Conception of Wide Band Surface Acoustic Waves Filter in L-band based on Lithium Niobate substrate

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SAW devices are widely used for filtering applications for radio-frequency (RF) telecommunications, defense or space and their number is still increasing in front-end devices and modules. The development of new generations of setups and telecommunication standards as well as the need of transmit more and more data require the development of new filters at high frequencies and/or with a wide pass band.

In this paper, we aim to design and manufacture a wide band (about 15% relative pass band) Surface Acoustic Waves (SAW) filter at a frequency comprises in L-band (between 1 and 2 GHz) based on Lithium Niobate ($LiNbO_3$) (YX) substrate. Due to the desired bandwidth, $LiNbO_3$ was chosen because of high electro-mechanical coupling coefficient (k^2) which can be achieved (in the order of 30%). The desired in-band losses must be better than 3 dB and the rejection better than 40 dB.

The mode considered here is the Pseudo Surface Acoustic Wave (PSAW) due to its high velocity (compared to the Rayleigh mode) and its high k^2, ideal for this application. The inconvenience of this mode is its radiation in the bulk if we consider a bulk $LiNbO_3$. The choice of the material used for the electrode gratings is then a key point in this design. Indeed, we have to consider heavy metals in order to shift, in terms of frequencies, the PSAW under the shear bulk [1]. Therefore, we can obtain an effect of guidance of the PSAW, which can then be compared to a “true” SAW. Furthermore, using such an electrode material also improves the value of k^2 up to 30% and more. A composite substrate can also be used instead of single crystal materials in order to have a guide wave. Unfortunately, this kind of wafers is not yet available at the begin of this study, but it is on going.

Another important parameter in the design of this filter is the presence of a Rayleigh wave in the frequency spectrum, near the PSAW. This mode can be problematic for the filtering function (decrease of the bandwidth, presence of spurious in the band...) if it is not well located. The use of heavy electrodes and the optimization of their thickness can potentially suppress the signature of the Rayleigh wave [2]. In this study, unfortunately, this goal is not totally achieved. So we are looking to place the “spurious” mode in the transition bands to minimize its effect on the filtering function by adjusting the frequency gap between the PSAW and the Rayleigh wave.

The filter architecture is considered as a ladder. It is composed of four (4) T cells (cf. Figure 1). So, the filtering function is realized thanks to twelve (12) resonators independent of each other by their aperture, number of electrodes pairs in the transducer, number of electrodes in the mirrors as well as their period. So, an optimization of each branch of the filter is done to realize the desired filtering function. In such a configuration, it’s well known the contribution of transverse modes is point to address. Therefore, we introduce an apodization function in the transducers to remove transverse modes.

An important step of this study is the characterization and the choice of the better metal for this application. The metal resistivity is then a key parameter, as well as the density, to allow an exploitable response of each resonator in the ladder. To validate our choice, Tantalum (Ta), Platinum (Pt), composite electrodes ($AlCu_{2\%}$/Ta), and finally Gold (Au) have been experimentally characterized. Even if, theoretically, Ta or Pt are good materials and allow to address the desired specifications, Au is a better choice in terms of resistivity. Considers experimental results from a first manufacturing of wafer in the well suited previously depicted configuration of piezoelectric and metal, the next step enables us to extract some experimental parameters and figures of merit. These data are used to improve our model, validate the location of Rayleigh modes and optimize the design. At last, a final design considering model improvements and a manufacturing run are achieved with final dimensions. We also propose in this work a characterization step performed on the wafer from the last run.

The final filter measurements are exposed (cf. Figure 1), showing the quality of the device operation concerning in-band losses and rejection (about 1.9 dB insertion loss (IL), with more than 32 dB rejection). The bandwidth of this filter is near our goal, with a relative pass band of about 13%, but an effort have to be done to maximize the rejection.

The first experimental S_{21} and S_{11} parameters of our filter are convincing compared to the specifications, but can be improved for a better filtering function. To understand the origin of these problems and overcome some of them, we use data from an electromagnetic study realized with Ansys HFSS©. These results allow us to decrease the rejection as well as high level in the lower transition band by adding some wire bonding between the grounds in the footprint (cf. Figure 1). This shows us that the footprint of our filter is not optimize and study must be done to improve this part.

Further works have to be done following this preliminary study to improve some negative aspects of our design, like the Rayleigh mode or the footprint which damage the performances. Despite these particular points, we have succeeded to realize a filtering function with a bandwidth of about 15%, with 1.9 dB insertion loss and rejection of about 32 dB thanks to the use of Lithium Niobate substrate and heavy metal electrodes. A main part of this study was to determine, theoretically and experimentally, the better material for the electrode gratings. After many tries, Gold was considered, but new developments must be done, especially to remove or move the Rayleigh mode. A new phase of optimization will also be performed in order to perfectly match the desired specifications.

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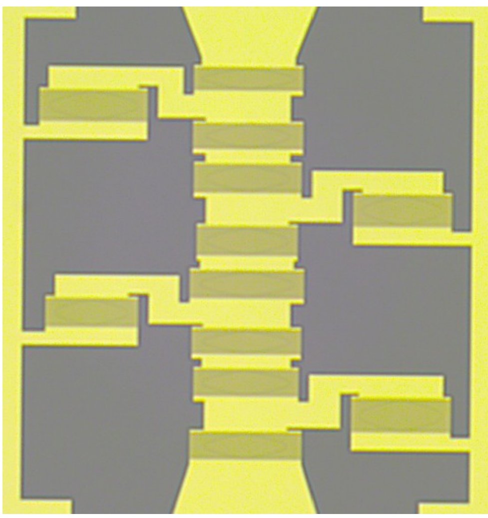
(a)

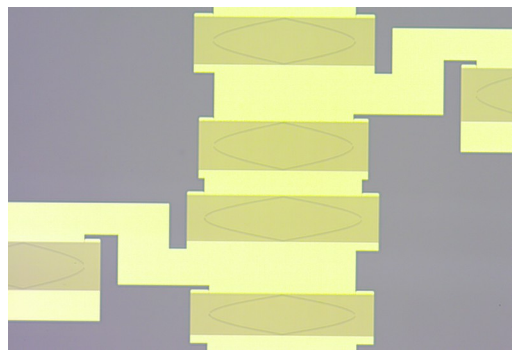
(b)

Figure 1: Final design of the ladder filter. (a) Observation of the 4 T cells in the design and (b) Enlargement of some resonators to see the apodization of each of them.

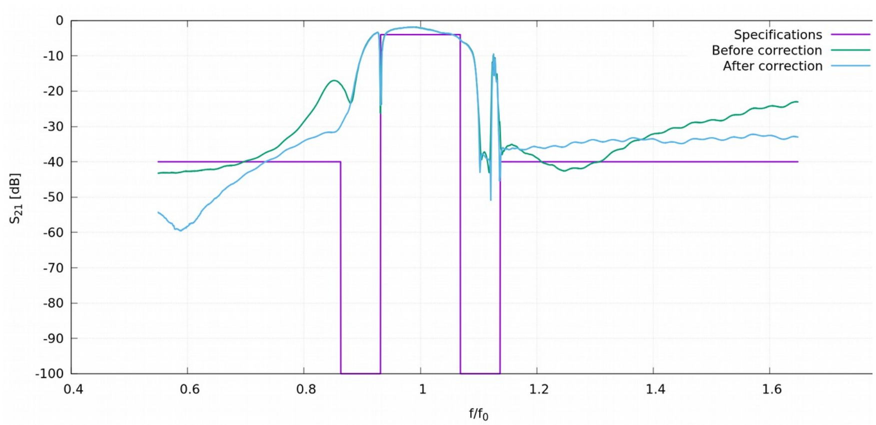

Figure 2: Experimental S21 of wide band filter in L-band on LiNbO3 substrate. The frequencies have been normalized due to confidentiality. In purple, the response without the bonding between the grounds. In green, the corrected response by the wire bonding.