# 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


1. C. E. Reed, K. Keiji Kanazawa, and J. H. Kaufman, “Physical description of viscoelastically loaded AT-cut quartz resonator”, J. Appl. Phys. 68(5)(1990)1993.
2. R A Crane and G Fischer, “Analysis of a quartz crystal microbalance with coatings of finite viscosity “ J. Phys. D: Appl. Phys. 12 No 12 (14 December 1979) 2019-2026
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

1. R. L. Filler and J. R. Vig, "The Effect of Bonding on the Frequency vs. Temperature Characteristics of AT-cut Resonators," Proc. 30th Ann. Symp. on Frequency Control, pp. 264-268, 1976.
2. M. Schmid et. al.,”A computer controlled system for the measurement of complete admittance spectra of piezoelectric resonators”, Meas. Sci. Technol. 1 (1990) 970.

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.
4. Bruckenstein, S., Michalski, M., Fensore A, Zhufen, L. and Hilman, A.R., "Dual Quartz Crystal Microbalance Oscillator Circuit. Minimizing Effects due to Liquid Viscosity, Density, and Temperature", Anal. Chem., 66 (1994)1847.
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.
7. E. Benes et. al.,"Comparison between BAW and SAW Sensor Principles", IEE Trans. of Ultrasonics and Freq. Control, 45(5) (1998) 1314.
8. E. Benes, et. al.,"Solving the cable problem between thee crystal sensor and electronics by use of a balanced bridge oscillator circuit", Joint meeting of the 13th European Frequency and Time Forum and the 1999 IEEE Int. Freq. Control Symposium, Besancon, France, Session C4, Wednesday, April 14th, 11:30.
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.
11. John T. Yates, "Reusable Quartz Crystals for Film Thickness Measurement", Experimental Innovations in Surface Science, AIP Press, Springer, 1997.
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.
13. Advincula, R.; Pispas, S.; Hadjichristides, N.; Park, M.; Youk, J.; "In-Situ Adsorption Studies of Functionalized Poly(Styrene-B-Isoprene) With Zwitterionic Groups: Correlation With Quartz Crystal Microbalance (QCM) and Surface Plasmon Spectroscopy (SPS), Polymer Preprints, 42,1,283, 2001
14. M. N. Rocklein and S. M. George, "Temperature-Induced Apparent Mass Changes Observed during QCM Measurements of Atomic Layer Deposition", Anal. Chem. 75 (2003) 4975. Note: this is a case where temperature effects are accounted for during accurate gas phase QCM measurements
15. S. Berg and D. Johannsmann, "High Speed Microtribology with Quartz Crystal Resonators", Physical Review Letters 91(14) (2003) 145505(4)
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


1. G. Sauerbrey, Z. Phys. 155 (1959) 206. Note: The original paper proposing QCMs as a viable tool for micro mass determination. This is the first report on the use of quartz oscillators as microbalances, and where the proportionality between mass load and frequency shift was first proposed.
2. C.D. Stockbridge, "Resonance Frequency vs. Mass Added to Quartz Crystals", in Vacuum Microbalance Techniques, edited by K. Behrndt, Plenum, NY 1966, Vol. 5, p. 193. Note: An alternative derivation of Sauerbrey's equation using Rayleigh's Perturbation Analysis as the starting point.
3. A. P. M. Glassford, "Analysis of the accuracy of a commercial quartz crystal microbalance", in Progress in Astronautics and Aeronautics, edited by Allie M. Smith (American institute of Aeronautics and Astronautics, NY, 1977), vol 56, p. 175-196. Note: The Rayleigh energy method is used again to derive the change in frequency of a harmonically oscillating system when subjected to a small perturbation.
4. K. H. Behrndt, "Long Term Operation of Crystal Oscillators in Thin-Film Deposition", J. Vac. Sci. Technol. 8(5) (1971) 622. Note: The Period-Measurement technique is described and applied to the measurement of film thickness. Many of the old Thin-Film monitors rely on this technique for thickness calculation.
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.
7. Chih-shun Lu, "Mass determination with piezoelectric quartz crystal resonators", J. Vac. Sci Technol., 12(1) (1975) 578. Note: A follow-up article on the Z-Match method.
8. E. Benes, "Improved quartz crystal microbalance technique", 56 (1984) 608. Note: Sequential measurement of the change in resonant frequency at the fundamental and its harmonic provides a method for real-time calculation of the acoustic impedance of the film during the deposition.
9. E. Benes, et. al.,"Enhanced Composite Resonator Analysis and its Application to the Quartz Crystal Microbalance", Proceedings from the 39th Annual Symposium on Frequency Control, 29, 30 & 32 May 1985, AFCS 85
10. E. Benes, M. Schmid and G. Thorn, "Progress in Monitoring Thin Film Thickness by Use of Quartz Crystals", Thin Film Solids 174 (1989) 307-314. Note: The Auto-Z Match technique, used by Leybold controllers, is explained and tested.
11. Abdul Wajid, "Improving the accuracy of a quartz crystal microbalance with automatic determination of acoustic impedance ratio", Rev. Sci. Instrum. 62(1991) 2026

12. Wajid, Abdul, "Measuring and controlling deposition on piezoelectric monitor crystal", US Patent, US5112642, May 12, 1992.
13. Advincula, R.; Park, M.; Yang, J.; Mays, J. Subphase Adsorption of Polyelectrolyte Block Copolymer Amphiphiles at the Air-Water Interface: In-situ Investigations using the Quartz Crystal Microbalance Technique and the Langmuir-Blodgett Trough. Polymer Preprints 1999, 40, 1084
14. M.F. Doemling, et. al., "Using the quartz crystal microbalance for low energy ion beam etching studies", J. Vac. Sci. Technol. A 18(1) (2000) 232. Note: A QCM is used for etching yield measurements in a low energy ion beam system.
15. Scott Grimshaw, "Quartz Crystal Thin-Film Monitoring Forges Ahead", Photonics Spectra April 2003, p. 82. Note: A short and practical overview.
16. Bob Langley and Paul LaMarche, "QC Film Thickness Monitor Basics, Operation and Experimental Tool", Vacuum Technology and Coating, June 2002, p. 22.

# QCM with Liquid Deposit

1. A. P. M. Glassford, "Response of a quartz crystal microbalance to a liquid deposit", J. Vac. Sci. Technol. 15(6) (1978) 1836. Note: This theoretical model considers droplet type loading as well as uniform films.
2. Zuxuan Lin and Michael Ward, "Determination of contact angles and surface tensions with the quartz crystal microbalance", Anal. Chem. 68(1996) 1285. Note: A method based on the QCM for measuring the sessile contact angles and surface energies of liquid-air and liquid-liquid interfaces is described. The method involves measurement of the frequency change accompanying the introduction of a small liquid droplet to the center of a vibrating quartz resonator.

# QCM Immersed in Liquid

1. Nomura T. et. al., Nippon Kagaku Kaisi, 1980(1980) 1261
2. Nomura T., Anal. Chim. Acta 124 (1981) 81.
3. Konash P. et. al. , J. Anal. Chem. 52 (1980) 1929
4. Bruckenstein S. and Shay M., "Experimental aspects of use of the quartz crystal microbalance in solution", Electrochim. Acta 30(1985) 1295. Note: Includes a description of the "Boundary-Layer" derivation of frequency shifts in liquid solution (which yields a result similar to that provided by Kanazawa and Gordon). A functional relationship between the frequency shift and the density and viscosity of the solution is derived.
5. K. K. Kanazawa and J. G. Gordon II, "Frequency of a Quartz Microbalance in contact with Liquid", Anal. Chem. 57 (1985) 1770. Note: The dependence of frequency shift on density and viscosity of the liquid is derived by examining the coupling of the elastic shear waves in the crystal to the viscous shear waves in the liquid. This is the currently accepted formula used to explain the frequency shift in a quartz crystal oscillator when it is immersed in liquid.
6. K. K. Kanazawa and J. G. Gordon, "The oscillation frequency of a quartz resonator in contact with a liquid", Anal. Chim. Acta 175 (1985) 99-105.Note: This is the paper where Kanazawa clearly derives the relationship which expresses the change in

oscillation frequency of a quartz crystal in contact with a fluid in terms of material parameters of the fluid and the quartz.

7. Muramatsu, H. et. al., "Computation of Equivalent Circuit Parameters of Quartz Crystals in Contact with Liquids and Study of Liquid Properties", Anal. Chem. 60(1988) 2142. Note: The dependence of the frequency shift and deficit resistance on the viscosity and density of the liquid is derived and tested experimentally. An Equivalent-Circuit description of the QCM is used to derive an equation relating the resistance to the viscosity and the density. This formula is currently used to calculate in-situ viscosities of liquids.
8. P.J. Cumpson, M.P. Seah, "The quartz crystal microbalance; radial/polar dependence of mass sensitivity both on and off the electrodes", Meas. Sci. Technol. 1 (1990) 544–555
9. Ward M. D. and Delawski E. J., "Radial Mass Sensitivity of the Quartz Crystal Microbalance in Liquid Media", Anal. Chem. 63(1991) 886. Note: Coating uniformity is determined as being very important for accurate measurements. The need for calibration is discussed.
10. M. Yang and M. Thompson, "Multiple Chemical Information from the Thickness Shear Mode Acoustic Wave Sensor in the Liquid Phase", Anal Chem. 65(1993) 1158. Note: The effects of viscosity, density and dielectric constant of a liquid on the response of a TSM bulk acoustic wave sensor are examined with respect to frequency response and the electrical properties of the equivalent circuit representation.
11. S. J. Martin et. al., "Effect of Surface Roughness on the Response of Thickness-Shear Mode Resonators in Liquids", Anal. Chem. 65(1993)2910. **Note:** The effect of surface microstructure on the response of the TSM resonator in contact with liquids was examined. Results show that, for roughness features much less than the liquid decay length, the surface may be considered hydrodynamically smooth and the response depends only on the density-viscosity product.
12. Michael Urbakh and Leonid Daikhin, "Roughness effect on the frequency of a quartz-crystal resonator in contact with a liquid", Phys. Rev. B, 49(1994-I)4866.
13. Jorg Auge, Peter Hauptmann et. al., "Quartz Crystal Microbalance Sensor in Liquids", Sensors and Actuators B,18-19 (1994)518-522.
14. M. Rodahl, B. Kasemo et. al., "Quartz Crystal microbalance setup for frequency and Q-factor measurements in gaseous and liquid environments", Rev. Sci. Instrum. 66(7) (1995) 3924. Note: An experimental setup is reported that allows simultaneous measurement of frequency, Q-factor and amplitude of oscillation of a QCM.
15. Zuxuan Lin and Michael Ward, "The role of longitudinal waves in quartz crystal microbalance applications in liquids", Anal Chem. 67(1995) 685. Note: Important recommendations are presented to avoid the contributions of longitudinal waves to QCMs operated in liquids.
16. M. Rodahl, B. Kasemo et. al., "QCM Operation in Liquids: An explanation of Measured Variations in Frequency and Q-Factor with Liquid Conductivity", Anal. Chem., 68(1996) 2219. Note: the effects of electrode fringing fields and liquid's conductivity and dielectric properties on the frequency and dissipation factors of the QCM are discussed.
17. Cumpson P.J., "Quartz Crystal microbalance" A novel electrode design eliminates sensitivity outside the electrodes, often wrongly attributed to the electric fringing field", J. Vac. Sci. Technol. A15(4)(1997) 2407

18. Glen McHale, Michael I. Newton, Markus K. Barnejee and S. Michael Rowan, “Interaction of surface acoustic waves with viscous liquids”, Faraday Discuss. 107 (1997) 15-26
19. S. J. Martin, R. J. Huber et. al., “Resonator/Oscillator Response to Liquid Loading”, Anal. Chem. 69 (1997) 2050. Note: the effect of viscous liquid loading on a crystal is described based on the equivalent-circuit model. The model is carefully optimized to measure higher viscosity and higher density liquids with greater accuracy.
20. R.W. Cernosek et. al. “Analysis of the radial dependence of mass sensitivity for Modified electrode quartz crystal resonators”, Anal. Chem.50(1998) 237. Note: The radial dependence of mass sensitivity of the sensing surface is analytically calculated for two examples of “Modified electrode” QC resonator.
21. R. Thalhammer et. al., ”Viscosity Sensor Utilizing a Piezoelectric Thickness Shear Sandwich Resonator”, IEEE Trans. on Ultrasonics and Freq. Control. 45(5) (1998)1331.
22. M. Yoshimoto and S. Kurosawa, “Effect of immersion angle of a one face sealed QCM in Liquid”, Anal. Chem. 74 (2002) 4306.
23. Leonid Daikhin, et. al.,”Influence of Roughness on the admittance of the QCM immersed in Liquids”, Anal Chem 74(2002) 554.
24. Larry Van Bogaert, “Portable Viscometers Improve Process control”, June 1997, p. 115.

# Electrochemical QCM

1. Bruckenstein S. and Shay M., “Experimental aspects of use of the quartz crystal microbalance in solution”, Electrochim. Acta 30(1985) 1295. Note: Includes a derivation of the “Boundary-Layer” derivation of frequency shifts in liquid solution which yields a result similar to that provided by Kanazawa and Gordon. A functional relationship between the frequency shift and the density and viscosity of the solution is derived. The mass sensitivity calibration of the QCM is verified experimentally.
2. O. Melroy, K. Kanazawa, J. G. Gordon II, and D. Buttry, “Direct Determination of the Mass of an Underpotentially Deposited Monolayer of Lead on Gold”, Langmuir, 2(1986) 697.
3. M. Benje et. al., :An Improved Quartz Microbalance. Applications to Electrocrystallization and dissolution of Nickel”, Ber. Bunsenges, Phys. Chem. 90(1986) 435. Note: a Pierce-Miller oscillator design is described. A simple crystal holder design is also presented.
4. W. Stockel and R. Schumacher, “In Situ Microweighing at the Junction Metal/Electrolyte”, Ber. Bunsenges. Phys. Chem. 91 (1987) 345. Note: Interfacial processes are probed with the help of a EQCM. The results agree with those obtained through XPS measurements.
5. M. R. Deakin and Owen Melroy, “Underpotential Metal Deposition on Gold, Monitored in situ with a Quartz Microbalance”, J. Electroanal. Chem. 239(1988)321. Note: These experiments clearly demonstrate that the EQCM is a viable quantitative tool for examining monolayers and sub-monolayer metal deposits.
6. Michael Ward, “Investigation of Open Circuit Reactions of Polymer Films Using the Quartz Crystal Microbalance. Reactions of Polyvynilferrocene Films”, J. Phys. Chem. 92(1988) 2049.

7. M. R. Deakin and D.A. Buttry, "Electrochemical Applications of the Quartz Crystal Microbalance", Anal Chem. 61(1989) 1147A.
8. Buttry, Daniel, "Applications of Quartz Crystal Microbalance to Electrochemistry", in Electroanalytical Chemistry, A Series of Advances, ed. by Allen Bard, Volume 17, 1991.Note: An excellent review article on the subject of EQCMs.
9. Buttry, Daniel, ""The Quartz Crystal Microbalance as an in situ tool in electrochemistry", in Electrochemical Interfaces: Modern Techniques for in situ Interface Characterization, Chapter 10, 1991, p. 529-567.
10. S. J. Martin et. al. "Characterization of a Quartz Crystal Microbalance with Simultaneous Mass and Liquid Loading", Anal. Chem. 63 (1991) 2272. Note: The electrical admittance of an AT-cut crystal QCM simultaneously loaded by a surface mass layer and a contacting Newtonian liquid is derived. With this model, changes in surface mass can be differentiated from changes in solution properties.
11. F. Zhou, S-L. Yau, C. Jehoulet, D. A. Laude, Z. Guan, A. J. Bard, "Electrochemistry of C60 Films: Quartz Crystal Microbalance and Mass Spectrometric Studies," J. Phys. Chem., 96(1992)4160.
12. Buttry Daniel and Michael D. Ward, "Measurement of Interfacial Processes at Electrode Surfaces with the Electrochemical Quartz Crystal Microbalance", Chem. Rev. 92(6)(1992) 1355-1379. Note: Excellent review article, with perhaps one of the most straightforward explanations of the piezoelectric effect and the equivalent electrical representation of AT-cut quartz crystal resonators. Everybody in the field must read this paper!
13. Wei-Wei Lee, Henry S. White and Michael Ward, "Depletion Layer Effects on the Response of the EQCM", Anal. Chem. 65 (1993)3232. Note: This paper demonstrates the power of EQCM, showing the response of the EQCM to changes in density and viscosity at the depletion layer of a $Fe(CN)_6$ reaction couple.
14. C. Wei et. al., "A combined Voltammetry and electrochemical quartz crystal microgravimetry study of the reduction of aqueous Se(IV) at gold", J. Electroanal Chem. 375(1994) 109.Note: The EQCM is used to study a reaction mechanism.
15. G. C. Dunham et. al. , "Dual Quartz Crystal Microbalance", Anal. Chem. 67(1995) 267.
16. Eujin Hwang and Youngran Lim, "Construction of Low Noise Electrochemical Quartz Crystal Microbalance", Bull. Korean Chem. Soc. 17(1996) 39.
17. Euijin Hwang and Youngran Lim, "Construction of Low Noise Electrochemical Quartz Crystal Microbalance", Bull. Korean Chem. Soc. 17(1996) 39.
18. Y. Lim and E. Hwang, "An electrochemical Quartz Crystal Microbalance Study of oxygen reduction during the underpotential deposition of lead on a gold electrode", Bull. Korean Chem Soc. 17(12)(1996) 1091
19. R. A. Etchenique and E.J. Calvo, "Electrochemical Quartz Crystal Impedance Study of Redox Hydrogel Mediators for Amperometric Enzyme Electrodes", Anal Chem., 69(1997) 4833.
20. A. R. Hillman, "The QCM in Electrochemistry", Electrochimica Acta (Special Issue) 45(22 and 23), 304 pages, year 2000. Note: A special issue dedicated to the EQCM.
21. C. Eickes, J. Rosenmund, S. Wasle, K. Doblhofer, K. Wang, K.G. Weil, "The electrochemical quartz crystal microbalance (EQCM) in the studies of complex electrochemical reactions" Electrochimica Acta 45 (2000) 3623–3628

22. M. Itagaki et. al. , "EQCM/Wall Jet Split-Ring Disk Electrode Study on Copper Dissolution in Chloride Aqueous Solution", in Analytical Sciences, October 2000, vol. 16, p. 1049. A publication of the Japan Society of Analytical Chemistry.
23. Z. Jusys, G. Stalnionis, "Wall-jet electrochemical quartz crystal microgravimetry: oxidation of Co(II)–ethylenediamine complexes on copper electrode" Electrochimica Acta 45 (2000) 3675–3682
24. Qingji Xie, et. al., "An Electrochemical Quartz Crystal  impedance Study on the rising of an aqueous solution meniscus for a partially immersed gold electrode during the electrochemical reduction of Oxygen", Anal. Sciences 17 (2001) 265.
25. Bund *, G. Schwitzgebel,  "Investigations on metal depositions and dissolutions with an improved EQCMB based on quartz crystal impedance measurements" Electrochimica Acta 45 (2000) 3703–3710. Note: The frequency and damping changes of resonating quartz crystals in electrochemical experiments are measured at a time resolution of about 500 ms. The damping effects accompanying metal depositions and dissolutions (Ag and Cu) on polycrystalline Au electrodes of 6 and 10 MHz AT quartzes are studied and discussed in terms of roughness and sliding effects. Resistance measurement is not just useful for viscoelastic films.
26. Herve Ehahoun et. al., "Performance and Limits of a Parallel Oscillator for Electrochemical Quartz Crystal Microbalances", Anal. Chem. 74(2002)1119. Note: A driving circuit for an EQCM adapted to a large range of applications is described.
27. V. Tsionsky, G. Katz, E. Gileadi and L. Daikhin, "Admittance studies of the EQCM on rough surfaces: The double layer region", Journal of Electrochemical Chemistry 524-525(2002)110.
28. Magdalena Skompska, Angela Jackson and A. Robert Hillman,  "Evolution from gravimetric to viscoelastic response of poly(3-methylthiphene) loaded acoustic wave resonators"Phys. Chem. Chem. Phys. 2 (2000) 4748-4757
29. Kristien Bonroy, et. al. , "Realization and characterization of porous Gold for Increased Protein Coverage on Acoustic Sensors", Anal. Chem. 76 (2004) 4299-4306.
30. Nicolas P. Cosman and Sharon G. Roscoe, "EQCM to detect Solvent Displacement by pH-induced Conformational Changes of Proteins at Pt", Anal. Chem. 76 (2004) 5945

## Calibration

1. C. Gabrielli et. al., "Calibration of the Electrochemical Quartz Crystal Microbalance", J. Electrochem. Soc. 139(9) (1991) 2657. Note: A calibration procedure based on the deposition of Ag on Au electrodes is described.
2. Graeme Andrew Snook, "Investigation of Solid-State Reactions by Electrochemical and Quartz Crystal Microbalance Measurements" Ph.D. Thesis, 2000, Department of Chemistry, Monash University, Clayton 3168, Melbourne, Australia and Division of Minerals, CSIRO, Clayton South 3169 Melbourne, Australia, under the supervision of Professor Alan Maxwell Bond (Monash) and Professor Stephen Fletcher (CSIRO). Available for download from: http://www-bond.chem.monash.edu.au/theses/ Note: the use of Lead acetate is proposed as a better alternative to Cu and Ag deposition.

## Conductive Polymer Films

1. D. Orata and Daniel Buttry, "Determination of Ion Populations and Solvent Content as Functions of Redox State and pH in Polyaniline", J. Am. Chem. Soc. 109(1987) 3574. Note: The EQCM is used to investigate ion populations and solvent content of thin films of polyaniline on electrode surfaces as functions of redox state and pH. The ability to measure both electrochemical and gravimetric data simultaneously greatly simplifies modeling of this redox system.
2. C. K. Baker and J. R. Reynolds, "A quartz microbalance study of the electrosynthesis of polypyrrole", J. Electroanal. Chem., 251(1988) 307. Note: The EQCM is used to study the anodic electropolymerization of Pyrrole.
3. Adrian W. Bott, "Characterization of Films Immobilized on an Electrode Surface Using the Electrochemical Quartz Crystal Microbalance" Current Separations, 18(3) (1999) 79. Note: The principles of the EQCM are discussed, together with some examples of its application in the study of electrodeposition and ion and solvent transport in redox active films.
4. 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.
5. Advincula, R.; Baba, A.; Kaneko, F. Functional Ultrathin Multilayer Assemblies: Adsorption Properties of Charged Azo Dyes and Polyelectrolytes Investigated using the Quartz Crystal Microbalance (QCM) Technique, PMSE Preprints, 1999, 81, 95
6. Csaba Visy, Jouko Kankare, Emese Kriva´n , "EQCM and in situ conductance studies on the polymerisation and redox features of thiophene co-polymers" Electrochimica Acta 45 (2000) 3851–3864
7. Advincula, R., Baba, A., Kaneko, F. Polyelectrolyte Adsorption Processes Characterized In Situ Using the Quartz Crystal Microbalance Technique: Alternate Adsorption Properties in Ultrathin Polymer Films. Colloids and Surfaces: A. Physicochemical and Engineering Aspects 2000 173, p. 39-49
8. G. Inzelt, "Simultaneous chronoamperometric and quartz crystal microbalance studies of redox transformations of polyaniline films", Electrochimica Acta 45 (2000) 3865–3876
9. W. Paik, I.-H. Yeo, H. Suh, Y. Kim, E. Song, "Ion transport in conducting polymers doped with electroactive anions examined by EQCM" Electrochimica Acta 45 (2000) 3833–3840
10. Stanley Bruckenstein, Krystina Brzezinska, A. Robert Hillman, " EQCM studies of polypyrrole films. 1. Exposure to aqueous sodium tosylate solutions under thermodynamically permselective conditions", Electrochimica Acta 45 (2000) 3801–3811
11. A. L. Briseno, et. al.,"Quantification of dopant ions in polypyrrole films with electrochemical ICP-atomic emission spectrometry and comparison to electrochemical quartz crystal microbalance studies", Analytica Chimica Acta 21292(2001) 1-12. Note: Anion ejection out of polypyrrole films was performed with electrochemistry combined with on-line ICP-AES and EQCM. The techniques all show to be complimentary for the understanding of the transport processes.
12. Andrea Sabot and Steffi Krause, "Simultaneous Quartz crystal microbalance impedance and electrochemical impedance measurements. Investigation into the degradation of thin polymer films", Anal. Chem. 74 (2002) 3304

# Chemical Sensors


1. Czanderna, A. W.; Thomas T.M.; 1987, "A Quartz Crystal Microbalance Apparatus for Water Sorption by Polymers," Journal of Vacuum Science Technology , Vol. A5, No. 2412. Note: this is a very important paper describing the use of QCM technology to detect relative humidity.
2. W. H. King, "Piezoelectric Sorption Detector", Anal. Chem. 36(1964) 1735.Note: this is the first report of an analytical application of QCM.
3. G.G. Guilbault, "Determination of formaldehyde with an enzyme coated piezoelectric crystal", Anal. Chem. 55(1983)1682.
4. G.G. Guilbault and J. Jordan, "Analytical uses of piezoelectric crystals", CRC Reviews 19, p. 1-28.
5. G.G. Guilbault and Ngeh-Ngwainbi, "Use of protein coatings on piezoelectric crystals for assay of gaseous pollutants", in Guilbault , G.G. and Mascini, M. (Eds), Analytical Uses of Immobilized Biological Compounds for Detection, Medical and Industrial Uses. NATO reference series. Riedel.
6. M. Tersea Gomes, et. al.,"Determination of Sulfur Dioxide in Wine Using a Quartz Crystal Microbalance", Anal. Chem. 68(9) (1996) 1561. Note: A new method of analysis of both total and bound SO2 in wine is proposed, based on the QCM. Sulfur dioxide reduces Hg(II) ions in solution and the Hg(0) formed amalgams with the Au electrodes producing a frequency shift. The Hg(0) is easily driven off the crystals by heating.
7. K. Bodenhofer, et. al. "Performances of Mass-Sensitive Devices for Gas Sensing: Thickness Shear Mode and Surface Acoustic Wave Transducers", Anal. Chem. 68 (1996) 2210. Note: The use of TSM resonators as mass-sensitive transducers for gas detection is investigated. Very satisfactory results are demonstrated for TSMRs.
8. Wei Hongmei, et. al. ,"An Application of artificial neural networks. Simultaneous determination of the concentration of Sulfur Dioxide and relative humidity with a single coated piezoelectric crystal", Anal. Chem. 69 (1997) 699. Note: the concentrations of SO2 and H2O are calculated simultaneously with certainty around 10%.
9. M. Teresa S. R. Gomes, et. al. "Optimization of the experimental conditions of a new method based on a QCM for the determination of Cyanide", Analyst 122 (1997) 1139.
10. Harry O. Finklea, Mark A. Phillippi, Elizabeth Lompert and Jay W. Grate, "Highly Sorbent Films derived from Ni(SCN)2(4-picoline)4 for the detection of Chlorinated and aromatic hydrocarbons with quartz crystal microbalance sensors", Anal. Chem. 70 (1998) 1268-1276.
11. Potyrailo, Radislav A.; May, Ralph J.; Sivavec, Timothy M., "Recognition and quantitation of closely related chlorinated organic vapors with acoustic-wave chemical sensor arrays", Proc. SPIE 3856 (1999)80-87.
12. M. Teresa S. R. Gomes, et. al.,"Development of a methodology for the determination of carbon monoxide using a QCM", Analyst 124 (1999) 1449.
13. Seimei Sha Shiratori, et. al.,"High Performance smell sensor using spatially controlled LB films with polymer backbone", Sensors and actuators B 64 (2000) 70-75.

14. Chengdu Liang, et. al.,"Bulk Acoustic wave sensor for herbicide assay based on molecularly imprinted polymer", Frsenius J. Anal. Chem 367 (2000) 551.
15. M. Teresa S. R. Gomes, et. al., "The quantification of potassium using a quartz crystal microbalance", Analyst 125 (2000) 1983.
16. H. Nanto et. al. "Novel gas sensor using polymer-film-coated quartz resonator for environmental monitoring", Materials Science and Engineering C 12(2000) 43.
17. Rupa Patel, R. Zhou, K. Zinszer, F. Josse, and R. Cernozek, "Real-time Detection of Organic Compounds in Liquid Environments Using Polymer-coated Thickness Shear Mode Quartz Resonators", Anal. Chem. 72(2000) 4888. Note: The selection criteria for sensitive coatings are carefully described. The compounds considered include polar, non-polar and halogenated organic chemicals.
18. J. W. Grate, "Acoustic Wave Microsensor Arrays for Vapor Sensing," Chem. Rev., 100(7) (2000) 2627-2647. INVITED for Special issue on Chemical Sensors.
19. Dosil Pereira de Jesus, et. al., "Determination of Boron by using a Quartz crystal Resonator coated with N-Methyl-D-Glucamine-Modified Poly(epichlorohydrin)", Anal. Chem. 74 (2002) 3274
20. Robert J. Lippert et. al., "Thin Films of Block Copolymer Blends for Enhanced Performance of Acoustic Wave-Based Chemical Sensors", Anal. Chem. 74 (2002) 6383.
21. S. Stanley, C. J. Percival, et. Al.,"Detection of Polycyclic Aromatic Hydrocarbons using Quartz Crystal Microbalances", Anal. Chem. 75 (2003) 1573.
22. J. W. Grate, David A. Nelson, and Ronda Skaags, "Sorptive behavior of Monolayer-Protected Gold Nanoparticle Films: Implications for Chemical vapor sensing", Anal. Chem. 75 (2003) 1868-1879.
23. Yi Fu and Harry O. Finklea, "QCM Sensor for Organic Vapor Detection Based on Molecularly Imprinted Polymers", Anal. Chem. 75 (2003) 5387-5393.
24. Radislav A. Potyrailo and Timothy M. Sivavec, "Boosting Sensitivity of Organic Vapor Detection with Silicone Block Poluimide Polymers", Anal. Chem. 76 (2004) 7023
25. Radislav A. Potyrailo; Ralph J. May; Timothy M. Sivavec "Recognition and Quantification of Perchloroethylene, Trichloroethylene, Vinyl Chloride, and Three Isomers of Dichloroethylene Using Acoustic Wave Sensor Array", Sensor Letters, 2 (1), March 2004, pp. 31-36(6)
26. Diethekm Johannsmann, et. al., "Organic Vapor Sensing with Ionic Liquids Entrapped in Alumina Nanopores on Quartz Crystal resonators", Anal. Chem. 77 (2005) 615.


# Biological/Biochemical Research


1. K. Wakamatsu et. al.,"Direct in-situ measurement of Phospholipid hydration in an aqueous environment using a quartz crystal microbalance", Anal. Chem. 67 (1995) 3336.
2. Murray , B. S. and Deshaires, C., "Monitoring protein fouling of metal surfaces via a quartz crystal microbalance", J. Colloid Interface Sci., 227 (2000) 32–41


## Phage detection

3. Hengerer et. al., “Determination of Phage Antibody Affinities to Antigen by a Microbalance Sensor System”, BioTechniques 26 (1999) 956-964. Note: Antigen is immobilized on the QCM electrode and binding of the antibody is detected as a decrease in frequency. The technique is compared against SPR results.
4. Erich Uttenhaler, et. al., “Ultrasensitive QCM Sensors for detection of M13-Phages in liquids”, Biosensors and Bioelectronics, 16 (2001) 735-743.

## Cell Adhesion

5. Joachim Wegener, et. al.,”Cell Adhesion monitoring using a QCM: comparative analysis of different mammalian cell lines”, Eur. Biophys. Journal 28 (1998) 26-37.
6. C. Fredriksson, S. Kihlman, M. Rodahl and B. Kasemo, ”The Piezoelectric Quartz Crystal Mass and Dissipation Sensor: A means of Studying Cell Adhesion”, Langmuir 14(1998) 248. Note: The potential of using a QCM based technique for the characterization of living cells during the process of adhesion to a surface is explored.
7. Warren, M.C., Medeiros, D., Bump, E.A., S.J. Braunhut.. Oxidative stress-induced apoptosis of endothelial cells: The role of matrix metalloproteinases. Free Radical Biology & Medicine, 29 (2000) 537-547.
8. Zhou, T., K.A. Marx, M. Warren, H. Schulze and S.J. Braunhut, “The Quartz Crystal Microbalance as a Continuous Monitoring Tool for the Study of Endothelial Cell Attachment and Growth”, Biotechnology Progress, 16 (2000) 268-277
9. Marx, KA, Zhou, T., Montrone A., Shultze, H. and S.J. Braunhut.”A quartz crystal microbalance cell biosensor: detection of microtubule alterations in living cells at nM nocodazole concentrations”. Biosensors and Bioelectronics. 16 (2001) 773-782. Editor’s choice.
10. Marx, K.A., T. Zhou, A. Montrone and S.J. Braunhut “A quartz Crystal Microbalance Cell Biosensor: Detecting Nocodazole-Dependent Microtuble Disruption Dynamics in Living Cells”, Proceedings MRS: Advanced Biomaterials-Characterization, Tissue Engineering and Complexity, Materials Research Society, Pittsburgh, PA., 711 (2002)125-132.

## Adsorption

11. Makoto Muratsugu, et. al. ,”Quartz Crystal Microbalance for the Detection of microgram quantities of Human Serum Albumin: Relationship between the frequency change and the mass of protein adsorbed”, Anal. Chem. 65 (1993) 2933. Note: This is a nice paper that shows the strict relationship between frequency shift and the amount of BSA or HAS adsorbed on a polished gold-coated QCM crystal.
12. Jan Rickert, et. al.,”QCM Operation in Liquids: Constant Sensitivity during Formation of Extended Protein Multilayers by Affinity”, Anal. Chem. 69(1997) 1441. Note: The formation of protein multilayers with a QCM in situ is studied. The factors leading to frequency shifts are carefully separated and characterized.
13. F. Höök, M. Rodahl, B. Kasemo and P. Brzezinski, “Structural changes in hemoglobin during adsorption to solid surfaces: Effects of pH, ionic strength and ligand Binding”, Proc. Natl. Acad. Sci. 95(1998) 12271. (Biophysics)
14. F. Höök, M. Rodahl, P. Brzezinski and B. Kasemo, “Measurements Using the Quartz Crystal Microbalance Technique of Ferritin Monolayers on Methyl-Thiolated Gold:

Dependence of Energy Dissipation and saturation Coverage on Salt Concentration", J. Colloid and Interface Science, 208(1998) 63.
15. C. A. Keeller and B. Kasemo, "Surface Specific Kinetics of Lipid Vesicle Adsorption Measured with a QCM", Biophysical Journal 75(1998) 1397.
16. Fant, C., Höök, F., Kasemo, B., and Elwing" H. "Tyrosinase induced cross linking of monolayers of adsorbed mussel adhesive protein (Mefp-1). Visualization with Quarts micro balance (QCM-D®) and surface plasmon resonance" Non-toxic control of marine biofouling, MASTEC-symposium Tjärnö 1998
17. Mjörn, K., Keller, C., Kasemo, B., and Elwing, H. "Protein repellent phospholipid bilayers at SiO2 surfaces for biosensor applications with Quartz Crystal Micro balance (QCM-D®) and surface plasmon resonance"(SPR)" Poster at Non-toxic control of marine biofouling, MASTEC-symposium Tjärnö 1998
18. L. Daikhin, E. Gileadi, V. Tsionsky, M. Urbakh , G. Zilberman, "Slippage at adsorbate–electrolyte interface. Response of electrochemical quartz crystal microbalance to adsorption", Electrochimica Acta 45 (2000) 3615–3621
19. Roberto Etchenique and Thomas Buhse, "Anomalous behaviour of the QCM in the presence of electrolytes", Analyst 125 (2000) 785.
20. F. Höök, et. al., "A comparative study of protein adsorption on titanium oxide surfaces using in situ ellipsometry, optical waveguide light mode spectroscopy and quartz crystal microbalance/dissipation", Colloids and Surfaces B: Biointerfaces 2001.

# BioSensors

1. G.G. Guilbault and J.H. Luong, "Gas Phase Biosensors", J. Biotechnol. 9(1988) 1-10.
2. Minunni, M., Guilbault, G.G. and Hock, B., "Quartz Crystal microbalance as a biosensor", Anal. Lett. 28(1995) 749.
3. J. E. Pearson, A. Gill and P. Vadgama, "Analytical Aspects of Biosensors", Ann. Clin. Biochem. 37 (2000) 119-145. Note: A very comprehensive review of biosensors from a clinical chemistry perspective. Of course, QCMs are featured as a promising option.
4. Spangler, B.D., Wilkinson, E. A., and Murphy, J.,"Comparison of the Spreeta® surface plasmon resonance sensor and a quartz crystal microbalance for detection of Escherichia coli Heat-Labile Enterotoxin," J. Anal. Chim. Acta 444 , 149-161 (2001). Note: QCM and SPR technologies are compared against each other and also against ELISA testing. QCM is demonstrated to be more sensitive than SPR in this application.
5. F. Höök ,, J. Vörös , M. Rodahl , R. Kurrat , P. Böni , J. J. Ramsden , M. Textor , N. D. Spencer , P. Tengvall , J. Gold and B. Kasemo , "A comparative study of protein adsorption on titanium oxide surfaces using in situ ellipsometry, optical waveguide lightmode spectroscopy, and quartz crystal microbalance/dissipation", Colloids and Surfaces B: Biointerfaces , 24( 2) ( 2002) 155-170

## Immunosensors

6. G.G. Guilbault et. al. , "PZ immunosensor for atrazine in drinking water", Biosensors Bioelectron. 7 (1992) 411.

7. B. Konig and M. Gratzel, “”Detection of viruses and bacteria with piezoimmunosensors”, Anal. Lett. 26(1993) 1567.
8. C. Kosslinger, S. Drost, F. Aberl et. al., “HIV detection with a PZ immunosensor”, Sensors Actuators B 18-19 (1994) 271-275.
9. B. S. Attili and A.A. Suleiman, “Piezoelectric immunosensor for the detection of cortisol”, Anal. Lett.28(1995) 2149.
10. I. Karube et. al., “A novel method of immobilizing antibodies on a quartz crystal microbalance using Plasma-Polymerized Films for immunosensors”, Anal Chem. 68 (1996) 1695.
11. B. S. Attili and A.A. Suleiman, “Piezoelectric immunosensor for the detection of cocaine”, Microchem. J. 54(2) (1996) 174.
12. Y. Cohen, S. Levi, S. Rubin and I. Willner, “Modified Monolayer electrodes for electrochemical and PZ analysis. Novel immunosensor electrodes”, J. ElectroAnal Chem. 417(1996)65.
13. Iddo Ben-Dov et. al.,”Piezoelectric Immunosensors for Urine Specimens of Chlamydia trachomatis employing quartz crystal microbalance Microgravimetric analysis”, Anal. Chem. 69(17)(1997) 3506.
14. Jin Li, et. al. , “A Novel Piezoelectric Biosensor for the Detection of Phytohormone b-Indole Acetic acid”, Anal. Sciences 18 (2002) 403.
15. Yung-Chuan Liu , Chih-Ming Wang , Kuang-Pin Hsiung and Chienjin Huang , “Evaluation and application of conducting polymer entrapment on quartz crystal microbalance in flow injection immunoassay “, Biosensors and Bioelectronics, 18 (2003) 937. Note: this is also a great paper showing an example of a QCM interfaced to a sequential injection analysis system.
16. Ilaria Mannelli, Maria Minunni ,, Sara Tombelli and Marco Mascini , “Quartz crystal microbalance (QCM) affinity biosensor for genetically modified organisms (GMOs) detection “, Biosensors and Biotechnology, 18 (2003)129.
17. Tetsu Tatsuma et. al. , “Multichannel Quartz Crystal Microbalance”, Anal. Chem. 71 (1999) 3632-3636.
18. Boli Zuo, Shanmao Li, Zhao Guo, Jinfang Zhang, and Chuanzhi Chen, “Piezoelectric Immunosensor for SARS Associated Coronavirus in Sputum”, Anal. Chem. 76 (2004) 3536.
19. Zhihong Shen, et. al., “Single-chain Fragment Variable Antibody Piezoimmunosensors”Anal. Chem. 70 (2005) 797.


## DNA Sensors


20. S. Han, J. Lin, M. Satjapipat, Alfred Baca, and F. Zhou, "A Three-Dimensional Heterogeneous DNA Sensing Surface Formed by Attaching Oligonucleotide-Capped Gold Nanoparticles Onto a Gold-Coated Quartz Crystal," Chem. Commun. 2001, 7, 609-610.
21. Joseph Wang, “From DNA biosensors to Gene Chips”, Nucleic Acids Research, 28 (16)(2000) 3011-3016. Note: QCM devices are discussed on page 3013.
22. Frank Caruso et. al., “QCM Study of DNA Immobilization and Hybridization for Nucleic Acid Sensor Development”, Anal. Chem. 69 (1997) 2043. Note: DNA 30-mers are immobilized on chemically modified crystals.
23. Joseph Wang, et. al.,”Mismatch-sensitive Hybridization detection by PNA immobilized on a QCM”, Anal. Chem. 69 (1997) 5200.

24. Shuichiro Yamaguchi, et. al.,"Adsorption, Immobilization and Hybridization of DNA Studied by the use of QC Oscillators", Anal Chem 65 (1993) 1925. Note: Silanization is used to chemically modify the surface of the electrodes and provide chemically active surfaces.
25. Xiaodi Su, et. al.,"Detection of Point Mutation and Insertion Mutations in DNA Using a QCM and MuTS, a Mismatch Binding Protein", Anal. Chem. 76 (2004) 489.
26. Seongpil Hwang, et. al., "Electrochemical Detection of DNA Hybridization Using Biometallization", Anal. Chem. 77 (2005) 579.

# Self-Assembled Monolayers

1. D. S. Karpovich and G. J. Blanchard, "Direct measurement of the adsorption kinetics of alkanethiolate SAMs on a microcrystalline gold surface", Langmuir 10 (1994) 3315.
2. D. S. Karpovich and G. J. Blanchard, "An Undergraduate Laboratory Experiment for he Direct Measurement of Monolayer Formation Kinetics", J. Chem. Education, 72 (1995) 466.
3. H. M. Schessler et. al. , "Quantitating the Balance between Enthalpic and Entropic Forces in Alkanethiol/Gold Monolayer Self Assembly", J. Am. Chem. Soc. 118 (1996) 9645.
4. D. S. Karpovich and G. J. Blanchard, "Vapor adsorption onto metal and modified interfaces: Evidence for adsorbate penetration of an alkanethiol Monolayer on Gold", Langmuir 13 (1997) 4031.
5. Spangler, B.D. and Tyler, B., "Capture Agents for a Quartz Crystal Microbalance - Continuous Flow Biosensor: Functionalized Self-assembled Monolayers on Gold", Anal. Chim. Acta.,399, 51-62 (1999). Note: Professor Spangler is also CEO of SensoPath Technologies a company specialized in the development of materials for the design and fabrication of SAMs on gold surfaces (www.sensoPath.com)
6. E. J. Calvo, et.al., "Layer-by-layer Self-Assembly of Glucose oxidase and $Os(Bpy)_2CIPyCH_2NH$-poly(Allylamine) Bioelectrode", Anal. Chem. 73(2001) 1161
7. Ernesto Calvo, et, al.,"Study of layer-by-layer Self assembled viscoelastic films on thickness-shear mode resonator surfaces", Anal. Chem. 74 (2002) 3281.
8. Jingshi Shi, et. al. "Temperature effect on Layer-by-Layer Self-Assembly of Linear Polyions and Silica Multilayers", Chem. Letters 32(4)(2003)316.
9. A. Tlili et. al., "Electrical Charaacterization of a Thiol SAM on Gold as a First Step for the Fabrication of Immunosensors based on a Quartz Crystal Microbalance", Sensors 4 (2004) 105.
10. George M. Whitesides et. al., "Palladium as a substrate for SAMs used in Biotechnology", Anal. Chem. 76 (2004) 6116-6121. Notes: No QCM was used here, but Whitesides is the father of SAMs and this is certainly an interesting alternative to Au as a substrate.
11. Shaowei Chen et. al., "Fullerene-Functionalized Gold Nanoparticles: Electrochemical and Spectrosopic Properties", Anal. Chem. 76 (2004)6102. Note: A QCM system is used to monitor the growth of a multilayered system during lengthy incubations.

# Thermal Analysis

1. Smith, A. L. & Shirazi, H. M. (2000). Quartz microbalance microcalorimetry: a new method for studying polymer-solvent thermodynamics. J. of Thermal Analysis and Calorimetry 59(1-2), 171-186.

2. Smith, A. L., Shirazi, H. & Wadso, I. (1998). The QCM/HCC: simultaneous, isothermal, high sensitivity measurements of mass change and heat flow in polymer and fullerene films, Recent Advances in the Chemistry and Physics of Fullerenes and Related Materials, San Diego, CA., Vol. 98-8, 576-585

# Laser Ablation Studies

1. X. Zhang, S.S. Chu, J.R. Ho and C. P. Grigoropoulos, “Excimer Laser ablation of thin gold films on a quartz crystal microbalance at various argon background pressures”, Appl. Phys. A 64 (1997) 545.

# QCM/SPR Combination

1. Hengerer et. al., “Determination of Phage Antibody Affinities to Antigen by a Microbalance Sensor System”, BioTechniques 26 (1999) 956-964. Note: Antigen is immobilized on the QCM electrode and binding of the antibody is detected as a decrease in frequency. The technique is compared against SPR results.
2. Mjörn, K., Keller, C., Kasemo, B., and Elwing, H. "Protein repellent phospholipid bilayers at SiO2 surfaces for biosensor applications with Quartz Crystal Micro balance (QCM-D®) and surface plasmon resonance"(SPR)" Poster at Non-toxic control of marine biofouling, MASTEC-symposium Tjärnö 1998
3. Spangler, B.D., Wilkinson, E. A., and Murphy, J.,"Comparison of the Spreeta® surface plasmon resonance sensor and a quartz crystal microbalance for detection of Escherichia coli Heat-Labile Enterotoxin," J. Anal. Chim. Acta 444 , 149-161 (2001). Note: QCM and SPR technologies are compared against each other and also against ELISA testing. QCM is demonstrated to be more sensitive than SPR in this application.
4. Erik Reimhult et. al.,”Simultaneous SPR and QCM with Dissipation Monitoring Measurements of Biomolecular Adsorption Events Involving Structural Transformations and Variations in Coupled Water”, Anal. Chem. 76 (2004) 7211.

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