

Preface

Following the execution of the project PETRA-I, co-financed by the European Union in the framework of the ALFA Program (America Latina Formación Académica), as coordinator of the PETRA Network (PiezoElectric TRansducers and their Applications), I edited the first edition of this book. Now, four years later, I am submitting the manuscript of this revised and enlarged 2nd edition.

This edition has been, in fact, an unexpected result of the project PETRA-II, also co-financed by the European Union in the framework of the ALFA Program. Effectively, halfway through the execution of this project, Springer-Verlag informed me of the good reception that the book had received and asked me if we had thought about a new edition. This very good news meant that the work during the previous four years had been worth it. The initial idea of collecting in one single volume a set of “tutorials” covering topics spread on different disciplines and linked by the use of piezoelectric devices was therefore useful. The interdisciplinary character of the discipline was made clear and the “tutorial” based format could be useful as a guide for doctoral degree students and even researchers going into this complex and multidisciplinary issue. Now we have the opportunity of improving that first approach but without losing what we think are the keys of its success: the “tutorial” style and the multidisciplinary character of the contents.

The new edition covers, in 18 chapters and two appendices, different aspects of piezoelectric devices and their applications, as well as fundamental topics of related disciplines. The contents were selected according to the different areas of research of the partners of the PETRA Network; therefore, this book does not intend to be an encyclopaedia on piezoelectric transducers and their applications, which would be completely impossible in a single-volume work. Three different parts, although not explicitly separated, can be distinguished in the book: one part corresponds to general concepts on piezoelectric devices and to the fundamentals of related topics (Chapters 1,2, 7-12 and the two appendices), another part deals with piezoelectric sensors and related applications (Chapters 1,3,5,12-14) and the other part focuses on ultrasonic transducers and systems and related applications (Chapters 4,6, 15-18).

Basic concepts of piezoelectricity are presented in Chap. 1 along with an introduction into the field of microgravimetric sensors; appendices A and B, at the end of the book, include fundamental concepts of electrostatics

and physical properties of crystals which complement this initial introduction. Chapter 2 offers an overview of acoustic sensors, their basic principles of operation, the different types and their potential applications. Recent new excitation principles for bulk acoustic wave sensors such as lateral field or magnetic excitations have been added in this edition, as well as the topic of micromachined resonators such as cantilevers (MEMS) based on silicon technologies which are attracting current interest.

Chapters 3, 5, 13 and 14 delve more deeply into resonant sensors, especially bulk acoustic wave thickness shear mode resonators and their applications as quartz crystal microbalance sensors, their fundamentals and models (Chap. 3), electronic interfaces and associated problems (Chap. 5), the problems associated with the analysis and interpretation of experimental data (Chap. 14) and complementary techniques used with QCM (Chap. 13). In this 2nd edition, a thorough revision of these chapters with the addition of some important topics has been made. Sub-chapters dealing with the gravimetric and non-gravimetric regimes in QCM applications and the important aspect of kinetic analysis in acoustic wave sensor-based chemical applications have been added to Chap. 3. A comprehensive review of the different electronic interfaces for QCM sensors has been included in Chap. 5; in particular the topic of oscillators for in-liquid QCM applications is deeply treated in this edition, as well as the new interface systems based on lock-in techniques. Techniques based on impedance analysis, or adapted impedance analyzers, and decay method techniques have also been updated and interfaces for fast QCM applications, such as ac-electrogravimetry (Chap. 13), have also been included. The problem of compatibility between QCM and electrochemical set-ups is treated in Chap. 13. Chapter 14 has been thoroughly revised and a completely new section with case studies has been added to complement the complex aspect of data analysis and interpretation in real experiments. The section devoted to “other effects”, which complicates even more the interpretation of results, has been extended with the inclusion of the roughness effect.

As the case studies section in Chap. 14 makes clear, acoustic wave sensors are involved in applications such as biosensors, electrochemistry and polymer properties’ characterization, which require a minimum background to deal with. This background is intended to be given in Chaps. 7-12. Thus, Chap. 7 introduces the concept of viscoelasticity and describes in depth the physical properties of polymers. A very important aspect in resonant sensor applications is the shear parameter determination that has been added as a new subchapter in this tutorial.

Chapter 8 introduces the fundamentals of electrochemistry; in relation to the first edition, the section on “What is an electrode reaction?” has been extended with more explanation on the process of electron transfer and a

corresponding schematic figure. The section on “Rates of electrode reactions” now includes a paragraph and figure describing the important role of the interfacial region and the definition of Faraday’s law. Additionally, the section on electrochemical techniques has been significantly enlarged with respect to steady-state, pulse and impedance techniques. The final section shows the range of possible applications of electrochemistry.

Chapter 9 provides an overview of chemical sensors, which is of great interest for establishing the differences between chemical sensors based on piezoelectric transducers and those based on other techniques such as electrochemical, optical, calorimetric, conductimetric (added in this version) and magnetic techniques, with the aim of facilitating the interpretation of the different data. Chapter 10 treats the specific topic of biosensors from a biological point of view; this treatment is specifically useful to understand the mechanism of biological recognition and its potential use for the development of biosensors and especially for piezoelectric biosensors, which is a field of much current interest. A new chapter (Chap. 12) has been added which introduces the fundamentals of piezoelectric immunosensors giving the basic schemes of biosensor functioning, immunoassay formats, and the principle of competitive immunoassay. The different steps involved in the production and immobilization of immunoreagents are treated in detail in this chapter which finishes with a real example of characterization of a piezoelectric immunosensor.

The processes involved in a piezoelectric immunosensor make clear the necessity of the resonator sensor surface modification. This topic is treated in depth in Chap. 11 which provides a guide to the important subject of modification of piezoelectric surfaces in piezoelectric transducers for sensor applications. Some additional examples have been added in this new version.

Chapters 4, 6, 15-18 deal with ultrasonic systems and applications. Chapter 4 introduces the basic aspects and the different models of piezoelectric transducers for broadband ultrasonic applications; electronic interfaces used in broadband configurations are introduced in Chap. 6; implementations of ultrasonic schemes and electronic interfaces for non-destructive testing industrial applications are detailed and analysed in Chap. 16, and some applications of ultrasound in chemistry and in medicine are treated in Chaps. 15 (Sonoelectrochemistry), 17 (Medical imaging) and 18 (Ultrasound hyperthermia). In this edition new topics have been added in the previous chapters. In Chap. 4 three sub-chapters have been added dealing with the transfers functions and time responses at emission and reception of the transducer, the acoustic impedance matching and the electrical matching and tuning. Chap. 6 includes a new sub-chapter dealing with the analysis of electrical responses in pulse-driven piezoelectric transducers by means of linear approaches has been added, including

the inductive tuning case. In Chap. 16 two new sections have been added dealing with the electronic sequential scanning of ultrasound beams for fast operation in non-destructive testing applications. Chap. 17 is a new chapter added to deal with the application of ultrasound systems for medical imaging and tissue characterization; a basic introduction to the ultrasound properties of biological materials with different ultrasonic imaging modes is followed by a comprehensive review of the different techniques used for medical imaging. Chapter 18 includes a concise introduction to the clinical procedure and biological basis of hyperthermia therapy. In this second edition key information concerning the technical perspective of this treatment has been added: the ultrasound field measurement by the mechanically scanning method is described. In this section, it is explained how a 3D representation of the space domain response of the transducer can be obtained by using a hydrophone. In another section, the way ultrasound produces temperature increases in tissues is described. A description of the components of a general hyperthermia ultrasound system has also been included. Superficial and deep heat systems are also depicted. Finally, the ways in which ultrasound hyperthermia systems are characterized are treated, such as in the preparation and measuring of the properties of a tissue mimicking material (phantom) for use in ultrasonic hyperthermia.

Finally, Chap. 15 deals with the application of ultrasound in electrochemistry. In this edition the sections on basic consequences of ultrasound and on the experimental arrangements have been extended. In the former case, more discussion of the formation of cavitation bubbles and their collapse is included. In the latter case, the horn probes are discussed in more detail. Some more applications are referred to in particular nanomaterials (new sub-section).

The present volume is therefore a revised and enlarged version of the first edition which would not have been possible without the effort and dedication of all my colleagues, who contributed with the different chapters, to all of whom I will always be in debt. I would like to take advantage of this new opportunity to thank them again for giving me their confidence as coordinator of the PETRA group. My thanks also go to Springer for undertaking this new edition.

New challenges are waiting for us in the near future. I hope we will be able to face them enthusiastically and with excitement. The future is a challenge that we pose to our thoughts and makes sense of our lives.

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