Preface

Today's wireless communications and information systems are heavily based on microwave technology. Current trends indicate that in the future along with microwaves, the millimeter wave and Terahertz technologies will be used to meet the growing bandwidth and overall performance requirements. Moreover, motivated by the needs of the society, new industry sectors are gaining ground; such as wireless sensor networks, safety and security systems, automotive, medical, environmental/food monitoring, radio tags etc. Furthermore, the progress and the problems in the modern society indicate that in the future these systems have to be more user/consumer friendly, i.e. adaptable, reconfigurable and cost effective. The mobile phone is a typical example which today is much more than just a phone; it includes a range of new functionalities such as Internet, GPS, TV, etc. To handle, in a cost effective way, all available and new future standards, the growing number of the channels and bandwidth both the mobile handsets and the associated systems have to be agile (adaptable/reconfigurable). The complex societal needs have initiated considerable activities in the field of cognitive and software defined radios and triggered extensive research in adequate components and technology platforms. To meet the stringent requirements of these systems, especially in agility and cost, new components with enhanced performances and new functionalities are needed. In this sense the components based on ferroelectrics have greater potential and already are gaining ground. After years of research efforts in materials science, device physics and demonstration of large number laboratory demonstrators, the ferroelectric technology for microwave applications is making its way to the industry and commercial applications.

Ferroelectrics are a class materials characterized by spontaneous polarization (in ferroelectric phase). In this phase they are widely used in memory cells. The piezoelectric properties are used in sensors, actuators etc. Components based on ferroelectric phase have a wide range of commercial applications. Ferroelectrics in paraelectric (non polar) phase have even greater potential for microwave applications. A large class of ferroelectrics, especially perovskites, are very good dielectrics characterized by extremely high dielectric permittivity which depend on the applied electric field, mechanical stress and temperature. Good dielectric properties (low microwave loss and leakage currents) and electric field dependent permittivity makes the parametric phase ferroelectrics attractive for the development of a wide range of tunable microwave devices for applications in agile microwave systems. The materials properties from engineer's perspective, device, circuit and system applications of the paralectric phase ferroelectrics are the main subjects of the book.

The book consists of an introduction, several chapters covering the physics of ferroelectrics (engineer's perspective), methods of fabrication and microscopic analysis, modeling and microwave measurements of the materials and devices. The basic ferroelectric components – varactors and their microwave applications in devices (phase shifters, delay lines, filters etc.), circuits (oscillators, amplifiers etc.) and systems (i.e. phased arrays) are in the focus of the book.

The Introduction gives a general overview of the main material properties. It reviews the main competing tunable technologies and gives a historical overview on the ferroelectric materials and their microwave applications, current status, potential and trends.

Chapter 2 gives a brief introduction to the physics of the ferroelectrics. The temperature, DC field, and frequency dependences of the dielectric permittivity and microwave losses are considered and simple engineering formulas useful for device modeling are included. This chapter includes acoustic properties of the ferroelectrics where the emphasis is put on induced piezoelectric effect in paraelectric phase – a new phenomena useful for the development of tunable acousto-electric devices.

The fabrication processes of bulk (single crystal and ceramic), and film (thick, thin) are considered in Chap. 3. The fabrication process of the thin films, suitable for the industrial scale mass production (RF magnetron sputtering, sol-gel etc.), are described in more details. This chapter includes also methods and the results of the microstructure analysis of the ferroelectric films and correlation of the dielectric properties with the microstructure – allowing optimization of the fabrication processes and film properties. The laser ablation process is considered as a flexible and express method for the experiments with the new ferroelectric compositions.

The ferroelectric varactors, as the basic components used in tunable lumped and distributed devices and passive components (i.e. high density capacitors), are considered in Chap. 4. A comparison between the two main varactor designs – coplanar plate and parallel plate varactors is given. The equivalent circuit models and the design formulas for these varactors are provided. The power handling capability and tuning speed are considered in this chapter. The effects of the electrodes/interfaces, the substrates and the integration possibilities are considered and a detailed analysis of high resistivity silicon as the most promising substrate for integrated microwave modules incorporating ferroelectric (and other emerging components) is given. The passive components, such as high density decoupling capacitors based on ferroelectric films, dielectric spacers in MEMs and gates in field effect transistors are also included in this chapter.

Chapter 5 looks at the ferroelectric devices. It includes delay lines and delay line type phase shifters with frequency independent tunable delay time and phase shifters with frequency independent tunable phase shift. These devices along with tunable resonators, filters, matching networks, tunable power splitters and antennas are the most representative components considered for applications in microwave systems. Applications of the ferroelectric varactors in nonlinear devices like harmonic generators, frequency converters, power limiters, pulse shapers and parametric amplifiers are briefly reviewed. A new type of device – a tunable thin film bulk acoustic resonator using induced piezoelectric effect in paraelectric films concludes the chapter.

Chapter 6 is devoted to the circuit and system applications of the ferroelectric materials and components. Voltage Controlled Oscillators (VCO), power amplifiers, beam steering networks for the phased arrays and reconfigurable antennas are the typical applications considered. The nontraditional and lens type steerable beamformers based on ferroelectrics allow size and cost reduction.

Modeling of the microwave components and devices based on ferroelectrics and methods of the measurements and are considered in Chaps. 7 and 8. The simple analytic formulas are mainly based on the conformal mapping technique and assume uniform dielectric permittivity distribution in ferroelectrics layers. They are useful for device optimization and measurements of the dielectric properties of the ferroelectric layers. Chapter 8 discusses resonant and broad band measurements of the dielectric properties of bulk, thick and thin films ferroelectrics. It includes also methods for the measurement of the nonlinearities and tuning speeds.

Chapter 9 considers the further potential and perspectives of agile materials. New promising agile materials, like multiferroics, ferroelectric and ferromagnetic nanotubes, pyrochlores, oxides with resistive switching, and liquid crystals are reviewed in this chapter. Potentials for applications in metamaterials and THz technology are considered. New effects in ferroelectrics, like resistivity switching in doped $SrTiO_3$, nanoscale effects, integration with semiconductors and High Temperature Superconductors (HTS), are reviewed.

The concluding Chap. 10 summarizes the main performance features of the ferroelectric devices including temperature stabilization, nonlinearity and power handling capability, hysteresis, long term stability etc. It is shown that these and other "traditional" concerns pose no limitations on commercialization and wide scale applications of ferroelectrics in agile microwave devices and systems.

The book is an introduction into the field intended to give practical knowledge in physics, fabrication technology, methods of design, modeling and measurements of tunable components and circuits based on ferroelectrics. It is intended for students (undergraduate and graduate), microwave device, circuit and system designers both in academia and industry.

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