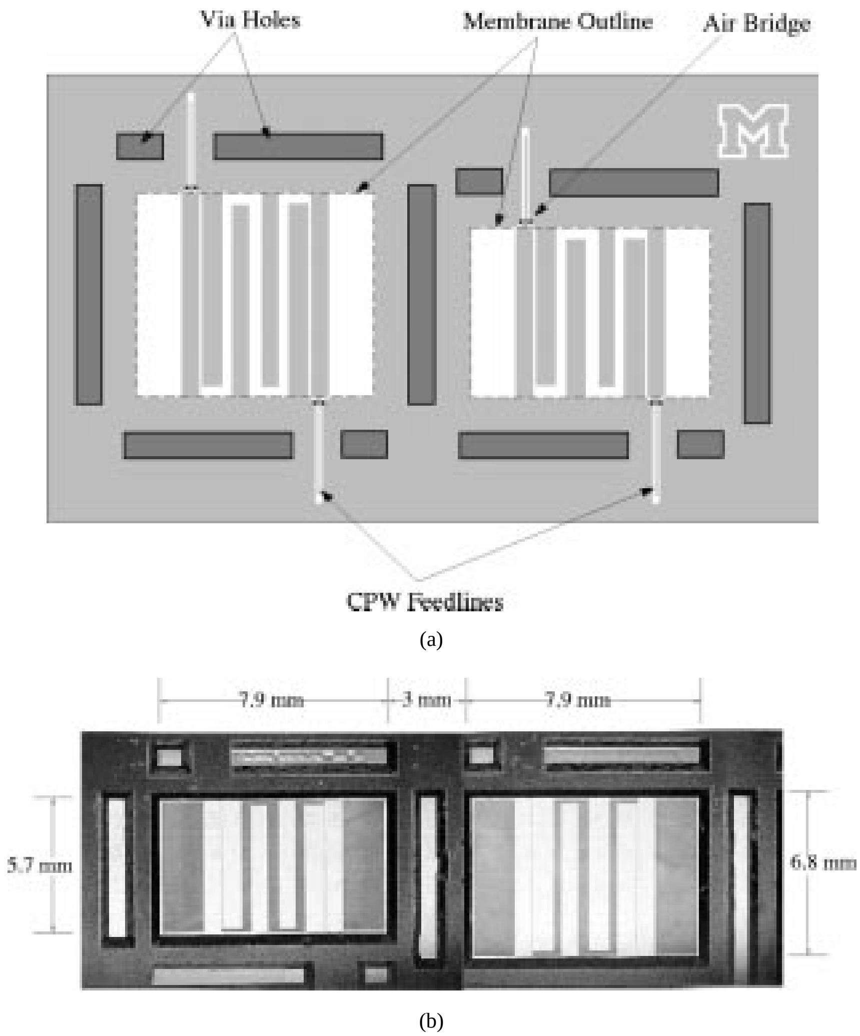

Fig. 3. Micromachined micropackaged filter bank with top cavity and carrier substrate removed. (a) Top view of filter substrate. (b) Bottom view of fabricated filters.

at the input of each filter to suppress undesired modes resulting from the strong coupling of the first finger of the filter.

The total surface area of the filter bank is 22.5 mm $\times$ 10.3 mm (Fig. 3). The entire structure is only 1 mm thick, which is about 5$\times$ smaller than conventional switched filter banks.

III. Measurements

The filter response and isolation were measured from 2 to 16 GHz using a Hewlett Packard 8510C Network analyzer. A Short-Open-Load-Through calibration method was used with 150-μm pitch Picoprobes and a calibration substrate from GGB Industries.

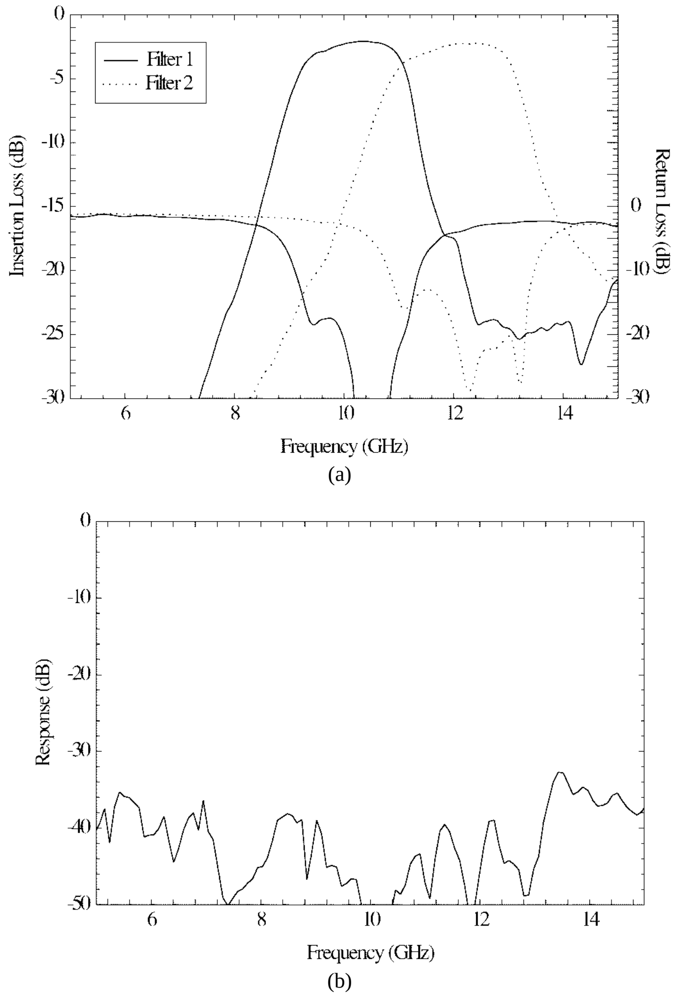

Fig. 4. (a) Measured response and (b) isolation of the micropackaged filter bank.

The measured port-to-port insertion loss is 2 dB for each filter [Fig. 4(a)]. The port-to-port loss includes the feedline loss, the transition loss between the silicon and the membrane, and the loss within the filter. The loss of each of the 0.4 mm GCPW feed lines is 0.4 dB each making a total feedline loss of 0.8 dB. The filter mismatch loss $(1-|S_{11}|^2)$ is 0.4 dB. The theoretical Q of the quarter-wave resonators is 310 using the attenuation coefficient from Zeland Software IE3D. [5]. This results in a calculated loss from the resonator fingers of 0.8 dB [4], and a port-to-port calculated loss of 2 dB, which is in very close agreement with the measurements.

The isolation between the filters was measured by loading one filter with a broad-band matched load at one port, applying a signal to the other port, and measuring the transmission at the closest port to the other filter. This is the case of the strongest coupling between the two filters. The measured isolation was below -40 dB across the passbands of the filters (Fig. 4b). We believe that this is limited by feedline radiation into the 525-μm silicon substrate [3]. It is important to note that micropackaging technologies will never achieve the isolation level obtained using two physically isolated substrates, but it does offer excellent performance for filters integrated close together on the *same* substrate.

IV. Conclusion

This letter demonstrates the capability of combining micromachining and micropackaging techniques to fabricate completely integrated high-performance filter banks with high isolation between elements. The processing used is compatible with via-hole fabrication in Silicon, SiGe, GaAs, and InP. This can result in low cost integration of high performance filter banks for communication systems.

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