MSW resonators on micromachined silicon membrane

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***Abstract* – Tunable band-stop and band-pass straight edge resonators (SER) on silicon membrane were obtained and characterized. S-parameters have been measured at different DC magnetic biasing fields showing a frequency tunability domain between 3 GHz and 9.5 GHz ca for band stop resonators and between 2 GHz and 7.5 GHz ca. for band pass resonators. An improvement of the performances for the SERs excited by micromachined microstrip transducers has been clearly demonstrated. The utilization of silicon membranes to support MSW-SERs offers important openings toward the integration of magnetostatic wave devices in microwave circuit with micromachined structures.**

Key words: Microwave resonators, YIG monocristalline film, Silicon membrane, Micromachining

I. INTRODUCTION

Microwave sources and filters having broadband characteristics and high spectral purity are generally required for modern satellite and ground communication systems. Dielectric oscillators, not electronically tunable but characterized by high quality factors Q (about 10000), and varactor oscillators, tunable but having lower Q's (about 1000), have been extensively studied and are currently used depending on the preferred performance (tunability or quality factor) [1 - 4].

Magnetostatic wave (MSW) technology is well known for providing frequency tunable filters and oscillators for linear and nonlinear microwave signal processing. Planar microwave oscillators and filters based on MSW excitation in epitaxial garnet films propose themselves as a natural improvement of the existing devices, because they exhibit reasonable Q_{ext} values (oscillators: between 1000 and 3000, resonators: more than 3000) and broadband tunability. The operative frequency limits depend just on the active part (when oscillators are considered) and on the dc magnetic bias for the MSW resonator. Furthermore, the possibility to use a planar geometry favors the integrability in complex structures, overcoming in that way the problems introduced by the well established bulk yttrium iron garnet (YIG) sphere devices.

The rezonators were characterized by measuring S-parameters for different biasing magnetic field values, comparing the results obtained with the bulk and micromachined configuration.

II. SILICON SUBSTRATE MICROMACHINING

Two kinds of substrate were used: a 4000 Ω.cm, 400 μm thick bulk silicon and a 50 μm thick membrane anisotropically etched by means of a KOH wet etching process in a bulk silicon substrate. Silicon permittivity is $\varepsilon = 11.7$, enabling a $w_0 = 500$ μm feeding microstrip lines in order to obtain a 50 Ω impedance at the device ports.

In order to obtain a membrane on the back-side and a microstrip configuration on the top-side of the silicon wafer, the following technological steps were performed.

a) The wafer was thermal oxided in order to obtain an 1.7 μm oxide layer on both faces

b) The device area was delimited on both the sides of the wafer by a double side photolithographic process.

c) A preliminary oxide etching (25% from initial thickness) was performed in order to superimpose the mask configuration in oxide layer. This is necessary for mask alignment on the two sides of silicon wafer.

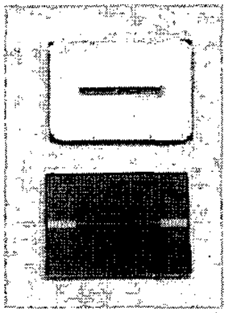
d) The membrane is obtained by anisotropic silicon wet etching in a KOH solution at 80 ^{0}C with a rate of 1 μm/min. The remaining silicon forms a 50 - 60 μm membrane, as it was the request for this experiment.

e) On the silicon substrate a 10,000 Å aluminium layer was deposed on top-side and 5 000 Å aluminium on the back-side of the wafer. The metallization on the backside is the ground plane of the microstrip geometry to be defined on the wafer topside.

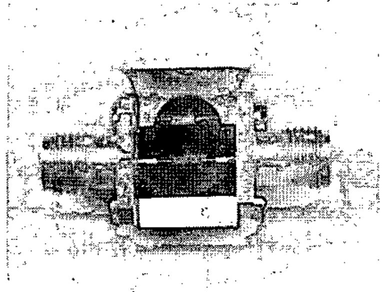
f) The microstrip line was obtained following a process of alignment/masking and metal etching.

III. BAND-STOP MSW RESONATORS. CONSTRUCTION AND EXPERIMENTAL RESULTS

Two rectangular samples of epitaxial yttrium iron garnet (YIG) layer grown on gallium gadolinium garnet (GGG) substrate were used as resonating structures on silicon bulk and on micromachined silicon membrane. The same YIG/GGG samples were used in all experiments. YIG/GGG resonating chips dimensions were: sample (A): 4×0.5×0.32 mm^3; sample (B): 4×0.4×0.32 mm^3. In both the samples the thickness of gallium-gadolinium garnet substrate was 300 μm and the thickness of yttrium-iron garnet layer was 20 μm. The resonator structure in a microwave test fixture is presented in Fig.1.



a)

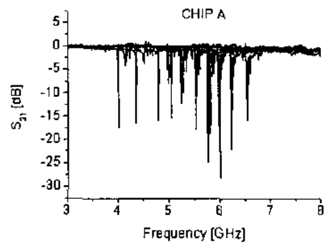


b)

Fig.1. The micromachined silicon substrate: back-side and top-side (a) and band-stop resonator in microwave test fixture (b).

The resonators were characterized by measuring S-parameters for different biasing magnetic field values, comparing the results obtained with the bulk and micromachined configuration.

Experimental results on the band-stop SERs supported on silicon bulk for samples A and B are presented in Fig.2, while in Fig. 3 the results for silicon membrane are shown.



a)

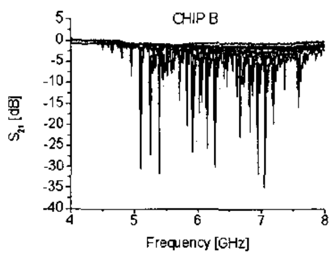


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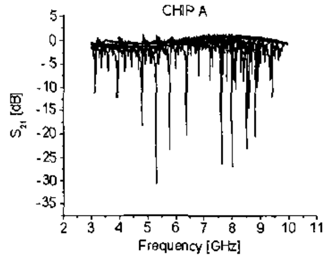
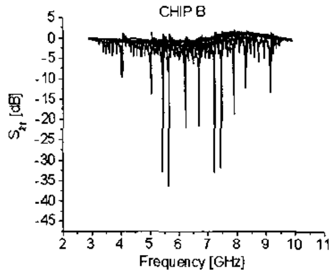
Fig.2. Experimental results. S_{21} record of the band-stop SER supported on ***silicon bulk*** for samples A and B.

For the membrane supported resonators the dc magnetic biasing fields were changed between H_{appl} = 0.02 T and H_{appl} = 0.34 T. providing a frequency tunability range between 3 GHz and 9,5 GHz ca.

Attenuation at resonance is ranged between -24 dB at the limits of the frequency domain (4.70 GHz and 7.5 GHz) and -36 dB in the mid-frequency band (5 GHz ... 6.5 GHz). The quality factor measured at two frequencies in the middle of the tunability domain was (approx.) Q = 520 at 5.34 GHz and Q = 480 at 6.00 GHz.



a)



b)

Fig.3. Experimental results. S_{21} record of the band-stop SER supported on ***silicon membrane*** for samples A and B.

From Fig.3 (a) and (b) it can be seen that there are not critical dimensions of YIG in the band-stop configuration.

IV. BAND-PASS MSW RESONATORS. CONSTRUCTION AND EXPERIMENTAL RESULTS

The same two rectangular samples of epitaxial YIG/GGG layer, supported by silicon bulk or by silicon membrane, were used in all experiments. The silicon (bulk and micromachined) substrates were obtained as it was previously described. Cr/Au followed by Au electroplating was used for the microstrip transducers, up to a 1.5 μm of thickness [5]. The band-pass resonator structure mounted in a microwave test fixture is presented in Fig.4.b) In the coupling region the transducers width/length dimensions were 50μm/4mm, to minimize the crosstalk effect.

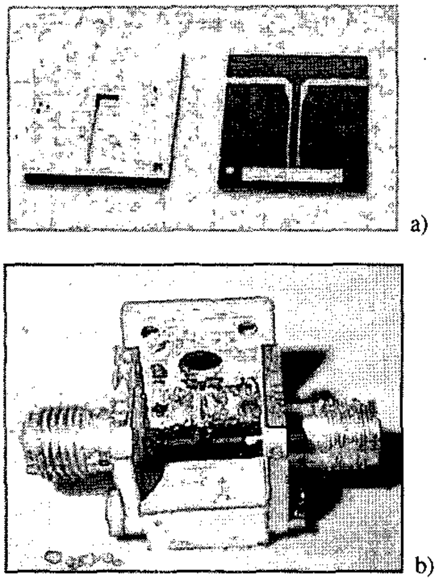


Fig.4. The micromachined silicon substrate: back-side and top-side (a) and microwave band-pass resonator in test fixture (b)

The resonators were biased with a DC magnetic field whose strength was changed to provide a frequency tunability from 2 GHz to 6 GHz ca. The frequency has been swept between 2 GHz and 5 GHz for silicon bulk resonators and between 2 GHz and 6.5 GHz for silicon membrane resonators. In Fig.5 (a) and (b) the measurements of the two YIG samples on the silicon bulk substrate are shown. For sample # A (Fig.5 a) the level of losses is quite high, close to -20 dB, and a high order mode appears not far from the main one with other lower intensity modes. The rejection ratio (RR) is greater than 20 dB.

Passing to the micromachined configuration, whose performances are shown in Fig.4 and 5, two main differences can be seen as compared to the bulk one. First of all, the 50 Ω matching condition for the microstrip is valid also in the coupling region, and this solution decrease the losses level, which is now less than 10 dB in S_{21}. Losses are between -10 dB and -7 dB within the operative range. Moreover, the crosstalk is still under control, with an isolation better than 30 dB. The micromachining of the silicon wafer has caused a shift of the operative frequencies available for the resonator, owing to the decrease of the effective permittivity for the exploited structure, and a widening of the operative range.

The S_{11} parameter was recorded (see Fig.7) in order to characterize the membrane supported resonator matching for different magnetic applied fields.

$|S_{11}|$ values (see Fig. 7) for membrane supported SER are:

- $|S_{11}| = 8.5$ dB for $H_{apl} = 540$ Gs, (VSWR = 2.2);
- $|S_{11}| = 7$ dB for $H_{apl} = 1333$ Gs (VSWR = 2.6)
- $|S_{11}| = 16$ dB for $H_{apl} = 1980$ Gs, (VSWR = 1.37).

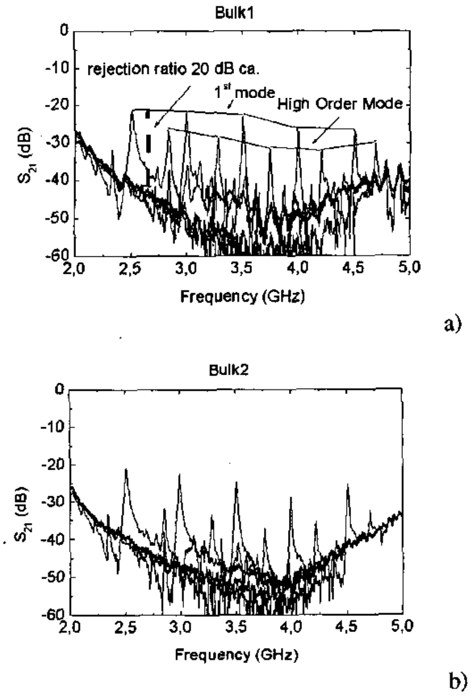


Fig. 5. Transmission characteristics for the ***silicon bulk*** MSW-SER

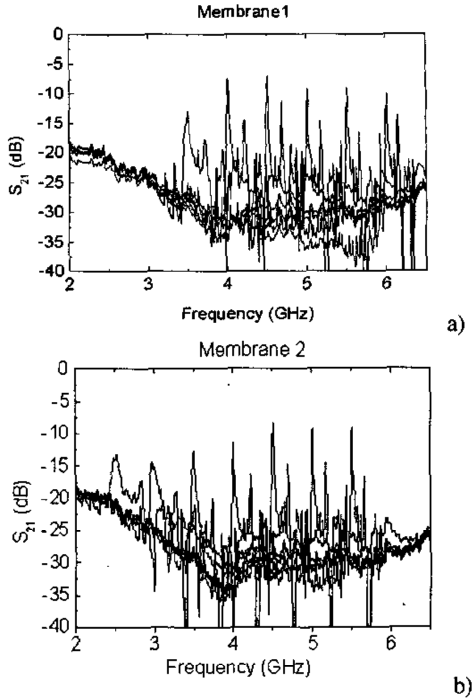


Fig. 6. Transmission characteristic for the MSW-SER on ***silicon membrane.***

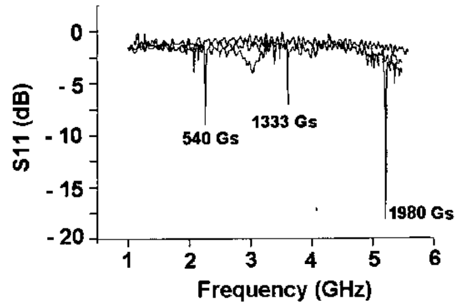


Figure 7. S_{11} of pass-band membrane supported SER for three different applied magnetic field.

V. CONCLUSIONS

Two stop-band SERs on silicon membrane were obtained and characterized. The frequency tunability domain for stop-band resonators was between 3 GHz and 9.5 GHz ca. obtained by changing the dc magnetic biasing field between $H_{appl} = 0.02$ T and $H_{appl} = 0.34$ T.

Measurements of S_{21} parameter demonstrate an important suppression with more than -20 dB of the higher modes showing a good selectivity of this kind of resonator. The rejection ratio was better than 20 dB with respect to the bias line in the frequency domain from f = 3 GHz to f = 9.5 GHz for the chip A and between f = 4.2 GHz and f = 9.5 GHz for the chip B.

Regarding band-pass micromachined resonators, three main differences can be seen as compared to the bulk one: (a) the matching condition for the microstrip is valid also in the coupling region, and this solution helps the losses to reach a level less than 10 dB. Losses are between -10 dB and -7 dB within the operative range. (b) the crosstalk is still under control, with an isolation better than 30 dB and (c) the micromachining of the silicon wafer has caused a shift of the operative frequencies available for the resonator widening the operative range.

The VSWR parameter shows values about 2 with a top value of 1.37 at a frequency of about 5.2 GHz.

These results demonstrate possibility to obtain microwave band-stop and band-pass MSW resonators supported on silicon membrane with high isolation and rejection ratios. The obtained results demonstrate both: (i) the possibility to combine the MSW technology with the micromachining one, and (ii) the improvement obtained by the resonators supported on silicon membrane, with respect to the silicon bulk one.

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