Preface

To handle many standards and the ever-increasing bandwidth requirements, large numbers of filters and switches are used in transceivers of modern wireless communications systems. It makes the cost, performance, form factor, and power consumption of these systems, including cellular phones, critical issues. At present the fixed frequency filter banks based on Film Bulk Acoustic Resonators (FBAR) are regarded as one of the most promising technologies to address performance-form factor-cost issues. Although FBARs improve overall performances the complexity of these systems remains high. Attempts are being made to exclude some of the filters by bringing the digital signal processing (including channel selection) as close to the antennas as possible. However, handling the increased interference levels is unrealistic for low-cost battery operated radios.

Replacing fixed frequency filter banks by one tuneable filter is the most desired and widely considered scenario. As an example, development of software-based cognitive radios is largely hindered by the lack of adequate agile components, first of all tuneable filters. In this sense the electrically switchable and tuneable FBARs are the most promising components to address the complex cost-performance issues in agile microwave transceivers, smart wireless sensor networks, etc.

The development of tuneable FBARs is a rapidly evolving and "hot" microwave topic (R. Aigner, "Tuneable RF Filters: Pursuing the 'Holy Grail' of Acoustic Filter R&D," Microwave Journal, June 16, 2008). Trimming by etching takes care of the processing tolerances; however, it is a costly process. Electric field tuning of FBARs is a cost-effective way that, in addition to "trimming," offers radically new functionalities, and RF system architectures. Heating, semiconductor varactor loading, etc. are used to make the fixed frequency ZnO and AlN FBARs tuneable. This concept results in limited tuning and the Q-factor of the FBAR is deteriorated due to the loading. Ferroelectric films in the polar/piezoelectric phase, such as $Pb(Zr_xTi_{1-x})O_3$ (PZT) are also considered for tuneable FBARs.

The inherently large hysteresis of these materials limits their applications. Switchable and tuneable FBARs make use of the electric field-induced piezoelectric effect in paraelectric phase ferroelectrics (i.e., $Ba_xSr_{1-x}TiO_3$, BST).

Electric field tuning of the resonant frequency and the electromechanical coupling coefficient represent two unique properties of BST-based resonators, offering design flexibility and allowing the development of tuneable frequency selective filters. The performances (Q-factor, sizes) of the reported switchable and tuneable FBARs are already better than that of resonators based on lumped inductors and semiconductor varactors (LC tank) and they may be used in microwave circuits.

The book consists of an introduction and a concluding chapter where the future challenges are discussed. Six other chapters cover physics, modeling, fabrication methods, microstructure analysis, measurements, and applications of tuneable FBARs. Chapters 2 and 5 are written by A. Tagantsev.

The introduction starts with brief discussions about the needs in tuneable resonators, focusing on advanced agile microwave communications systems. To assist in the reading of the following chapters vibrational modes in FBARs are reviewed. The concept of electrostriction-mediated-induced piezoelectric effect in paraelectrics, used in intrinsically tuneable ferroelectric FBARs, is discussed. A summary of the state of the art in intrinsically tuneable FBARs concludes the chapter.

Chapter 2 introduces the fundamentals of dielectric, mechanical, and electromechanical properties of insulating solids, primarily focusing on ferroelectric and piezoelectric materials, suitable for FBARs. Sections 2.1, 2.2, and 2.3 address these properties, neglecting the energy dissipation associated with AC signals, whereas Sect. 2.4 is reserved for the discussion of effects related to energy dissipation (e.g., dielectric and acoustic loss).

In Chap. 3 the conventional models of acoustic resonators, such as Mason, KLM, and Lakin are considered as a general background and the possibility of their applications (with adequate modifications) for modeling tuneable FBARs. In ferroelectric-based tuneable FBARs the basic parameters, stiffness, acoustic velocity, and relative dielectric permittivity of the ferroelectric film are assumed to be DC electric field dependent.

Possibilities of tuning the resonant and antiresonsnt frequencies of fixed frequency FBARs are considered in Chap. 4. The first two sections address the possibilities of intrinsic tuning where the stiffness of the piezoelectric film is changed by an applied high DC electric field and heating. The rest of the chapter deals with extrinsically tuneable FBARs. In this case the tuning is imposed by tuneable inductors and capacitors shunt or series connected with the FBAR. The maximum reported intrinsic tuning of the AlN resonators under applied DC field and heating is about 1 %, while the maximum extrinsic tuneability is less than 2 %.

Chapter 5 is devoted to the theoretical description of tuning of FBARs based on materials with an induced piezoelectric effect. Though DC field-induced piezoelectricity occurs in any centrosymmetric material, only ferroelectrics display an effect that is strong enough to be of interest for practical applications. Apart from the incipient ferroelectrics (regular ferroelectric in the paraelectric phase), ferroelectrics in ferroelectric phase are also considered.

Basic design features of the intrinsically tuneable FBARs are considered in Chap. 6 focusing on the Bragg reflectors for the solidly mounted resonators.

Effects of the electrodes and other layers on the tuneable performance of the FBARs including tuneability, Q-factor and electromechanical coupling coefficient are also addressed.

The first sections in Chap. 7 give a brief review of the main processes used in the fabrication of intrinsically tuneable ferroelectric FBARs. Test structures used for low frequency and microwave measurements and procedures for extracting the acoustic parameters of ferroelectric films used in tuneable FBARs are considered in Sect. 7.6. The last sections are devoted to studies of temperature dependence and power handling capabilities.

Chapter 8 looks at circuit applications of the intrinsically and extrinsically tuneable FBARs. VCOs seem to be one of the most attractive circuits for applications of the tuneable FBAR. They benefit both from high Q-factor (much higher than LC tanks based on semiconductor varactors) and tuneability. Perhaps tuneable and switchable filters are the most desired devices. The chapter includes several demonstrations of these types of filters. Some specific applications such as amplifiers, sensors, and clocks are also considered.

Possible ways of increasing the Q-factor, tuneability and electromechanical coupling coefficients are discussed in Chap. 9. Using new materials, improving the crystalline quality of ferroelectric films and the designs of FBARs are the main challenges. The potential of nanoscale resonators and resonators with graphene electrodes is also discussed.

The book is an introduction to the tuneable FBARs. It is intended for students both at undergraduate and graduate levels. It may be useful for designers of microwave devices, circuits, and systems both in academia and industry.

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