A Surface-Mountable Membrane Supported Filter

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***Abstract*—A silicon micro-machined filter with a simple planar integration on an other substrate is proposed in this article. The excitation is made from the top of the shielding substrate of a membrane supported micro-machined filter. Packaging and inter-connection are included in the design. Experimental results are presented on a two pole 30 GHz, 4% fractional bandwidth filter with a quality factor of 602 and insertion loss of 1.8 dB. Such a filter can be easily integrated in any circuit using flip-chip technology.**

***Index Terms*—Filter, integration, micro-machining, vertical transition.**

I. Introduction

WITH the demand for broad-band and mobile wireless communication systems, the need for high performance, low-cost and small-size microwave circuits is increasing. For instance, planar technology is very attractive regarding cost and integration but it is well known that micro-strip or coplanar wave-guide (CPW) circuits have several disadvantages at millimeter wave frequencies. Among them, dispersion and radiation losses, as well as dielectric losses are increasing with frequency. For filter applications, performances are limited by insertion loss and low unloaded quality factors (Q_0). Therefore this technology is not well suited for narrow-band selective filters. Micro-machined planar filters, supported by thin dielectric membranes have proven to have good performances for millimeter wave applications, thanks to their high Q_0 [1]–[3]. However practical integration remains difficult to achieve, since for shielded structures, the top wafer prevents direct connection from the top or the bottom of the component. Wire-bonding may be required for external circuit connection. Therefore, obtaining a true planar connection to other circuits is very desirable. Vertical integration schemes have been proposed in the literature [4], [5], based on micro-machining. Trough-wafer transition have shown very attractive performances. Also, vertical single layer transitions, using electromagnetic coupling have been developed, without the need of via-holes [6]–[8]. For filters, a slot-coupled silicon micro-machined cavity filter has been presented in [9]. In [10], it has been shown that surface-mountable millimeter wave-guide like band pass filter can be achieved. However, integration of micro-strip filters is highly desirable because it allows to use a wide range of structures and it is very flexible for the design of various filters, compared to quasi planar cavities or wave-guides.

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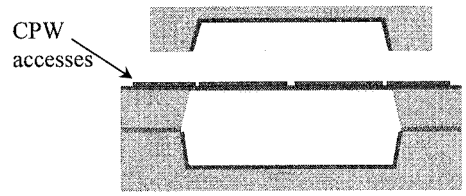

Fig. 1. Membrane supported micro-machined filter.

In this article, we propose a surface-mountable 30 GHz micro-machined planar filter. Such filter can be easily reported on an other substrate. Collective fabrication and tight mechanical tolerances can be achieved using photolithography and silicon wet etching. This solution combines high performance of micro-machined filters with easiness of integration.

II. Presentation of the Structure

For passive components, high resistive silicon (Si) has been used as a substrate for its possibilities to be micro-machined. Filters, antennas and diplexers have been fabricated with attractive performances [11], [12]. One of the most popular micro-machining technique consists in etching Si substrate and to suspend the circuit on a thin dielectric membrane. The use of two other micro-machined substrates enables to shield the structure to avoid radiation losses. The propagation occurs in air, with almost no dispersion and no dielectric losses. Such a structure is very attractive for millimeter-wave filters, since it allows to achieve high Q_0.

The problem with this technique is integration and connection of such filters. A micro-machined filter is presented in Fig. 1. Wire-bondings are needed for connection to compensate the height of the top wafer. Unfortunately with such techniques, important losses and high inductances are inevitable at high frequencies. We propose a filter with input/output on top of the structure. This planar integration allows an easy connection by flip-chip techniques [13], for instance.

The structure is described in Fig. 2. Fig. 2(a) presents a cross section, Fig. 2(b) the top level and Fig. 2(c) the circuit level. A CPW line is used on the upper substrate (high resistive Si) to feed the filter using a slot in the shielding of the upper cavity. Input-output couplings of the resonators are achieved with the magnetic field loops of the lines across the slots, as shown in Fig. 2(a).

III. Fabrication

This filter is fabricated using three wafers, two high resistivity (HR) silicon wafer and one Low Resistivity (LR) with a permittivity equal to 11.7. The thickness is 425 μm for the HR substrates and 525 μm for the LR. Thermally grown $SiO_2 (1\ \mu m)$ and evaporated Cr (300 Δ) are used as etch masks. The micro-

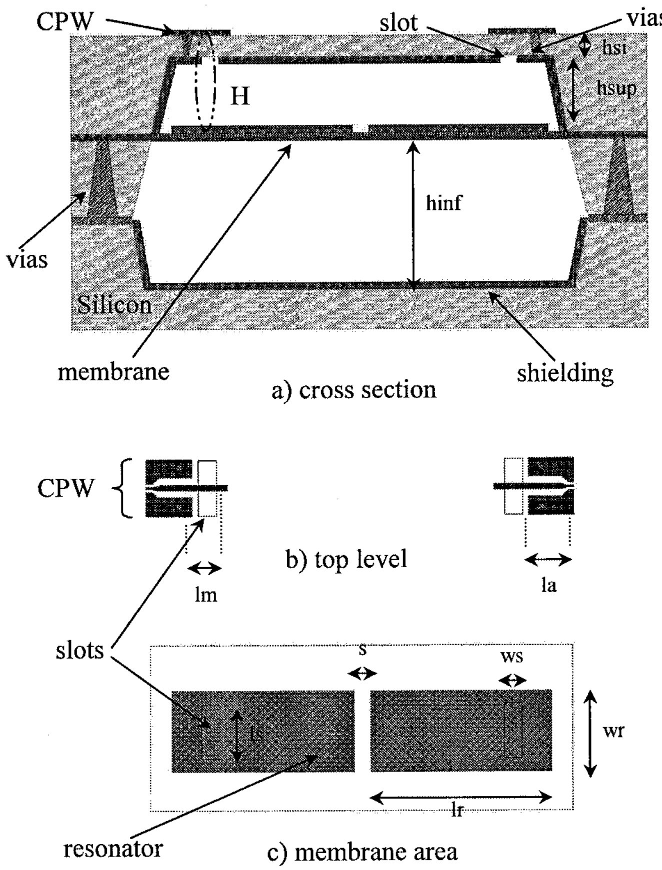

Fig. 2. Presentation of the structure.

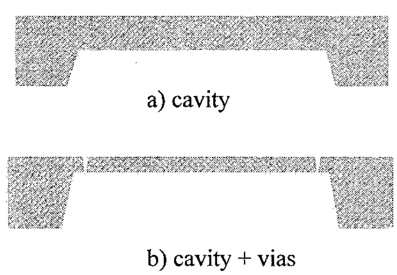

Fig. 3. Top wafer process.

machined cavities are etched with TMAH. The height of the upper cavity is 325 μm (hsup) and 760 μm (hinf) for the lower one. The air thickness has been chosen to achieve important Q_0 [14].

Concerning the top wafer, the first step is to etch about 200 μm of the cavity [Fig. 3(a)]. Then a second mask is used to etch the cavity and the vias from the top until the vias are open (Fig. 3(b)). The vias connect the ground of the CPW accesses with the ground of the micro-strip resonator. The resulting depth of the vias is 100 μm with lateral dimensions 100 μm by 100 μm on the top level plane. They have pyramidal-shape due to silicon wet etching properties. For electrical connection and shielding, the lower side of the wafer is metallized with 3 μm thick evaporated and electroplated gold. The upper CPW input-outputs are fabricated. Then slots are defined on the lower part on the bottom of the deep cavity by lithography techniques.

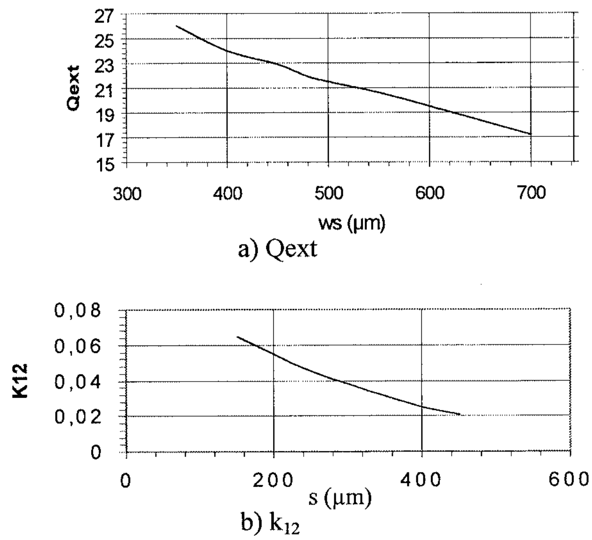

Fig. 4. Computed Qext (a) and K_{12} (b).

TABLE I
DIMENSIONS OF THE STRUCTURE, IN MILLIMETERS

wr	lr	s	ws	ls	lm	la	hsup	hsi	hinf
2	4.5	0.42	0.45	1.355	0.85	1.135	0.32	0.1	0.76

The fabrication techniques that are used for the membrane wafer and the lower shielding wafer are extensively described in [2], and will only be summarized below.

For the membrane wafer, 8 μm thick BCB is used as membrane to support the circuit. The filter layout is defined using classical deposition/lithography techniques, using 3 μm electroplated gold. Vias and membrane area are etched from the back of the wafer until the circuit is left free standing on the BCB membrane. The lower substrate is micro-machined to a depth of 335 μm and metallized with gold. The three wafers are then bonded together with sliver epoxy.

IV. Filter Design and Experiments

In order to validate this planar integration scheme, a two-pole Chebyshev band-pass filter with a center frequency close to 30 GHz and a 4% 3 dB bandwidth has been designed. Resonators are half wavelength end-coupled micro-strip transmission lines. Simulations have been made in a classic manner [15], [16] using Agilent Momentum (method of moments). According to the proposed prototype the target values for the filter are an external quality factor (Qext) close to 22 and 0.05 for the inter-resonator coupling (k_{12}). The value of k_{12} is deduced from odd and even mode resonance frequencies computation, obtained by simulating a de-coupled two resonators structure [16]. Qext is computed for different sizes of slot. Fig. 4(a) and (b) shows results for Qext and k_{12}.

The final dimensions of the filter are presented Table I.

Measurement were taken with a HP 8510C vector network analyzer and a cascade probe station. A SOLT calibration procedure was used and the presented results include CPW to micro-strip and vertical transition loss. A simple $\lambda/2$ resonator has shown a measured Q_0 of 602. Q_0 was deduced from the 3 dB

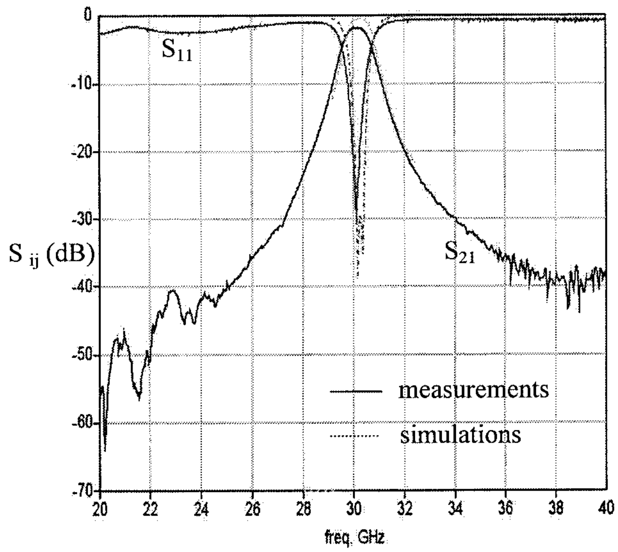

Fig. 5. Measured and simulated results of the filter.

response of a half-wave-length resonator in a free oscillation configuration with the Input/Output strongly de-coupled from the resonator. For the filter, measured and simulated results are presented Fig. 5. Good agreement is obtained both in center frequency and bandwidth. The frequency shift between simulations and measurements is only 0.7%. Insertion losses are 1.8 dB (0.8 dB in simulation). This shift is mainly due to the radiation of the upper CPW lines that are not shielded (but shielded in the simulation) and to metallic losses in the top shielding, that are not taken into account in simulations.

V. Conclusion

We have succeeded to implement an easily surface-mountable micro-machined filter at 30 GHz. Measured losses of the filter and the transitions are 1.8 dB. The associated design methodology has been presented and by changing the geometrical parameters of the circuit, it is possible to achieve rigorous designs of various micro-strip high-Q filters.

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