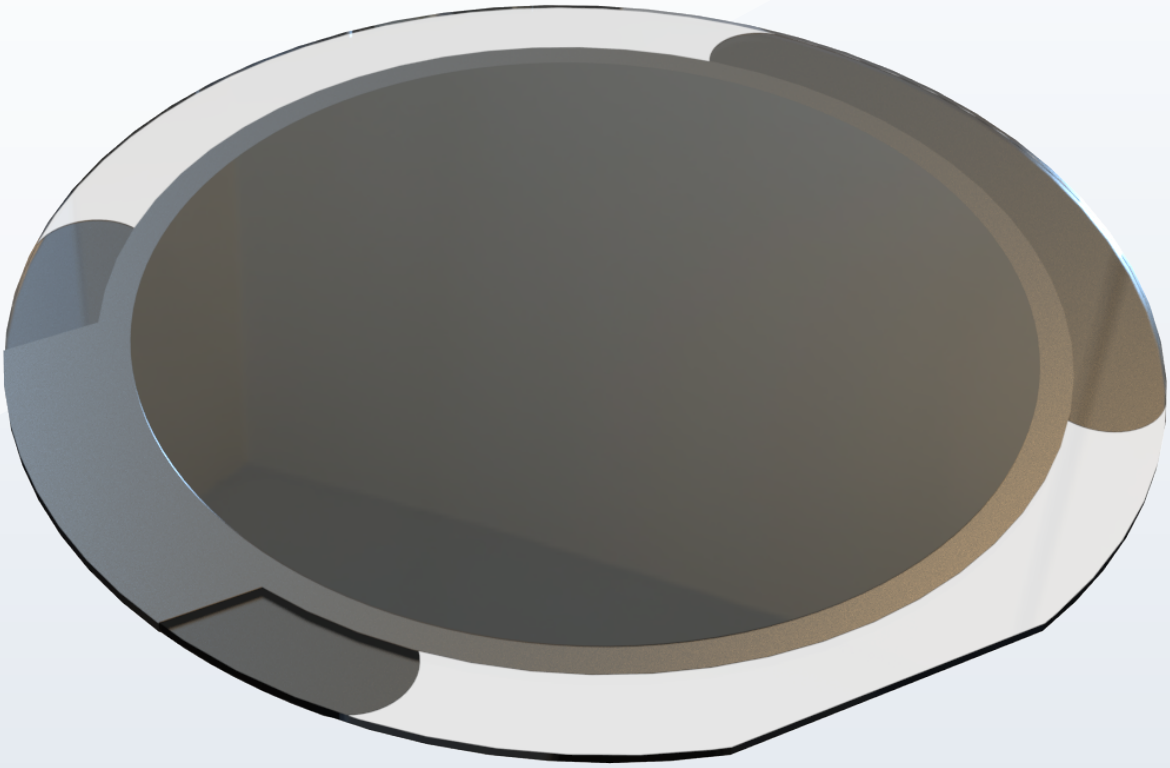
QUARTZ CRYSTAL MICROBALANCE SENSOR

AT5-14-12-SS304-WRAP

SPECIFICATIONS, CLEANING AND CARE



openQCM devices are released as scientific open hardware instruments, and they are intended solely for use for SCIENTIFIC, RESEARCH and DEVELOPMENT APPLICATION, DEMONSTRATION, OR EVALUATION PURPOSES and are not considered to be finished end-products fit for general consumer use.

openQCM by Novaetech Srl
Piazza Bartolo Longo, 28
80045 Pompei (NA)
Italy
https://openqcm.com

DATE
11 November 2026

VERSION
1.0

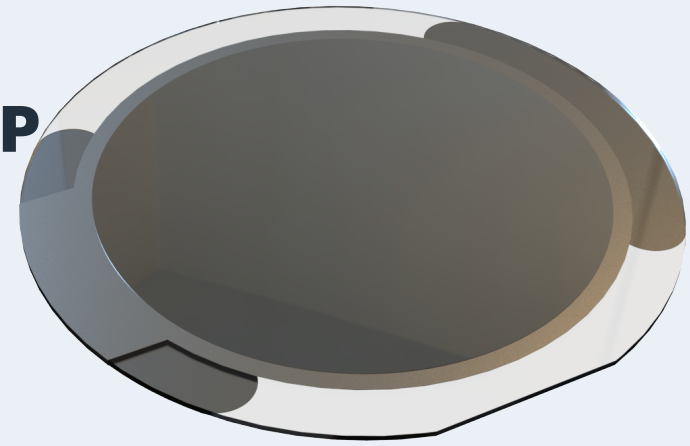
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QUARTZ CRYSTAL MICROBALANCE SENSOR

AT5-14-12-SS304-WRAP

5 MHz Quartz Sensors, Stainless Steel SS304

BOX OF 5 PIECES



SS304 5 MHZ

FREQUENCY	BLANK DIAMETER	ELECTRODES	SURFACE
5 MHz	14 mm	12 / 5 mm	SS304

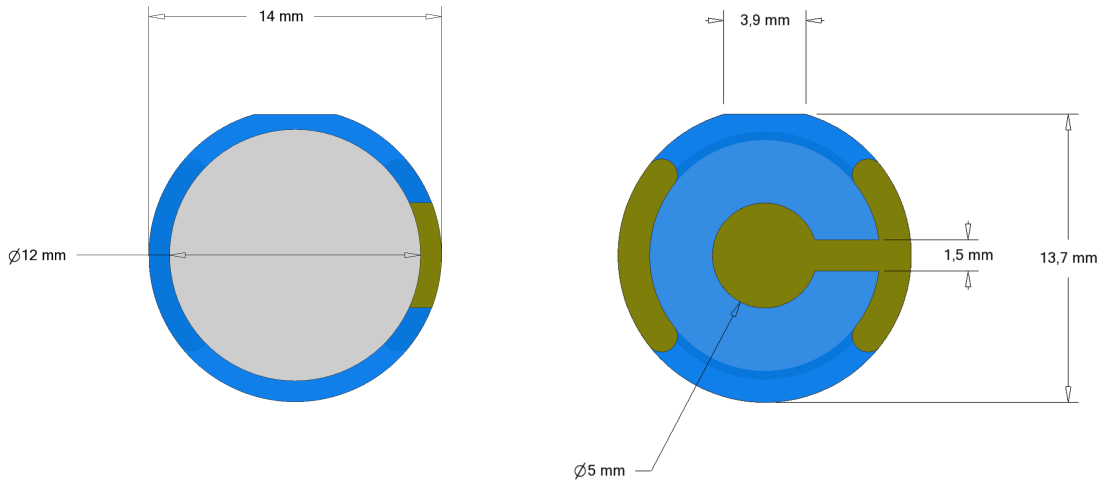
KEY FEATURES

- 5 MHz
- 14.0 MM SENSOR DIAMETER
- 12.0 / 5.0 MM ELECTRODE DIAMETER
- SS304 ELECTRODE (Stainless Steel with Ti adhesion layer)
- WRAPPED ELECTRODES (SINGLE SIDE CONTACT)
- FOR LIQUID SENSING, FOULING AND CLEANING STUDIES

DESCRIPTION

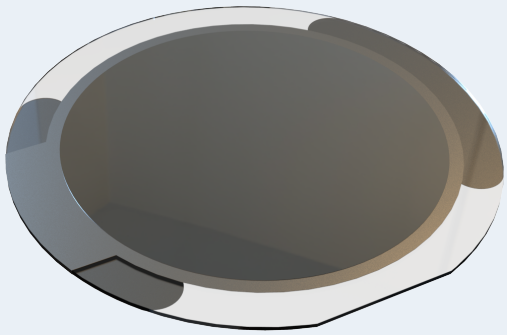
The Quartz Crystal Microbalance (QCM) sensor is a 5 MHz AT-cut crystal coated with AISI 304 stainless steel on a titanium adhesion layer. AISI 304 is the most common austenitic stainless steel in food, dairy and process equipment, and the sensor reproduces its passive surface for fouling, cleaning-in-place and adsorption studies in liquid. Compared with AISI 316 it contains no molybdenum and is less resistant to chloride pitting. The front electrode is wrapped around the edge of the blank, so both electrodes are contacted from the back face only.

2D DIMENSIONS



FRONT (SENSING SIDE) BACK (CONTACT SIDE)

3D VIEWS



FRONT (SENSING SIDE)

MECHANICAL

Nominal blank diameter	14.0 mm (13.95 ± 0.05 mm)
Nominal blank thickness	≈ 0.33 mm (AT cut, 5 MHz fundamental)
Crystal axes orientation	Yes, orientation flat on the blank edge
Surface appearance	Transparent, polished
Edge bevel	To be confirmed

GENERAL

Sensor design	Plano-Plano
Angle of cut	AT, 35° 15′ ± 3′
Oscillation mode	Fundamental
Frequency vs Temp stability	< ± 15 ppm (0 to +50 °C)
Operating temperature	-20 °C to +70 °C
Storage temperature	-40 °C to +125 °C
Compatibility	openQCM™, Q-SENSE™

ELECTRICAL

Nominal frequency	5.000 MHz
Frequency tolerance	± 7 kHz
Resonance resistance	< 15 Ω
Shunt capacitance, C0	Typ. 8 pF
Q-value	To be confirmed
Mass sensitivity (Sauerbrey, n = 1)	17.7 ng cm^{-2} Hz^{-1}

ELECTRODES

Front electrode diameter	12.0 mm
Front electrode material	Stainless steel AISI 304
Back electrode diameter	5.0 mm
Back electrode material	To be confirmed
Adhesion layer	Titanium (Ti)
Layer thickness	~10 nm Ti / ~200 nm SS304
Electrode configuration	Wrapped front electrode, single side contact

PACKAGING & STORAGE

Sensor package type	Box
Storage quantity	5 pieces
Package protection	Package is protected with a vacuum sealed plastic bag
Storage recommendation	After opening plastic vacuum bag preferably store in dust free dry Air or Nitrogen @ room temperature.

AT5-14-12-SS304-WRAP

CLEANING AND CARE

BEFORE YOU START

The sensing film is only about 200 nm thick and sits on a 10 nm titanium adhesion layer. Titanium and chromium are the two adhesion metals used for thin film electrodes on quartz, and they fail in different ways: titanium is attacked by fluoride, hot alkali and piranha, chromium by peroxide, ceric ammonium nitrate and anodic polarization [1, 2]. Along the edge of the electrodes and on the wrapped contact the adhesion layer is exposed, so a reagent that only attacks the adhesion metal can still undercut and lift the electrode. The procedures below were chosen to be safe for both adhesion metals and for the quartz substrate. Where no procedure written for QCM sensors is published, methods developed for the same surface in other fields (electrochemistry, microfabrication, surface science, food processing) were adapted to these limits, and the source of each step is given.

HANDLING AND MOUNTING

- Hold the sensor only at the outer edge of the quartz, with clean plastic tipped tweezers and powder free nitrile gloves. Never touch or wipe the electrodes or the wrapped contact area.
- Dry with a gentle stream of filtered, oil free nitrogen blown from the center outwards. Do not let droplets evaporate on the electrode: they leave rings of residue [3].
- Mount the sensor with the sensing face towards the measurement chamber and tighten the holder finger tight only. Clamping force shifts the resonance frequency: three point clamping changed the frequency of 10 MHz crystals by up to 3 ppm [4], and the force-frequency effect of AT-cut quartz is described in [5].
- After mounting, wait for the frequency to stabilize in the measurement medium before taking the baseline. Swelling O-rings and contact pressure cause slow drift in the first minutes.
- Do not use ultrasonic baths. No study quantifies cavitation damage on thin film QCM electrodes, but cavitation is itself used as a delamination test for sub-micrometre coatings, so we treat it as a risk for the film and for the thin blank.
- Use one fixed pretreatment for a whole series of measurements. Different cleaning methods give different surface states and therefore different sensor responses [6].

CLEANING PROCEDURES FOR STAINLESS STEEL AISI 304

A sputtered stainless steel film is not identical to bulk steel: films sputtered from austenitic targets are often body centred cubic and can differ in composition from the target [7, 8], but they form a continuous and uniform passive film free of the inclusions found in bulk material [9]. Acid passivation, which on bulk steel mainly removes manganese sulfide inclusions [10], is therefore a regeneration step, not a routine one. No cleaning procedure written for stainless steel QCM sensors has been published; the steps below adapt food industry cleaning in place [11], ASTM passivation practice [12, 13] and surface science studies to a 200 nm film on quartz, with lower concentrations and temperatures, immersion only and no mechanical action. Prepare all solutions with ultrapure water (18 MΩ cm), free of chloride. In air 1 nm of steel corresponds to about 45 Hz on this sensor [14], so the frequency in air is a direct check of film loss.

LEVEL 1 ROUTINE CLEANING BETWEEN MEASUREMENTS

1. Flush with the running buffer, then with ultrapure water for 5 min (at least 10 cell volumes). PBS contains about 4900 mg/L of chloride, about 25 times the guideline for continuous exposure of AISI 304 [15].
2. Protein or soft soil: 0.1 M NaOH at 20 to 40 °C for 10 min. Adapted from dairy cleaning in place (1 % NaOH at 65 °C [11]), with lower concentration and temperature to protect the quartz and the adhesion layer [1, 16]. Sodium hydroxide removes beta-lactoglobulin from stainless steel [17].
3. Rinse with ultrapure water for 5 min.
4. Optional acid rinse to neutralize and remove mineral traces: 0.5 to 1 % HNO_3 or 1 to 2 % citric acid at room temperature for 5 min [11].
5. Rinse with ultrapure water for 5 min and, if the sensor is removed, dry with nitrogen.

Buffer rinsing alone is not enough between protein experiments: albumin, mucin and lysozyme adsorb irreversibly on stainless steel [18], and proteins in PBS change the oxide and increase metal release [19].

LEVEL 2 STANDARD PRE-USE CLEANING

1. Immerse in acetone for 5 to 7 min, then in isopropanol for 5 to 7 min, rinse with ultrapure water and dry with nitrogen. Adapted from the degreasing of 304 and 316L samples in [19], by immersion instead of ultrasound.
2. Immerse in 0.1 M NaOH, or in a phosphate free and chloride free alkaline laboratory detergent at the lowest dilution recommended by its maker, at 20 to 40 °C for 10 to 15 min. Rinse in at least three changes of ultrapure water [11, 20].
3. Dry with nitrogen.
4. Remove the remaining organic contamination with ONE of the following: argon plasma for a few minutes at low power (preferred: it removes contamination and thins the oxide-hydroxide layer without changing the oxidation state of Cr, Fe and Mo [21]); or UV/ozone for 5 to 10 min a few millimetres from the lamp [22]. Avoid oxygen plasma, or keep it below 1 min: it thickens the oxide and forms Cr(VI) [21].
5. Rinse with ultrapure water for at least 1 min before mounting: the wettability of plasma treated steel changes at the first contact with water [21], and this should happen before the baseline is taken.
6. Equilibrate in the running buffer until the baseline is stable. Use the sensor within about 30 min of step 4.

LEVEL 3 DEEP CLEANING AND REGENERATION

- **Proteins and biofilms.** Enzymatic detergent with serine protease (and amylase for unknown biofilms), formulated with non ionic surfactant and chelator, at 40 to 50 °C for 30 to 60 min or at the maker's dose [23]. Rinse, then 0.25 M NaOH at no more than 50 °C for 10 to 15 min [11], and rinse again.
- **Mineral scale** (calcium phosphates from milk or media [24]). 1 % HNO_3 at 20 to 50 °C for 10 min, or 2 to 5 % citric acid at 20 to 40 °C for 10 to 20 min [11, 20]. Never use hydrochloric acid based descalers.
- **Re-passivation** (only after accidental exposure to chloride or reducing acids, or when the oxide is iron rich). 4 to 5 % citric acid at 25 to 40 °C for 20 to 30 min, the low end of the ASTM A967 citric treatments [12, 20]; on 316L, 10 to 20 % citric acid enriches the film in Cr_2O_3 while 30 % lowers the corrosion resistance [25]. Alternatively 20 vol% HNO_3 at room temperature for 20 to 30 min [12]. Never use dichromate inhibited nitric baths (Cr(VI) hazard [20]). Rinse with running ultrapure water, dry with nitrogen and let the oxide age for 24 h in a desiccator before use [19, 26].
- After every deep cleaning record the frequency in air: an increase of about 45 Hz means that about 1 nm of film has been removed.

CHEMICAL COMPATIBILITY

RATING	AGENT	WHY
SAFE	**Ultrapure water, ethanol, isopropanol, acetone**	Compatible [1, 19]
SAFE	**0.1 to 0.25 M NaOH, up to 50 °C, up to 15 min**	Removes proteins [11, 17]
SAFE	**HNO_3 up to 1 % (cleaning), 20 vol% at room temperature (passivation)**	Compatible [11, 12]
SAFE	**Citric acid 2 to 10 %, up to 40 °C**	Compatible [12, 20, 25]
SAFE	**Protease or amylase detergents with non ionic surfactant**	Compatible [23]
SAFE	**Argon plasma; short UV/ozone followed by a water rinse**	Compatible [21, 22]
CAUTION	**PBS, saline and cell media (chloride)**	Rinse out at the end of every run, never store in it [15]
AVOID	**Seawater and marine media (about 3 % NaCl)**	Not recommended for AISI 304 beyond short tests [15]
CAUTION	**Oxygen plasma, long UV/ozone**	Forms Cr(VI), changes oxide and wetting [21]
CAUTION	**NaOH above 0.25 M or above 50 °C**	Etches quartz, softens Ti [1, 16]
AVOID	**Piranha**	Etches Ni quickly and undercuts Ti [1]
NEVER	**HF, fluorides, HF-HNO_3 pickling pastes**	Attack Ti and quartz [1]
NEVER	**HCl, HCl based descalers, $FeCl_3$**	$FeCl_3$ with HCl is the solution used to induce pitting in corrosion tests
NEVER	**Hypochlorite, bleach, chlorinated cleaners**	Free chlorine guideline about 2 ppm [15]
NEVER	**Above 60 °C with chloride present**	Chloride stress corrosion cracking [15]
NEVER	**Abrasives, brushes, wiping**	Remove the 200 nm film

AISI 304 contains no molybdenum and has a pitting resistance equivalent number of about 18 to 21, against about 23 to 28 for AISI 316 [27]; its chloride guideline for continuous exposure is only about 200 ppm [15]. Because the sputtered film may differ in composition from the bulk grade [7], these figures are a guide, not a guarantee.

VERIFYING CLEANLINESS

- **Water contact angle.** Plasma cleaning lowered the surface carbon of stainless steel from 63 % to 38 % and the contact angle from 71° to 29° [28]. Measure within 5 min of cleaning and again after the water rinse, and compare with the value of a new sensor.
- **XPS on a witness sensor.** The native film is about 2 nm thick with a chromium rich inner layer [26]; passivation raises the Cr/Fe ratio [25, 26]. Chlorine signals show chloride residues; Ti or Cr from the adhesion layer show that the film is breached.
- **Frequency.** Baseline drift in buffer back to the value of the clean sensor; frequency in air stable from cycle to cycle (about 45 Hz per nanometre of film lost).

STORAGE AFTER USE

Store dry, in clean polypropylene or PTFE holders, in a desiccator or under nitrogen. Never store wet in PBS or saline, especially AISI 304. Keep 316 and 304 sensors labelled and separate. Repeat Level 2 shortly before use, and keep a log of cleaning level, chemicals, temperature, frequency in air and contact angle for each sensor.

TEMPERATURE

The operating and storage temperature ranges of this sensor are listed in the GENERAL table. Within those ranges please consider the following.

- **Frequency vs temperature.** The resonance frequency of AT-cut quartz follows a cubic function of temperature whose shape depends on the cut angle [5, 29]. The cut of this sensor keeps the intrinsic drift small around room temperature, but over wide temperature ranges the frequency change is much larger than the mass signals of interest.
- **Measurements in liquid.** The viscosity and density of the liquid change with temperature and shift the frequency [30]. In water near 25 °C the shift is about +8 Hz/°C at 5 MHz (calculated from the Kanazawa-Gordon equation with the viscosity of water [31]). Control the temperature of the measurement chamber to better than 0.1 °C and let it settle after every liquid change [3].
- **Cleaning temperature.** Wet cleaning steps in this datasheet are performed at room temperature or slightly above, never above the limit given for each step. Never flame anneal, oven anneal or quench the sensor.
- **Adhesion layer.** Titanium diffuses along the grain boundaries of gold and reaches the surface from about 250 to 300 °C [32, 33]; chromium does the same and oxidizes at the surface at about 300 °C [34, 35]. The surface chemistry and the adhesion of the electrode change long before the quartz is damaged.
- **Quartz.** The resonator quality degrades above about 300 °C [36], cooling stresses between 200 and 550 °C create Dauphiné twins that ruin the resonator [37], and at 573 °C quartz goes through the alpha to beta transition with a sharp change of thermal expansion [38].

WHEN TO REPLACE THE SENSOR

Every cleaning cycle removes a little material and changes the surface. On openQCM 10 MHz gold sensors three regeneration cycles reduced the sensor performance by 7 % with electrochemical cleaning, 16 % with oxygen plasma and 25 % with piranha [39]. Replace the sensor when one of the following occurs [3]:

- cracks or chips on the edge of the quartz, scratches or holes in the electrode;
- peeling of the electrode, visible from the contact side, or permanent discoloration;
- noisy or unstable baseline, higher motional resistance (lower Q, higher dissipation);
- the frequency in air drifts from cycle to cycle, showing that the film is being consumed;
- the cleanliness test of this datasheet no longer passes after a deep cleaning.

Record the resonance frequency in air of every new sensor and after each deep cleaning: comparing the values is the simplest way to follow the condition of the electrode.

REFERENCES

[1] K. R. Williams, K. Gupta, and M. Wasilik. "Etch rates for micromachining processing. Part II". In: *Journal of Microelectromechanical Systems* 12.6 (2003), pp. 761–778. DOI: 10.1109/JMEMS.2003.820936.

[2] J. C. Hoogvliet and W. P. van Bennekom. "Gold thin-film electrodes: an EQCM study of the influence of chromium and titanium adhesion layers on the response". In: *Electrochimica Acta* 47 (2001), pp. 599–611. DOI: 10.1016/S0013-4686(01)00793-9.

[3] *QCM200 Quartz Crystal Microbalance Digital Controller: Operation and Service Manual, Revision 2.5*. Stanford Research Systems. 2018. URL: https://www.thinksrs.com/downloads/pdfs/manuals/QCM200m.pdf.

[4] D. Scaccabarozzi et al. "Measurement of the Instrumental Effect Caused by Flexure Clamping on Quartz Crystal Microbalances". In: *Applied Sciences* 15 (2025), p. 9261. DOI: 10.3390/app15179261.

[5] J. R. Vig. *Quartz Crystal Resonators and Oscillators for Frequency Control and Timing Applications: A Tutorial*. Tech. rep. SLCET-TR-88-1 (Rev. 8.4.2), AD-A328861. US Army Communications-Electronics Command, 2000.

[6] L. S. J. Ho, J. L. Limson, and R. Fogel. "Certain Methods of Electrode Pretreatment Create Misleading Responses in Impedimetric Aptamer Biosensors". In: *ACS Omega* 4 (2019), pp. 5839–5847. DOI: 10.1021/acsomega.9b00075.

[7] X. Zhang, A. Misra, R. K. Schulze, et al. "Critical factors that determine face-centered cubic to body-centered cubic phase transformation in sputter-deposited austenitic stainless steel films". In: *Journal of Materials Research* 19 (2004), pp. 1696–1702. DOI: 10.1557/JMR.2004.0215.

[8] J. R. Childress, S. H. Liou, and C. L. Chien. "Ferromagnetism in metastable 304 stainless steel with bcc structure". In: *Journal of Applied Physics* 64 (1988), pp. 6059–6061. DOI: 10.1063/1.342154.

[9] T. Li, L. Liu, B. Zhang, Y. Li, and F. Wang. "An investigation on the continuous and uniform thin membrane passive film formed on sputtered nanocrystalline stainless steel". In: *Corrosion Science* 104 (2016), pp. 71–83. DOI: 10.1016/j.corsci.2015.11.031.

[10] J. S. Noh, N. J. Laycock, W. Gao, and D. B. Wells. "Effects of nitric acid passivation on the pitting resistance of 316 stainless steel". In: *Corrosion Science* 42 (2000), pp. 2069–2084. DOI: 10.1016/S0010-938X(00)00052-4.

[11] P. J. Bremer, S. Fillery, and A. J. McQuillan. "Laboratory scale Clean-In-Place (CIP) studies on the effectiveness of different caustic and acid wash steps on the removal of dairy biofilms". In: *International Journal of Food Microbiology* 106 (2006), pp. 254–262. DOI: 10.1016/j.ijfoodmicro.2005.07.004.

[12] *ASTM A967/A967M-25: Standard Specification for Chemical Passivation Treatments for Stainless Steel Parts*. ASTM International, 2025.

[13] *ASTM A380/A380M-25: Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems*. ASTM International, 2025.

[14] G. Sauerbrey. "Verwendung von Schwingquarzen zur Wägung dünner Schichten und zur Mikrowägung". In: *Zeitschrift für Physik* 155 (1959), pp. 206–222. DOI: 10.1007/BF01337937.

[15] *Chlorine and chloride: guidelines for stainless steel grades*. Industry association technical note citing Nickel Institute guidelines. Australian Stainless Steel Development Association. URL: https://www.assda.asn.au.

[16] K. G. Knauss and T. J. Wolery. "The dissolution kinetics of quartz as a function of pH and time at 70 °C". In: *Geochimica et Cosmochimica Acta* 52 (1988), pp. 43–53. DOI: 10.1016/0016-7037(88)90055-5.

[17] C. A.-C. Karlsson, M. C. Wahlgren, C.-O. A. Olsson, and A. C. Trägårdh. "Detergent-Induced Removal of beta-Lactoglobulin from Stainless Steel Surfaces as Influenced by Surface Pretreatment". In: *Journal of Colloid and Interface Science* 220 (1999), pp. 471–473. DOI: 10.1006/jcis.1999.6503.

[18] M. Lundin, Y. Hedberg, T. Jiang, et al. "Adsorption and protein-induced metal release from chromium metal and stainless steel". In: *Journal of Colloid and Interface Science* 366 (2012), pp. 155–164. DOI: 10.1016/j.jcis.2011.09.068.

[19] Y. Hedberg, X. Wang, J. Hedberg, M. Lundin, E. Blomberg, and I. Odnevall Wallinder. "Surface-protein interactions on different stainless steel grades: effects of protein adsorption, surface changes and metal release". In: *Journal of Materials Science: Materials in Medicine* 24 (2013), pp. 1015–1033. DOI: 10.1007/s10856-013-4859-8.

[20] D. G. Enos and D. Wichhart. *Refinement of Citric Acid Passivation Methods and Comparison to Traditional Nitric Acid Based Chemistries*. Tech. rep. SAND2021-12075C. Sandia National Laboratories, 2021. URL: https://www.osti.gov/servlets/purl/1890611.

[21] T. Sönmez, M. Fazeli Jadidi, K. Kazmanlı, Ö. Birer, and M. Ürgen. "Role of different plasma gases on the surface chemistry and wettability of RF plasma treated stainless steel". In: *Vacuum* 129 (2016), pp. 63–73. DOI: 10.1016/j.vacuum.2016.04.014.

[22] J. R. Vig. "UV/ozone cleaning of surfaces". In: *Journal of Vacuum Science & Technology A* 3 (1985), pp. 1027–1034. DOI: 10.1116/1.573115.

[23] Y. Lequette, G. Boels, M. Clarisse, and C. Faille. "Using enzymes to remove biofilms of bacterial isolates sampled in the food-industry". In: *Biofouling* 26 (2010), pp. 421–431. DOI: 10.1080/08927011003699535.

[24] H. A. Huellemeier, N. M. Eren, T. D. Payne, Z. D. Schultz, and D. R. Heldman. "Monitoring and Characterization of Milk Fouling on Stainless Steel Using a High-Pressure High-Temperature Quartz Crystal Microbalance with Dissipation Monitoring". In: *Langmuir* 38 (2022), pp. 9466–9480. DOI: 10.1021/acs.langmuir.2c00419.

[25] A. T. da Costa, M. C. L. de Oliveira, and R. A. Antunes. "Interplay between passive film composition and corrosion resistance of citric acid-passivated AISI 316L". In: *Surface and Interface Analysis* 53 (2021), pp. 374–384. DOI: 10.1002/sia.6927.

[26] Z. Wang, F. Di-Franco, A. Seyeux, S. Zanna, V. Maurice, and P. Marcus. "Passivation-Induced Physicochemical Alterations of the Native Surface Oxide Film on 316L Austenitic Stainless Steel". In: *Journal of The Electrochemical Society* 166 (2019), pp. C3376–C3388. DOI: 10.1149/2.0321911jes.

[27] *Calculation of pitting resistance equivalent numbers (PREN)*. Industry association technical note. British Stainless Steel Association. URL: https://bssa.org.uk.

[28] J. Zhang, M. Dang, C. Luo, Y. Ba, and Q. Li. "Surface Analysis of Stainless Steel Electrodes Cleaned by Atmospheric Pressure Plasma". In: *Materials* 17 (2024), p. 3621. DOI: 10.3390/ma17143621.

[29] R. Bechmann. "Frequency-temperature-angle characteristics of AT-type resonators made of natural and synthetic quartz". In: *Proceedings of the IRE* 44.11 (1956), pp. 1600–1607. DOI: 10.1109/JRPROC.1956.274879.

[30] K. K. Kanazawa and J. G. Gordon. "The oscillation frequency of a quartz resonator in contact with liquid". In: *Analytica Chimica Acta* 175 (1985), pp. 99–105. DOI: 10.1016/S0003-2670(00)82721-X.

[31] M. L. Huber, R. A. Perkins, A. Laesecke, et al. "New International Formulation for the Viscosity of H2O". In: *Journal of Physical and Chemical Reference Data* 38 (2009), pp. 101–125. DOI: 10.1063/1.3088050.

[32] W. E. Martinez, G. Gregori, and T. Mates. "Titanium diffusion in gold thin films". In: *Thin Solid Films* 518 (2010), pp. 2585–2591. DOI: 10.1016/j.tsf.2009.07.187.

[33] T. C. Tisone and J. Drobek. "Diffusion in thin film Ti-Au, Ti-Pd, and Ti-Pt couples". In: *Journal of Vacuum Science and Technology* 9 (1972), pp. 271–275. DOI: 10.1116/1.1316577.

[34] P. H. Holloway, D. E. Amos, and G. C. Nelson. "Analysis of grain-boundary diffusion in thin films: Chromium in gold". In: *Journal of Applied Physics* 47 (1976), pp. 3769–3775. DOI: 10.1063/1.323259.

[35] M. A. George, W. S. Glaunsinger, T. Thundat, and S. M. Lindsay. "Electrical, spectroscopic, and morphological investigation of chromium diffusion through gold films". In: *Thin Solid Films* 189 (1990), pp. 59–72. DOI: 10.1016/0040-6090(90)90027-B.

[36] J. Haines, O. Cambon, D. A. Keen, M. G. Tucker, and M. T. Dove. "Structural disorder and loss of piezoelectric properties in alpha-quartz at high temperature". In: *Applied Physics Letters* 81 (2002), pp. 2968–2970. DOI: 10.1063/1.1515363.

[37] C. Frondel. "Secondary Dauphiné twinning in quartz". In: *American Mineralogist* 30 (1945), pp. 447–460.

[38] R. J. Ackermann and C. A. Sorrell. "Thermal expansion and the high-low transformation in quartz. I. High-temperature X-ray studies". In: *Journal of Applied Crystallography* 7 (1974), pp. 461–467. DOI: 10.1107/S0021889874010211.

[39] T. Wasilewski et al. "Development and Assessment of Regeneration Methods for Peptide-Based QCM Biosensors in VOCs Analysis Applications". In: *Biosensors* 12 (2022), p. 309. DOI: 10.3390/bios12050309.