GaAs membrane supported millimeter wave filters

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ABSTRACT

This paper presents the fabrication processes for micromachined millimeter wave devices on micromachined GaAs substrate. For the first time, a 2.2 μm thin GaAs/AlGaAs membrane, obtained by MBE growth and micromachining of semiinsulating <100> GaAs, is used as support for millimeter wave filter structures. Cascaded coplanar waveguide open-end series stubs filter type structures, with central frequency of 38 respectively 77 GHz were designed and manufactured on GaAs micromachined substrate.

“On wafer” measurements for the filter structures were performed. Losses less than 1.5 dB at 38 GHz and less than 2 dB at 77 GHz have been obtained for both the silicon as well as for the GaAs based micromachined filters.

Keywords: micromachining, GaAs membranes, millimeter wave filters

1. INTRODUCTION

The development of millimeter wave integrated circuits requires low-loss, low-dispersion planar transmission lines. Microstrip lines and coplanar waveguides (CPW) suffer from several problems at microwave and millimeter wave frequencies. These include dielectric losses, which increase with frequency, as well as dispersion, substrate mode problems and radiation losses.

To avoid some of these drawbacks, substrate supported structures require mainly substrate thinning to improve millimeter wave performance of planar circuits. An alternative solution to the frequency limitations of planar circuits is to integrate the antennas, components and transmission lines on a thin dielectric membrane using micromachining techniques. A very thin dielectric or semiconductor layer used as support for passive circuits elements (inductors, capacitors, transmission lines, filters and antennas) reduces the effective dielectric permittivity to values very close to 1, so circuits looks like being “air suspended”. One of the most exciting applications consists in the technology for manufacturing of semiconductor and dielectric membrane supported microwave circuits.

The technology of dielectric membranes - as support for microwave circuits - was introduced by the group of Ann Arbor University, Michigan [1-5]. The key element of this technology is the three-layer membrane (SiO2/Si3N4/SiO2) obtained by micromachining of high resistivity <100> silicon. In the last years, European groups have also reported significant results on micromachined microwave circuit elements supported on dielectric membranes [6 - 10]. In addition, passive devices on polyimide membranes were also reported [10 - 11]. A semi-insulating GaAs semiconductor membrane, as support for microwave circuits, represents an interesting solution due to the possibility of passive elements integration with active elements manufactured on the same substrate. The higher value of the GaAs dielectric permittivity only slightly increases the effective permittivity because the very small thickness of the membrane.

In the last decade, a major effort has been focussed on silicon micromachined sensors manufacturing, based mainly on the existing processing techniques associated with silicon technology [12]. The main advantages of silicon are the better mechanical endurance, its low cost and the fact that it is the mostly used semiconductor material in micromechanics [13]. As a sensor and actuator material, GaAs has advantages as well as disadvantages, in comparison with silicon. Among the advantages are his direct bandgap transition, the high value of the band gap, the presence of the piezoelectric effect, its higher Peltier coefficient, and its wider operative temperature range. The disadvantages of GaAs regard mainly the costs, the lower degree of crystalline perfection, therefore the difficulties in technological processing.
The specific material properties of GaAs and others III-V’s semiconductors, that assures performances advantages in special applications is the reason for the development of micromechanical sensors based on these materials. Among these properties there is the high energy band gap (1.424 eV) allowing high temperature electronics, monolithic electronics in GaAs being operative up to 400°C [3]. Also, from the integration viewpoint, GaAs is preferable to silicon, due to the easy integration of sensing elements with MMIC’s or optoelectronic active devices.

Since GaAs manufacturing technology has been rapidly progressing, the micromachining of GaAs and other III-V’s compounds has been developed in the last years [13,14]. There are two methods for bulk micromachining of GaAs, in order to obtain membranes and cantilevers. One method is the nonselective etching, based on isotropic etching of bulk GaAs; 10-25µm thin GaAs membranes can be manufactured [15]. The other method uses selective etching, with AlxGa1-xAs as effective etch-stop layer [16]. Heteroepitaxial layers AlxGa1-xAs on GaAs of controllable fraction of x can be grown by means of expensive equipment as MBE or MOCVD. In particular, some dry and wet etching systems exhibit etching rates of AlGaAs with orders of magnitude higher than for GaAs and vice versa (if x >0.5).

This feature offers the possibility to apply the whole “arsenal” of micromachining to the GaAs system (including bulk and surface micromachining). Using the GaAs/AlGaAs heterostructures and the etch stop properties of AlGaAs, GaAs membranes and cantilevers were manufactured and pressure, power, and thermoelectric sensors were reported [17-19] as well as membrane supported circuits [20]. If wet etching is used, three possible micromachining techniques for GaAs RF MEMS devices manufacturing are presented in figure 1.

![Figure 1. Possible micromachining techniques for GaAs based RF MEMS](image)

This paper presents, for the first time, the manufacturing of millimeter wave filters supported on thin GaAs/AlGaAs membrane. Cascaded coplanar waveguide open-end stub filter type structures, with central frequency of 38 respectively 77 GHz were designed and manufactured.

**2. MANUFACTURING OF GaAs MEMBRANE SUPPORTED FILTERS**

Conventional and Low Temperature III-V MBE growth was used to fabricate the GaAs/AlGaAs/GaAs heterostructure. Semi-insulating GaAs wafers (ρ = 10⁷ Ωcm), with a thickness of 460 µm, were used as substrate. The MBE process started with a very thin (50nm) buffer GaAs layer deposition. Over this layer, a 0.2 µm thin AlxGa1-xAs layer with x=0.6 was deposited (the AlxGa1-xAs layer is the etch-stop respective to GaAs in numerous dry and wet etching systems, when x > 0.5). Over the AlGaAs layer, a low temperature semi-insulating 2 µm thin GaAs layer (ρ > 10⁸ Ωcm) was deposited (figure 2). This value of the resistivity is high enough to ensure very good performances in the millimeter and submillimeter wave frequency range.
The growth experiments were performed in a VG80 horizontal MBE chamber with a background pressure of $10^{-10}$ mbar. During growth, the chamber pressure was $10^{-7}$ mbar.

![Figure 2. The experimental heterostructure](image)

Conventional contact lithography, e-gun evaporation and lift-off techniques were used to define the filter structure. A 500Å Ti / 7000Å Au metallization was used. Then the wafers were mounted face-down on special glass plates and the GaAs substrate was thinned down to 150 μm by lapping technique. The etching pattern for the membranes was defined by backside alignment contact photolithography. The membranes were fabricated in a Vacutec 1350 RIE chamber using CCl$_2$F$_2$. End point detection and optical (visual) detection was used during the RIE etching. After the selective etching, the thickness is approximately 2.2 μm. The SEM photo of the GaAs/AlGaAs membrane is presented in figure 3 a., where it is evident that the RIE procedure yielded practically vertical sidewalls.

![Figure 3. SEM photo of the GaAs/AlGaAs membrane: (a) the selective dry etching profile; (b) detail](image)

![Figure 4. Bottom AFM photo of the GaAs/AlGaAs membrane](image)

A detailed SEM photo of the membrane is presented in figure 3.b. The roughness of the bottom of the membrane (the surface of the AlGaAs etch stop layer after the RIE process) was analyzed using AFM techniques (figure 4). The

![Figure 5. SEM photo of the 77 GHz filter on membrane](image)
measured average roughness on the bottom of the membrane was small (about 8 nm), with no influence on devices (which are manufactured on the top of the membrane).

The band-pass filter for 38 GHz was based on a four cascade / opposite double folded CPW open-end series stubs structure. Quarter wavelength folded stubs were used to decrease the length of the filter. The 77 GHz filter design was based on four cascaded standard CPW open-end series stubs, non-folded due to the lower length of the quarter wavelength stubs. A SEM photo of the membrane supported filter structure is presented in figure 5.

The design was based on a quarter-wavelength coplanar waveguide stubs synthesis procedure, taking into account the open-end effects and neglecting the coupling between adjacent stubs.

Top view and bottom view photographs (details) of the 38 GHz CPW and 77 GHz double folded four-cell band-pass filter on GaAs/AlGaAs membrane, patterned by lift-off technique, are presented respectively in figures 6 and 7. The transparency of the membrane can be seen. It can be observed that the position of the filter structure with respect to the membrane-bulk transition is very close to the designed layout.

The membrane dimensions were 3550 μm x 1200 μm for the 38 GHz filter structure and 4070 μm x 900 μm for the 77 GHz filter structure. The bending was very small (less then 0.2μm), for the regions far from the metallized areas and has a maximum value of about 3μm in the regions with high density of metallized lines. This value is very small compared with the membrane dimensions and has no effect on device performances. The bending was analyzed using white light interferometry.
Figure 8. White Light Interferometric analysis of 38 GHz (a) and 77 GHz (b) membrane supported filter

One can see that the maximum membrane deflection, due to the stress induced by the metalization, is reasonably low (up to 3.5\(\mu\)m) for a few millimeter long membrane.

3. MICROWAVE MEASUREMENT RESULTS

The microwave measurements were performed at IRCOM - Limoges, France, using an “on-wafer” measuring set-up equipped with Cascade Microtech coplanar probes (with working frequency ranges of 0-50 GHz and 70-110 GHz, respectively) and a HP 8510 network analyzer.

The S parameter measurements for 38 GHz GaAs based band-pass filters are presented in figure 10, while those for 77 GHz are presented in figure 12. The 38 GHz filter characteristics exhibited approximately 1.46 dB insertion loss at 38 GHz and a maximum return loss of 34.2 dB at 36.4 GHz. The 77 GHz filter responses exhibited a minimum insertion loss of 1.87 dB at 72.4 GHz and a maximum return loss of 17.4 dB at 74.8 GHz. There is a fairly good agreement between the measured and the calculated characteristics of the filter structures, less than 3.4% between the measured and design values as concerns the band-pass central frequencies.
Micromachined passive circuit millimeter wave elements - filters for 38 and 77 GHz - supported on GaAs membranes are presented for the first time. The membranes were obtained using MBE, selective dry etching (RIE) and the etch-sop property of a thin AlGaAs layer. Very low losses at 38 and 77 GHz were obtained. The main advantage of this technological process consists in the possibility of manufacturing of integrated receiving modules on GaAs including the active devices together with the passive elements in the millimeter and submillimeter wave range.

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