Electrode Sizing for Guided Wave Resonator Above a Bragg Mirror

Issiaka Kone*†‡, Alexandre Reinhardt*, Frédéric Domingue*, Bertrand Dubus†,
Lionel Buchaillot†, Fabrice Casset*, Jean François Carpentier‡, Marc Aïd*
*CEA, Leti, Minatec, F-38054 Grenoble, France
Email: issiaka.kone@cea.fr
†IEMN département ISEN, CNRS UMR 8520, Lille, France
‡FTM-Crolles, STMicroelectronics, F-38920 Crolles, France

***Abstract*— This paper describes how to reduce spurious resonances which can take place in a resonator using guided waves above a Bragg mirror. These parasitics arise from overtone resonances as well as from higher order modes also excited by electrodes having inappropriate dimensions. In this paper, the influence of period and metalization ratio on the harmonic admittance of a resonator is studied.**

I. Introduction

Acoustic resonators are used in RF systems for their compactness and their high quality factors. Unlike BAW (Bulk Acoustic Wave) or SAW (Surface Acoustic Wave) devices which respectively exploit waves propagating in the thickness direction or waves guided at the surface of a piezoelectric medium, guided acoustic wave devices exploit laterally propagating waves guided by a piezoelectric layer [1]. In this frame, they are similar in their principle to Lamb wave devices, except that the wave confinement is obtained by the use of a Bragg mirror instead of a free surface. These waves are excited by pairs of interdigitated electrodes. The center frequency is globally determined by the spatial period of the finger-like electrodes. When the Bragg mirror achieves a high isolation [1], some care must be taken in order to reduce spurious resonances.

In this paper, we will first present a guided wave resonator in section II. Section III will present a method for overtones suppression. The influence of the metalization ratio will be presented in section IV.

II. Guided Wave Resonators

Guided wave resonators consist of a thin piezoelectric AlN films transducers as for Lamb Wave or Contour Mode Resonators [2],[3]. However, the resonator is acoustically isolated from the substrate by a Bragg mirror similar to the one used in Solidly Mounted BAW Resonators (SMR). Unlike the case of SMR BAW resonators, the design of the Bragg mirror is more complicated for guided wave resonator, since 1D propagation perpendicular to the interfaces between layers cannot be assumed. Indeed, the modes can be seen as a linear superposition of so-called partial waves, corresponding to the longitudinal and shear waves propagating in a homogeneous and unbounded medium. To improve isolation, these partial waves must be isolated from the substrate, taking into account the fact that one partial wave can be transmitted or reflected into another polarization at the interface separating two layers (mode conversion).

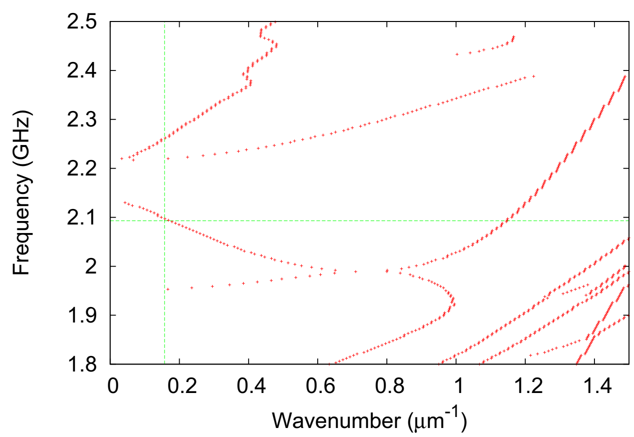


Fig. 1. Dispersion curve of the structure represented in table I. The intersection between the horizontal and vertical dashed lines correspond to the working point.

In this work, the scattering matrix method [4] is used for the calculation of dispersion curves [5]. This computation method takes into account the conversion of modes at each interface. Using the same model, we have implemented a calculation of the harmonic admittance of an infinitely long interdigitated transducer under the assumption of infinitely thin electrodes based on the derivations from Blotekjaër and Ingebrigsten [6].

III. Overtone suppression

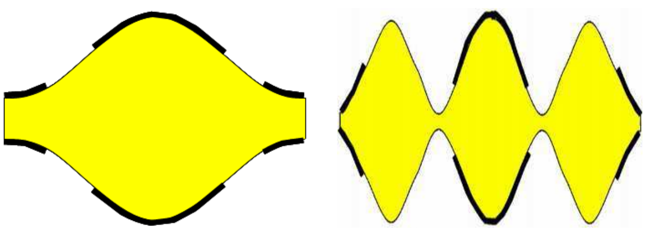
Using the computed dispersion curves, the next step consists in the selection of the working point. This point defines the operating mode and the center frequency. A typical dispersion curve is plotted on Fig. 1 for the resonator stack described in Table I. This working point is fixed by the period of the excitation interdigitated transducers, which corresponds to half of a wavelength. In this example, the chosen mode is similar to the second symmetric Lamb wave of the piezoelectric layer.

Ideally, this working point corresponds to a displacement shape like in Fig. 2(a). However, the same boundary conditions

TABLE I

LAYER THICKNESSES OF THE STRUCTURE USED AS EXAMPLE.

Layer number	Material	Thickness (μm)
# 1	Si	Semi-infinite
# 2	SiO_2	1.1
# 3	SiN	0.8
# 4	$SiOC$	1.0
# 5	SiN	0.6
# 6	$SiOC$	1.0
# 7	SiN	0.5
# 8	SiO_2	0.6
# 9	Mo	0.3
# 10	AlN	1.7
# 11	SiN	0.3



(a) (b)

Fig. 2. Displacement shapes of the modes which can be excited by the structures : (a) fundamental mode with a wavelength matching the periodicity of the electrodes and (b) first overtone.

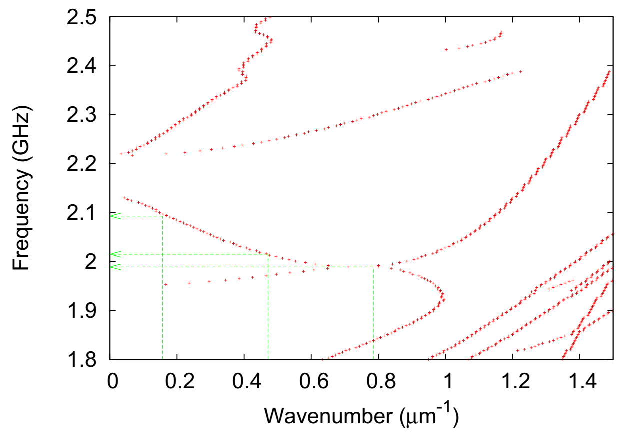
are satisfied by the displacement shape of Fig. 2(b) and by parasitic modes with higher wave-vectors.

As example, in Fig. 3(a), the working point is first fixed to a wavenumber $k_1 = 0.16\ \mu m^{-1}$, corresponding to a wavelength of 40 μm. The main resonance is thus located at 2.093 GHz. Overtones with wave-numbers odd multiples of the fundamental wavenumber can also be electrically excited since they satisfy the electrical boundary conditions. The first two are represented in Fig. 3(a). In particular, the first overtone generates a parasitic resonance close to 2 GHz, which appears on the electrical response represented in Fig. 4. As it is close in frequency to the main resonance, it affects the spectral purity of the resonator.

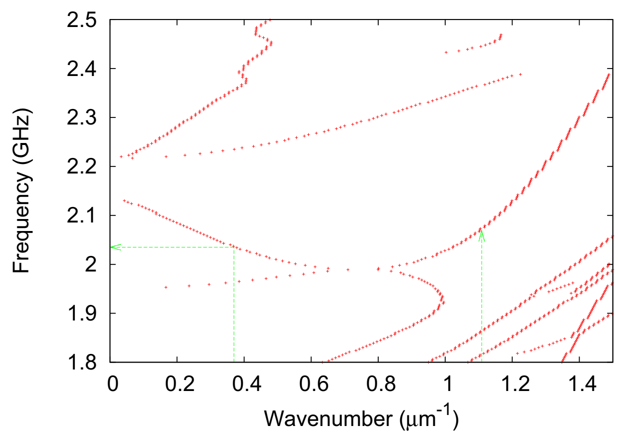
On the other hand, if we start with a higher wavenumber $k_2 = 0.37\ \mu m^{-1}$, the overtones exhibit very large wave-numbers, and in practice correspond here even to another dispersion branch with nearly no piezoelectric coupling, as can be seen in Fig. 3(b). Therefore, these overtones do not generate any spurious resonance and the resonator response in Fig. 4 is therefore clean.

There is however a limitation to this. A very high wavenumber would add several problems:

- the effective coupling factor k^2_{eff} drops significantly when increasing the wavenumber,
- the number of spurious resonances increases as overtones approach the region of dispersion curves where the density of modes is high due to low frequency modes which raise and tend to their asymptotic limit. Even if these modes exhibit neglectible piezoelectric coupling coefficients, and thus are not likely to generate parasitics on the electric response, there are still some possibilities of mode coupling between the desired mode and the other ones, and this leads globally to a decrease in quality factor.
- the wavelength may become very small, what may put more constraints on the fabrication process.



(a)



(b)

Fig. 3. Representation of overtones which can be generated by interdigitated electrodes with periods (a) 20 μm and (b) 8.5 μm.

So the choice of wavenumber is a tradeoff between the reduction of spurious resonances and the decrease in coupling and/or quality factor. Typically, the suitable region can be optimized with a proper design of the Bragg mirror.

It is necessary to note that another source of spurious resonances comes from higher order modes, which correspond to other dispersion branches. Where these modes exhibit the same wavenumber as the desired mode, or odd multiples of this wavenumber, they can also give rise to parasitics on the

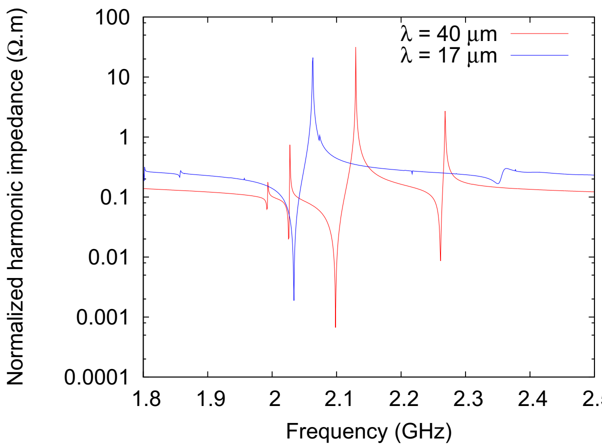
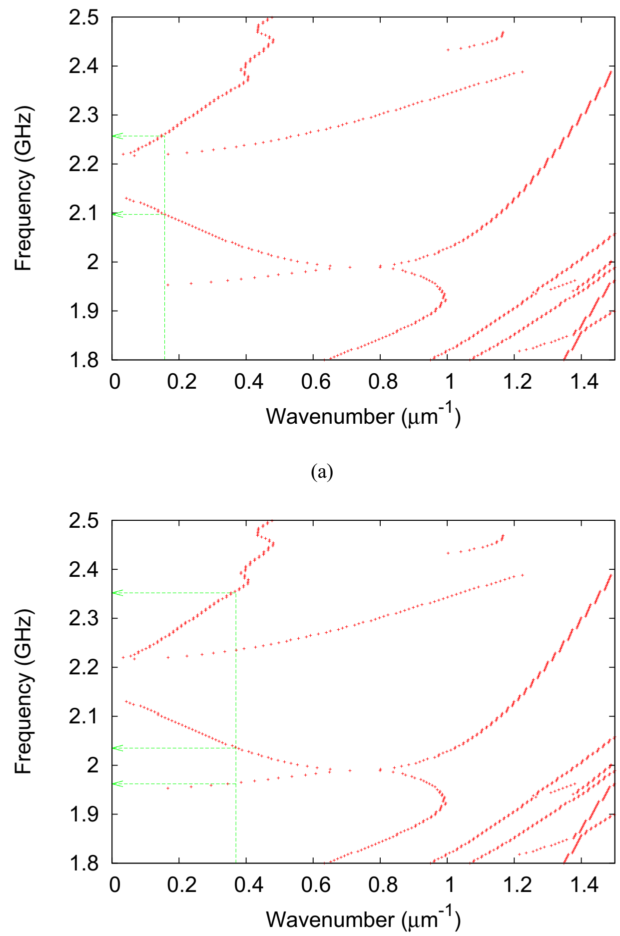


Fig. 4. Harmonic impedance responses of : wavenumber $k = 3.7\ 10^5 \mu m^{-1}$ in blue color and wavenumber $k = 1.85\ 10^5 \mu m^{-1}$ in red color where the spurious resonances are more coupled around the center frequency.

electrical response if they exhibit a piezoelectric coupling. Fig. 5 shows the relation between the dispersion curves and the parasitics which can be seen on the electrical response of the two resonators of Fig. 4. For both of them, parasitics above the resonance frequency are caused by the mode which has a cut-off frequency of 2.2 GHz. But again, a lower electrodes period leads to an increased wavenumber and to parasitics located further from the main resonance. Overall, this leads also to a higher spectral purity. These kinds of parasitics are however highly dependent on the exact dispersion behavior of the resonator, i.e. on the material stack. So a proper material stack design should bring any other branches than the desired one as far as possible from the resonance frequency.



(a)

(b)

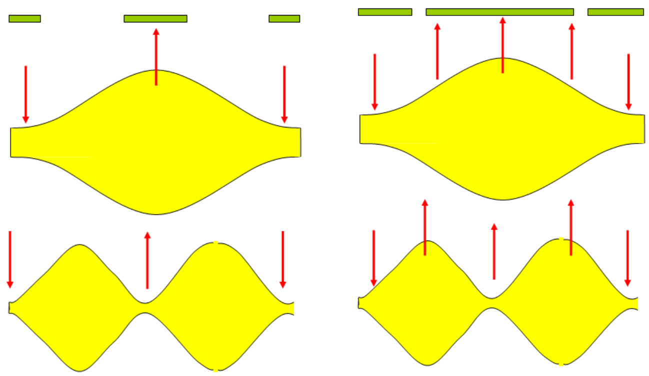
Fig. 5. Representation of parasitics related to other modes generated by interdigitated electrodes with periods (a) 20 μm and (b) 8.5 μm.

IV. Influence of Metalization Ratio

After the choice of the wavelength, some care must be taken to choose the metalization ratio. In the case of guided wave resonators, the electrical boundary conditions have a large influence on the effective piezoelectric coupling coefficient, not only of the desired mode, but also on parasitic modes. Mostly two mechanisms come into play:

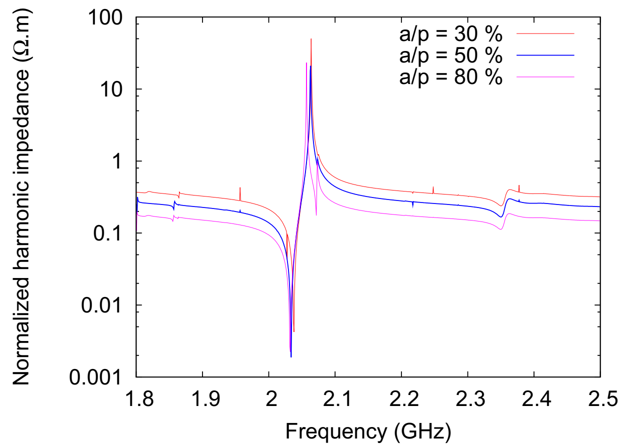
- the electric potential is uniform under metalizations. As a rule of thumb, the degree to which this electric potential matches the vibration shape of an acoustic waves will determine the excitation efficiency. For this reason, narrow electrodes only generate a vertical electric field over a small part of the resonator. So they only cause extension or compression over a small part of the wavelength. Therefore, one can expect the excitation efficiency of the desired mode to be low for low metalization ratios. In this case, one can expect overtones with smaller wavelength to be excited with a similar efficiency, what may lead to an increase in spurious resonances content.
- conversely, for large metalizations, the excitation efficiency of overtones is lower, since their vibration shapes match much less the electric potential distribution than the desired mode, as shown in Fig. 6. However, in this case two electrodes with opposite polarities come closer and thus the horizontal component of the electric field becomes stronger. This may make modes more sensitive to the in-plane electric field to be excited and if these modes exhibit wavelengths compatible with the periodicity of the electrodes, they may lead to parasitic resonances.

From these two considerations, one can expect that an optimum metalization ratio exists. In Fig. 7, the harmonic admittance has been calculated for various metalization ratios. As expected, for a metalization ratio of 30 %, the effective piezoelectric coupling factor is reduced, because of a lower excitation efficiency of the desired mode. For a metalization ratio of 80 %, a strong spurious appears close to the antiresonance. The electric response for a metalization ratio close to 50 % seems to be the best compromise.

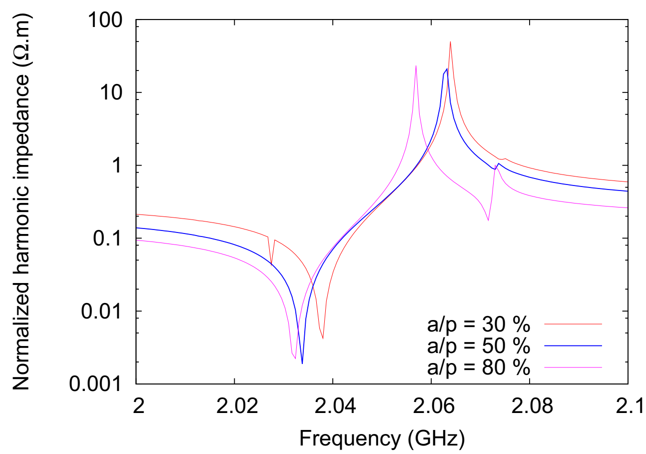


(a) (b)

Fig. 6. Schematic of the excitation for a metalization ratio of 50% (a) and 70% (b). Arrows correspond to the electric field. The deformation shape is plotted with respect to the disposition of the electrodes.



(a)



(b)

Fig. 7. Harmonic impedance for various metalization ratios: (a) wide band response and (b) focus on spurii in the 2-2.1 GHz range.

V. Conclusion

We have shown that the design of a resonator using guided acoustic waves is closely related to the dispersion characteristics of the material stack. These characteristics define a window in which the wavelength of the exploited mode can be chosen to reach a sufficient effective piezoelectric coupling factor while keeping spurious resonances caused by overtone resonances far from the main resonance. Parasitics can also be caused by other modes. Therefore, the dispersion branch exploited should be isolated as much from the others as possible. This puts high constraints on the design of Bragg mirrors for such applications.

We have also investigated the influence of the metalization ratio of the interdigitated excitation electrodes. We have seen that a compromise must be found between a high excitation efficiency, which tends to require large electrodes, and the excitation of unwanted waves by in-plane electric fields caused by electrodes with opposite polarities coming close together. We found that in our case, this optimum lies close to a 50 % metalization ratio.

The studies performed so far were based on the assumption of infinitely thin electrodes and of an infinite number of electrodes. Further work will consist in refining this study by also considering the mechanical influence of metalizations as well as by considering structures of finite length.

References

[1] I. Kone, B. Dubus, L. Buchaillot, A. Reinhardt, F. Casset, M. Aid, J. Carpentier, and P. Ancey, "Resonator using guided waves in a piezoelectric layer above a Bragg mirror," May 2008, pp. 581–585.

[2] H. Lavasani, R. Abdolvand, and F. Ayazi, "A 500 MHz low phase-noise AlN-on-Silicon reference oscillator," Sept. 2007, pp. 599–602.

[3] A. Volatier, G. Caruyer, D. Tanon, P. Ancey, E. Defay, and B. Dubus, "UHF/VHF resonators using Lamb waves co-integrated with bulk acoustic wave resonators," vol. 2, Sept. 2005, pp. 902–905.

[4] T. Pastureaud, V. Laude, and S. Ballandras, "Stable scattering-matrix method for surface acoustic waves in piezoelectric multilayers," *Applied Physics Letters*, vol. 80, no. 14, pp. 2544–2546, 2002. [Online]. Available: http://link.aip.org/link/?APL/80/2544/1

[5] A. Reinhardt, S. Ballandras, and V. Laude, "Simulation of transverse effects in FBAR devices," in *2005 IEEE MTT-S International Microwave Symposium Digest*, June 2005.

[6] K. Blotekjaer, K. Ingebrigtsen, and H. Skeie, "Acoustic surface waves in piezoelectric materials with periodic metal strips on the surface," *Electron Devices, IEEE Transactions on*, vol. 20, no. 12, pp. 1139–1146, Dec 1973.