

Contents

Associated Editors and Contributors.....	XVII
1 Fundamentals on Piezoelectricity	1
1.1 Introduction.....	1
1.2 The Piezoelectric Effect.....	2
1.3 Mathematical Formulation of the Piezoelectric Effect. A First Approach	4
1.4 Piezoelectric Contribution to Elastic Constants.....	5
1.5 Piezoelectric Contribution to Dielectric Constants.....	5
1.6 The Electric Displacement and the Internal Stress	6
1.7 Basic Model of Electric Impedance for a Piezoelectric Material Subjected to a Variable Electric Field.....	7
1.8 Natural Vibrating Frequencies	12
1.8.1 Natural Vibrating Frequencies Neglecting Losses.....	12
1.8.2 Natural Vibrating Frequencies with Losses	16
1.8.3 Forced Vibrations with Losses. Resonant Frequencies	20
1.9 Introduction to the Microgravimetric Sensor.....	26
Appendix 1.A	29
The Butterworth Van-Dyke Model for a Piezoelectric Resonator	29
1.A.1 Rigorous Obtaining of the Electrical Admittance of a Piezoelectric Resonator. Application to AT Cut Quartz.....	29
1.A.2 Expression for the Quality Factor as a Function of Equivalent Electrical Parameters	36
References.....	37
2 Overview of Acoustic-Wave Microsensors.....	39
2.1 Introduction.....	39
2.2 General Concepts	40
2.3 Sensor Types	42
2.3.1 Quartz Crystal Thickness Shear Mode Sensors	42
2.3.2 Thin-Film Thickness Longitudinal Mode Sensors.....	44
2.3.3 Surface Acoustic Wave Sensors.....	44
2.3.4 Shear-Horizontal Acoustic Plate Mode Sensors	47

2.3.5 Surface Transverse Wave Sensors	47
2.3.6 Love Wave Sensors.....	48
2.3.7 Flexural Plate Wave Sensors.....	48
2.4 Operating Modes.....	49
2.5 Sensitivity	51
References	53
3 Models for Piezoelectric Transducers Used in Broadband Ultrasonic Applications.....	55
3.1 Introduction.....	55
3.2 The Electromechanical Impedance Matrix	56
3.3 Equivalent Circuits.....	60
3.4 Broadband Piezoelectric Transducers as Two-Port Networks. Transfer Functions.....	63
References	67
4 Models for Resonant Sensors	69
4.1 Introduction.....	69
4.2 The Resonance Phenomenon	69
4.3 Concepts of Piezoelectric Resonator Modeling	70
4.4 The Equivalent Circuit of a Quartz Crystal Resonator	75
4.5 Four Important Conclusions	78
4.5.1 The Sauerbrey Equation	78
4.5.2 Kanazawa's Equation.....	79
4.5.3 Resonant Frequencies.....	79
4.5.4 Motional Resistance	80
Appendix 4.A	80
4.A.1 Introduction	80
4.A.2 The Coated Piezoelectric Quartz Crystal. Analytical Solution	81
4.A.3 The Transmission Line Model	85
4.A.4 Special Cases	91
References	99
5 Interface Electronic Systems for Broadband Ultrasonic Applications.....	101
5.1 Introduction.....	101
5.2 General Interface Schemes for an Efficient Coupling of Broadband Piezoelectric Transducers.....	102

5.3 Electronic Circuits Used for the Generation of High Voltage Driving Pulses and Signal Reception in Broadband Piezoelectric Applications	104
5.3.1 Some Classical Circuits to Drive Ultrasonic Transducers	104
5.3.2 Electronic System Developed for the Efficient Pulsed Driving of High Frequency Transducers.....	106
5.3.3 Electronic Circuits in Broadband Signal Reception..	109
References.....	110
6 Interface Electronic Systems for AT Quartz Crystal Microbalance Sensors	111
6.1 Introduction.....	111
6.2 A Suitable Model for Including a QCMS as Additional Component in an Electronic Circuit	112
6.3 Critical Parameters for Characterizing the QCMS	113
6.4 Systems for Measuring Sensor Parameters and their Limitations	115
6.4.1 Impedance or Network Analysis.....	116
6.4.2 Decay and Impulse Excitation Methods	117
6.4.3 Oscillators	121
6.4.4 Parallel Capacitance Compensation Techniques	130
6.4.5 The Transfer Function Method	132
6.5 Conclusions.....	133
Appendix 6.A	134
Critical Frequencies of a Resonator Modeled as a BVD Circuit	134
6.A.1 Equations of Admittance and Impedance.....	134
6.A.2 Critical Frequencies.....	136
6.A.3 The Admittance Diagram	138
References.....	140
7 Modified Piezoelectric Surfaces	141
7.1 Introduction.....	141
7.2 Metallic Deposition.....	141
7.2.1 Vacuum Methods	142
7.3 Electrochemical Method	143

7.3.1 Technique Based on Glued Solid Foil (Nickel, Iron, Stainless Steel...)	145
7.3.2 Organic Film Preparation	146
7.3.3 Monolayer assemblies	146
7.4 Biochemical Modifications	149
7.4.1 Direct Immobilization of Biomolecules (Adsorption, Covalent Bonding)	149
7.4.2 Entrapping of Biomolecules (Electrogenerated Polymers: Enzyme, Antibodies, Antigens...)	150
7.4.3 DNA Immobilization	150
References	151
8 Sonoelectrochemistry	153
8.1 Introduction	153
8.2 Basic Consequences of Ultrasound	154
8.3 Experimental Arrangements	154
8.4 Applications	156
8.4.1 Sonoelectroanalysis	157
8.4.2 Sonolectrosynthesis	157
8.4.3 Ultrasound and Bioelectrochemistry	157
8.4.4 Corrosion, Electrodeposition and Nanopowders	158
8.4.5 Waste Treatment and Digestion	159
8.4.6 Multi-frequency Insonation	159
8.5. Final Remarks	159
References	159
9 Chemical Sensors	161
9.1 Introduction	161
9.2 Electrochemical Sensors	163
9.3 Potentiometric Sensors	164
9.4 Amperometric Sensors	166
9.5 Optical Sensors	168
9.6 Acoustic Chemical Sensors	170
9.7 Calorimetric Sensors	171
References	171
10 Biosensors. Natural Systems and Machines	173
10.1 Introduction	173
10.2 General Principle of Cell Signaling	173

10.3 Biosensors	177
10.3.1 Molecular Transistor	181
10.3.2 Analogy and Difference of Biological System and Piezoelectric Device.....	181
References.....	183
11 Fundamentals of Electrochemistry	185
11.1 Introduction.....	185
11.2 What is an Electrode Reaction?	185
11.3 Electrode Potentials	187
11.4 The Rates of Electrode Reactions	188
11.5 How to Investigate Electrode Reactions Experimentally	189
11.6 Electrochemical Techniques and Combination with Non- Electrochemical Techniques	191
11.7 Applications	192
11.8 Bibliography	193
11.9 Glossary of Symbols	193
References.....	194
12 Viscoelastic Properties of Macromolecules	195
12.1 Introduction.....	195
12.2 Molecular Background of Viscoelasticity of Polymers .196	196
12.3 Shear Modulus, Shear Compliance and Viscosity	199
12.4 The Temperature-Frequency Equivalence.....	205
12.5 Conclusions.....	210
References.....	211
13 Combination of Quartz Crystal Microbalance with other Techniques	213
13.1 Introduction.....	213
13.2 Electrochemical Quartz Crystal Microbalance and other Techniques	214
References.....	222
14 Ultrasonic Systems for Non-Destructive Testing Using Piezoelectric Transducers	225
14.1 Generalities about Ultrasonic NDT	225

14.1.1 Some Requirements for the Ultrasonic Responses in NDT Applications	226
14.2 Through-Transmission and Pulse-Echo Piezoelectric Configurations in NDT Ultrasonic Transceivers	227
14.3 Analysis in the Frequency and Time Domains of Ultrasonic Transceivers in Non-Destructive Testing Processes	229
14.4 Multi-Channel Schemes in Ultrasonic NDT Applications for High Resolution and Fast Operation	232
14.4.1 Parallel Multi-Channel Control of Pulse-Echo Transceivers for Beam Focusing and Scanning Purposes.	233
14.4.2 Electronic Sequential Scanning of Ultrasonic Beams for Fast Operation in NDT	235
References.....	237
15 Ultrasonic Hyperthermia	241
15.1 Introduction.....	241
15.2 Ultrasonic Fields	241
15.3 Ultrasonic Generation	243
15.3.1 Piezoelectric Material.....	244
15.3.2 The Therapy Transducer	244
15.3.3 Additional Quality Indicators.....	245
15.3.4 Beam Non Uniformity Ratio	245
15.3.5 Effective Radiating Area (ERA)	246
15.4 Wave Propagation in Tissue	246
15.4.1 Propagation Velocity	246
15.4.2 Acoustic Impedance	246
15.4.3 Attenuation	247
15.5 Ultrasonic Hyperthermia.....	248
15.6 Focusing Ultrasonic Transducers.....	249
15.6.1 Spherically Curved Transducers	250
15.6.2 Ultrasonic Lenses	250
15.6.3 Electrical Focusing.....	250
15.6.4 Transducer Arrays	251
15.6.5 Interstitial Transducers	251
15.7 Trends	253
References.....	253

16 Data analysis and Interpretation in Bulk Acoustic Wave – Thickness Shear Mode Sensors	255
16.1. Introduction.....	255
16.2. Transmission Line Model, Experimental Data and Interpretation.....	256
16.2.1. Experimental Parameters for Sensor Characterization	258
16.2.2 Interpretation of Simple Cases	262
16.3.2. Limits of the Simple Cases	269
16.3 The General Case. The Problem of Data Analysis and Interpretation.....	275
16.3.1 Different Strategies to Face the Problem	276
16.3.2 Additional Considerations. Calibration.....	283
16.3.3. Other Effects. The N-layer Model	284
References.....	285
Appendix A Fundamentals of Electrostatics.....	287
A.1 Principles of Electrostatics.....	287
A.2 The Electric Field.....	288
A.3 The Electrostatic Potential	289
A.4 Fundamental Equations of Electrostatics.....	290
A.5 The Electric Field in Matter. Polarization and Electric Displacement.....	291
Appendix B Physical Properties of Crystals	299
B.1 Introduction	299
B.2 Elastic Properties.....	299
B.2.1 Stresses and Strains	300
B.2.2 Elastic Constants. Generalized Hooke's Law	306
B.3 Dielectric Properties	310
B.4 Coefficients of Thermal Expansion.....	311
B.5 Piezoelectric Properties	311
Index	315