LN Membrane Suspended on Pedestals as a Waveguide

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***Summary*—Crystalline lithium niobate (LN) membrane attached by pedestals to a substrate having high acoustic velocity can be an ideal waveguide with the acoustic energy concentrated mainly inside the membrane and not leaking into the supporting substrate. The acoustic modes of the membrane can have extremely high piezoelectric coupling, the device being more robust than the membrane suspended over a cavity.**

Keywords—piezoelectric; membrane; Lamb modes; SH-modes; resonator; XBAR; YBAR

I. INTRODUCTION

Crystalline piezoelectric membranes either suspended over a cavity or attached to a substrate are now intensively studied for the development of micro/nano acoustic resonators and filters. Thickness resonances are used to develop XBARs [1] – laterally excited resonators operating at a 5 GHz frequency range with excellent parameters. However, the sub-micron membranes are fragile and the evacuation of heat from such a membrane is a problem, because of the low thermal conductivity of LN. To solve these problems numerous variants to use a membrane deposited on a substrate (especially with high acoustic velocity, such as diamond, *SiC,* etc.) were proposed (see e.g., [2]). Unfortunately, the hard substrate radically changes the acoustic mode structure and concentrates a significant part of acoustic energy (even if wave guiding is yet conserved) and, thus, visibly decreases piezo coupling.

Here we show that using the membrane suspended on pedestals solves both problems: the structure remains robust, the heat is easily evacuated in perpendicular to the membrane direction through metal electrodes, and the coupling is reduced not dramatically compared to a free membrane. Such a suspended membrane remains an ideal waveguide in a frequency range depending on the pitch p between pedestals and acoustic velocity in the substrate.

II. METHODS/RESULTS

Acoustic waveguides are widely used in resonators allowing them to channel wave propagation and avoid acoustic energy loss caused by waves radiated into the substrate. Usually, a waveguide is created by a slow acoustic velocity layer deposited on the high-velocity substrate. Such a structure used in the I.H.P. technology [3] gave a radical decrease in filter losses. Another example is Lamb modes and shear modes in a free membrane suspended over a cavity, such as in the A1 Lamb mode devices [1, 4].

Here we propose a kind of intermediate case: when a membrane is solidly attached to a substrate through pedestals. One example of such a device, exploiting XBAR-type of acoustic mode (A1 Lamb mode) was already briefly described in [5]. A similar structure, with cavities under the membrane, was recently proposed in [6]. The same idea can be applied to different types of membrane modes: SH0, S0, YBAR (SH1), and A1. Three moments are important here:

1. If we can use a rather mall pitch p: $p * F_R < V_{bulk}$, where V_{bulk} is the bulk wave velocity in the substrate (skimming along the surface and with the same direction of the main displacement components as in membrane mode) then we avoid radiation into substrate because of destructive interference of the bulk waves generated by stress at the interface between the pedestals and substrate.
2. For the shear waves in the membrane, close to SH0 or SH1 modes, with displacement in the Y-direction (Fig.1), the propagation of shear waves down through pedestals might be impossible if the pedestal is sufficiently narrow.
3. The metallic pedestals supporting the membrane can be used as low-resistivity transducer electrodes and, simultaneously, serve for efficient heat evacuation.

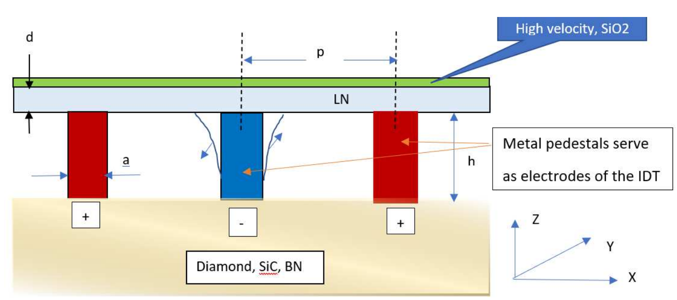

Fig.1 Device geometry, schematically; proportions are not observed

Additional layers can be deposited on the top of the membrane, for example increasing the wave velocity or improving the TCF (Fig.1). For the moment the technology of manufacturing this device is under development; meanwhile, as a positive feature we can mention that no precise alignment of electrodes is demanded – we have only one periodic set of electrodes/pedestals to which uniform membrane must be attached.

We modeled this device using FEM software analogous to that described in [7]. Here we present simulations of S0 mode in an LN membrane suspended on pedestals over a diamond or SiC substrate. The device includes a 200 nm thick LN X-cut membrane (Euler angles [90° 90° 30°]) with Nt=50 pairs of electrodes, $a = 0.3\ \mu m$ wide electrodes/pedestals situated with the pitch $p = 0.5\ \mu m$, $h_{Al} = 100\ nm$ thick, aperture $W = 50\ \mu m$. The diamond substrate was simulated, although the very similar curve is obtained with SiC substrate.

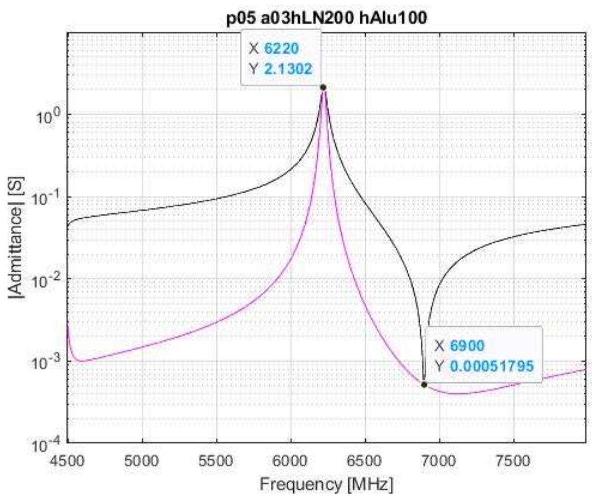

Fig.2a FEM-simulated admittance Y. Black curve is for $abs\ (Y)$ and pink curve for $real(Y)$

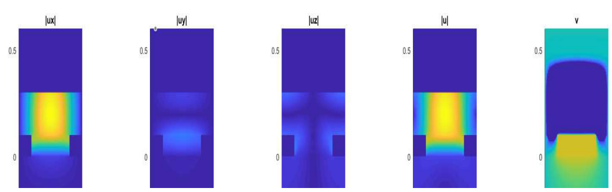

Fig.2b Acoustic fields (ux, uy, uz, abs(u)), and potential: only intensive longitudinal mode is present at resonance.

Very strong coupling with Resonance-antiresonance relative frequency distance R-a-R = 10.3% is found (Fig.2a), with the wave velocity at antiresonance of 6900 m/s. Due to such high velocity, the 6.5 GHz resonator is realized with the pitch $p = 0.5\ \mu m$. This velocity, being high compared to typical SAW velocities of around 4000m/s, is still smaller than shear bulk wave velocity in SiC (or in diamond), and in Fig.2a we do not see visible losses due to the bulk wave scattering/generation into the substrate.

The visualized acoustic fields (Fig.2b) show that only one strong compressional longitudinal component u_x is present in membrane. Similar results are obtained for SH0 mode, with the main displacement component u_y which will be published elsewhere.

III. DISCUSSION/INTERPRETATION

In this suspended-over pedestal waveguide structure the limiting frequency, when there is no intensive bulk wave radiation in the substrate is determined by the velocities of acoustic waves in the substrate, which means a significant increase in operating frequency. Meanwhile, we use here the propagating waves in the membrane, with a resonance frequency determined by the pitch, which makes the design of devices similar to usual SAW devices. In the above example we profit of the high velocity of S0 mode, around 6 km/s and we can design resonators for 3 GHz – 5 GHz frequency range with critical dimensions > 0.3 μm. The suspended on pedestals waveguides might give significant advantages: robust devices with low loss and high power handling

IV. CONCLUSIONS

We have proposed here the use of a suspended membrane as an ideal waveguide for the design of resonators and filters. The ion-sliced sub-micron crystalline layers transferred on silicon and other substrates are now available as 4-inch wafers and that makes devices exploiting such suspended membranes more realistic than pure fantasy. Our simulations show that the resonators with R-a-R frequency difference of 10% to 12% are possible, close to the values achieved in XBARs, exploiting free membranes suspended over a cavity. Further optimization of the structure is necessary, including different types of Lamb modes in the membrane, multilayered membrane, optimal cuts of LN, etc. An intensive study of the LN membranes in combination with different substrates finally will result in devices with excellent parameters: low loss and high power handling.

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