Quartz Crystal Microbalance References

Books and Review Articles

1. D.S. Ballantine et. al., “Acoustic Wave Sensors-Theory, Design, and Physico-Chemical Applications”, Academic Press, 1996.
2. C. Lu and A.W. Czanderna, in “Applications of Piezoelectric Quartz Crystal Microbalances", Czanderna and Lu (Eds.) Elsevier, New York, 1984.
3. C. K. O’Sullivan and G.G. Guilbault, “Commercial Quartz Crystal Microbalances-Theory and Applications”, Biosensors and Bioelectronics 14(1999) 663.
4. Celia Henry, “Measuring the Masses: Quartz Crystal Microbalances”, Anal Chem., News and Features, Oct 1996, p. 625A.Note: Original product review by the editors of Analytical Chemistry, covers the QCM commercial offerings
5. Judith Handley, “Quartz Crystal Microbalances” Some New Innovations Stand Alongside the Standard, reliable workhorse”, Anal Chem., April 2001, 225A. Note: An updated product review from the editorial team of Anal. Chem. Journal.
6. Daniel A. Buttry and Michael Ward, “Measurement of Interfacial Processes at Electrode Surfaces with the electrochemical Quartz Crystal Microbalance”, Chem. Reviews 92(6) (1922) 1355-1379. Note: This is one of the best review articles written on the subject of EQCMs. The theory is clearly explained, and the limitations of the technique and the current understanding are presented. Everybody in the field must read this paper!
7. Stephen Martin, “Closing Remarks”, Faraday Discuss 107(1997)463. Note: This is an excellent review of the QCM technology and theory as of 1997. It includes sections on: measurement techniques, modern devices, models and unsolved problems. The surface roughness issue is also discussed. S. Martin is one of the leaders in the field-read everything he writes.
8. A. R. Hillman, “The QCM in Electrochemistry”, Electrochimica Acta (Special Issue) 45(22 & 23), 304 pages, year 2000. Note: A special issue dedicated to the EQCM.
9. Faraday Discussions, volume 107, 1997. Excellent compilation of articles by several leaders in the field including Stephen Martin, K.K. Kanazawa, *Johannsmann, Hauptmann, etc. A must read for QCM practitioners.*
10. Cass, T. & Ligles, F.S., “Immobilized Biomolecules in Analysis - A Practical Approach”, Oxford University Press 1998; ISBN 0 19 963636 2.

Theoretical Models

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3. E. Benes et. al., “Vibration modes of mass-loaded plano-convex quartz crystal resonators”, J. Acoust. Soc. Am. 90(2) (1991) 700.
4. H. Nowotny et. al., “Layered piezoelectric resonators with an arbitrary number of electrodes (general one-dimensional treatment), J. Acoust. Soc. Am. 90(3) (1991) 1238.

5. T. W. Schneider and S. J. Martin, "Influence of compressional wave generation on a thickness shear mode resonator response in a fluid", Anal. Chem. 67 (1995) 3324. Note: Acoustic interferometry was performed with TSM resonators to investigate the effect of compressional wave generation on the response (frequency and damping). The results indicate that even in semi-infinite liquids, compressional wave generation contributes significantly to device damping (motional resistance) but not to frequency shift.
6. K. Keiji Kanazawa, "Mechanical behavior of films on the quartz microbalance", Faraday Discuss. 107 (1997) 77-90
7. Helen L. Bandey, Stephen Martin, Richard Cernozek and A. R. Hillman, "Modeling the response of thickness-shear mode resonators under various loading conditions", Anal. Chem. 71 (1999) 2205. Note: This "equivalent-circuit" model incorporates a diverse set of simple component loadings including rigid solids, viscoelastic media and fluids. It also allows for any number of those components to be combined in any configuration.
8. D. Johannsmann, "Viscoelastic Analysis of Organic Thin Films on Quartz Resonators", Macromol. Chem. Phys. 200(1999) 501. Note: This article presents a way to calculate the viscoelastic coefficients of coatings by analyzing the frequency shifts and bandwidths of coated quartz resonators.
9. S. Martin, H. Bandey , R. Cernozek, A. R. Hillman and M.J. Brown, "Equivalent-circuit model for the thickness-shear mode resonator with a viscoelastic film near film resonance", Anal Chem. 72(2000) 141. **Note**: An equivalent-circuit model for viscoelastic films which leads to a simple graphical interpretation of the coupling between the quartz and film resonances and facilitates understanding of the resulting responses.
10. Ralf Lucklum, Peter Hauptmann, "The Δf–ΔR QCM technique: an approach to an advanced sensor signal interpretation", Electrochimica Acta 45 (2000) 3907–3916. Note: The frequency shift and the resistance change of a quartz crystal microbalance (QCM) coated with a viscoelastic film and working in a viscous liquid are analyzed. A method is presented for the accurate estimation of the complex shear modulus of the coating.
11. R.A. Etchenique & E.J. Calvo, "Gravimetric measurement in redox polymer electrodes with the EQCM beyond the Sauerbrey limit [Short Communication]" Electrochemistry Communications, 1:5 (1999) 167-170. Note: The mass of non-rigid films is calculated based on electroacoustic impedance data and interpreted with Martin's viscoelastic model.
12. Mikko Salomaki, Kari Loikas and Jouko Kankare, "Effect of Polyelectrolyte Multilayers on the Response of a Quartz Crystal Microbalance", Anal. Chem. 75 (2003) 5895-5904.

Tips, Tricks and Instrumentation

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3. J. H. Teuscher and Robin L. Garrell, "Stabilization of Quartz Crystal Oscillators by a conductive adhesive", Anal. Chem. 67 (1995) 3372.Note: The use of silver epoxy to improve the electrical contact to the crystal electrodes is presented as a definitive advantage.
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5. Noboru Oyama, et. al., "Scanning electrode quartz crystal analysis", Anal. Chem. 69(1997) 1023.
6. A. Krozer and Michael Rodahl, "X-ray Photoemission spectroscopy study of UV/ozone oxidation of Au under ultrahigh vacuum conditions", J. Vac. Sci. Technol. A 15(3) (1997) 1704. Note: A simple way to clean gold electrodes and provide a hydrophilic layer.
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9. Cheryl Chagnard, Patty Gilbert, A. Neal Watkins, Theodore Beeler and David W. Paul, "An Electronic Oscillator with Automatic Gain Control: EQCM Applications", Sensors and Actuators B 32 (1996) 129-136.
10. M. I. Jeffrey et. al., "The development of a rotating electrochemical quartz crystal microbalance for the study of leaching and deposition of metals", Meas. Sci.Technol. 11 (2000) 560. Note: the design and construction of a rotating disk EQCM is described.
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12. F. N. Dultsev, et. al.,"Hearing Bond Breakage. Measurement of Bond rupture forces using the QM", Langmuir 16(2000) 5036-5040. Note: this includes a detailed description of the amplitude of the shear mode oscillation in quartz crystals.
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16. S.J. Geelhood, C. W. Frank and K. Kanazawa, "Transient Quartz Crystal Microbalance
Behaviors Compared", Journal of the Electrochemical Society, 149(2002) H33-H38. Note: A very useful comparison between the dissipation and resonance resistance methods.

Thin Film Deposition

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5. D. R. Denison, "Linearity of Heavily Loaded Quartz Crystal Microbalance", J. Vac. Sci. Technol. 10(1973) 126. Note: The Period-Measurement technique is analyzed further and tested under heavy loads.
6. C. Lu and O. Lewis, "Investigation of film-thickness determination by oscillating quartz resonators with large mass load", J. Appl. Phys. 43 (1972) 4385. Note: This paper includes the original derivation of the "Lu-Lewis" equation used by all modern thin-film monitors and controllers to calculate film thickness while properly accounting for the acoustic properties of the film deposited. A one-dimensional acoustical composite resonator model is used to study the behavior of a quartz crystal resonator with large mass load. It is found that the exact relationship between the frequency shift and the added mass depends on the acoustic impedance of the deposited material. This is also known as the Z-match model.
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QCM with Liquid Deposit

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QCM Immersed in Liquid

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24. Larry Van Bogaert, "Portable Viscometers Improve Process control", June 1997, p. 115.

Electrochemical QCM

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15. G. C. Dunham et. al. , "Dual Quartz Crystal Microbalance", Anal. Chem. 67(1995) 267.
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Calibration

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Conductive Polymer Films

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