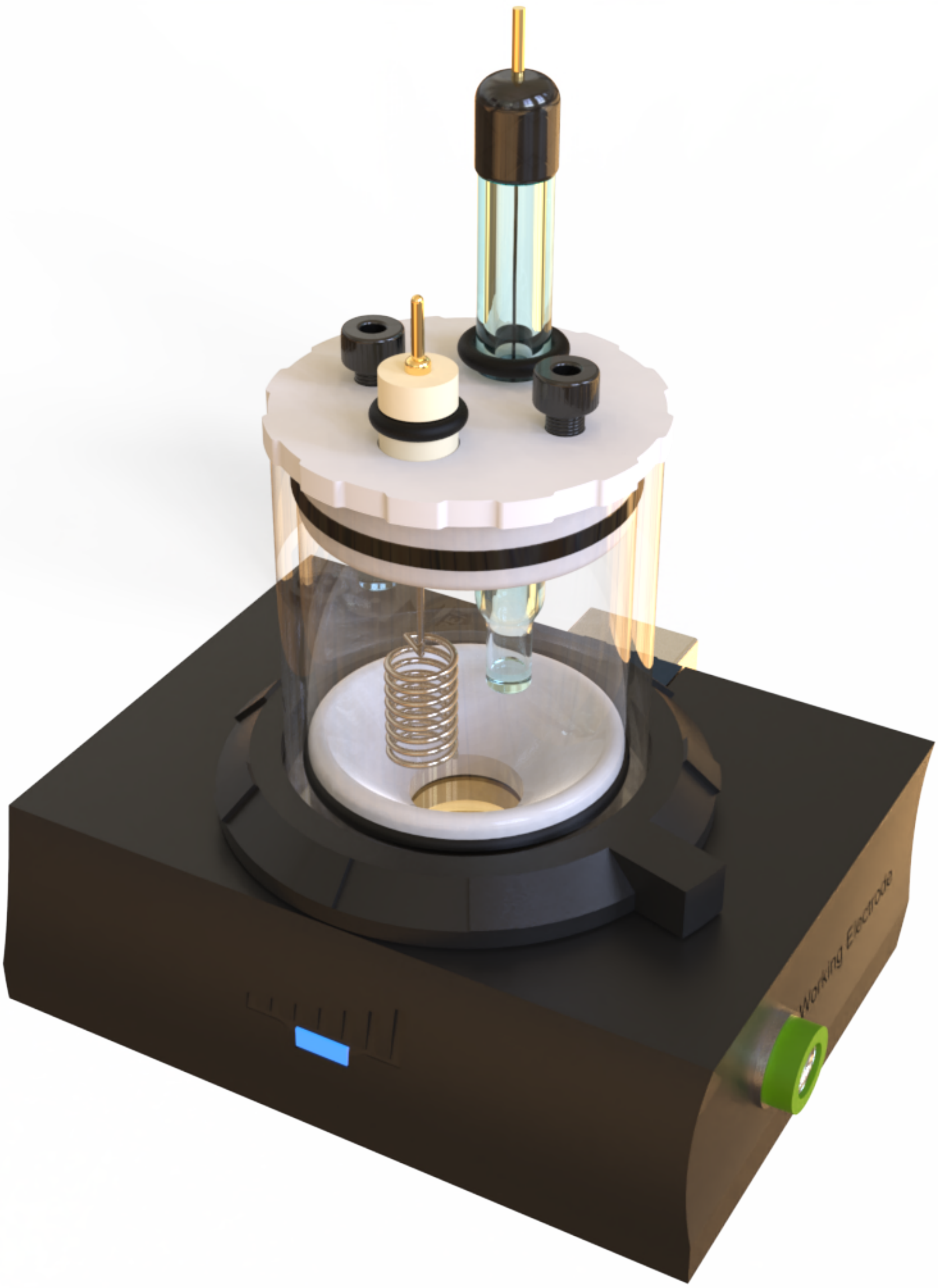

The Electrochemistry module

THE OPENQCM ELECTROCHEMISTRY MODULE

USER GUIDE

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
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https://openqcm.com

Written by: Raffaele Battaglia
Date Friday, 30 June 2023
Version: 1.0

SUMMARY

Preliminary notes

Temperature

Some and parts of the openQCM case are 3D-printed and are made of nylon material. This material is resistant up to about 80°C. However, higher temperatures can significantly change its mechanical properties. It is therefore recommended to operate within the values ranging from 0°C to 50°C and not beyond.

The passive and integrated components (IC) of the electronic board have been selected to operate at temperatures in the so-called commercial range, therefore operation is recommended within the temperature limits from 0 ° to 70°C.

Using the device at temperatures other than those indicated may significantly alter the materials and components, consequently causing the device to malfunction. The openQCM device is intended solely for use for scientific purposes, R&D applications or demonstration and testing purposes. Users handling the device must comply with the rules of good engineering practice.

Voltage

The main electronics of the openQCM device are designed to be powered with 5 VDC through the connection to the USB port, designed to be powered with continuous 5 VDC and a maximum current of 1.6 A

Using a power supply other than that indicated will damage the device. The openQCM device is intended solely for use for scientific purposes, R&D applications or demonstration and testing purposes. Users handling the device must comply with the rules of good engineering practice.

Warnings regarding materials

The openQCM devices are also made using the 3D printing technique. The 3D printed case is made of durable and flexible plastic. This material is highly adaptable, dishwasher safe and heat resistant up to 80°C / 176°F. The material data sheet is available at this link: https://goo.gl/NzkbSG and the material safety data sheet is available here https://goo.gl/abrP8y. In any case, it is advisable to pay close attention to aggressive chemical materials.

The only materials of the fluidic module that are in contact with the sample are those of the measuring chamber, consisting of the fluidic cell and the o-ring. The standard exposed material of the fluid cell is the synthetic fluoropolymer PTFE (Teflon®). The standard o-ring is made of FKM Viton®.

In any case, it is advisable to pay close attention to aggressive chemical materials. The openQCM device is intended solely for use for scientific purposes, R&D applications or demonstration and testing purposes. Users handling the device must comply with the rules of good engineering practice.

Safety

In no event Novaetech S.r.l. ever be held responsible or liable for any direct, indirect, incidental, special or consequential damages or costs whatsoever resulting from or related to the use or misuse of the openQCM instrument or components thereof, even if Novaetech S.r.l. has been advised, knows of, or should be aware of the possibility of such damages. Novaetech S.r.l. emphasizes the importance of consulting experienced and qualified professionals to assure the best results when using openQCM devices.

Safety Precautions

The safety requirements listed in this manual must be followed in order to avoid personal injury and damage to the openQCM instruments.

General Precautions

RISK OF ELECTRICAL SHOCK. Do not connect openQCM device to electrical power if the enclosure is damaged or any of the covers or panels are removed. Make sure the voltage rating on the instrumentation matches the line voltage available in the lab. Connect only to outlets with safety earth ground. Make sure that the power cord is easily accessible when the equipment has been installed.

Warnings

RISK OF ELECTRICAL SHOCK OR FIRE HAZARD. Switches may produce electrical sparks. Do not use the openQCM devices in the presence of flammable gases, fumes or liquids. · The instrument has been designed for indoor use only. Do not expose it to rain, snow or dust. During storage or transport the instrument should be kept dry. Temperatures below 0ºC and above 50ºC should be avoided.

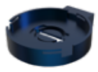
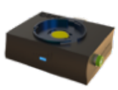
CAUTION! · Use only as specified in the operating instructions. Follow all instructions. Skipping steps can result in damage to the openQCM device. · Handle carefully when removing the instrument from the transport packaging. The product must always be shipped in either the original packaging supplied by Novaetech S.r.l. or equivalent.

CAUTION! · Do not use force when connecting or disconnecting connectors as damage may occur. · Do not subject the equipment to external shocks. Do not block or restrict ventilation slots. · Do not expose any parts other than the sample volume in the flow module(s) to water or other liquids.

CAUTION! If liquid is spilled on the instrument, disconnect it from the power source and have it checked by an authorized person. When handling chemicals, refer to the safety information from the supplier and general safety regulations in your country. Carry out appropriate decontamination if equipment is exposed to hazardous material. Do not install substitute parts or perform any unauthorized modification to the product. Return the product to Novaetech S.r.l. or other qualified and authorized personnel for service and repair to ensure that safety features are maintained. Before returning the instrument it must be free of hazardous contamination.

eQCM module components

The module for the use of openQCM with electrochemistry is composed by these following main parts

	Description	Quantity
	Proximity electronics	1
	Quartz holder	1
	PTFE reservoir	1
	Fixing ring	1
	Quart Cylinder	1
	PTFE cover with fittings	1
	E-QCM module case	1
	Fitting Adapter for 4mm Electrochemistry Probes	2
	2mm Male Banana Plug	1

openQCM electrochemistry module

Main specifications

Hardware and Material Specification	
Volume of chamber	~ 15 ml
Materials	PTFE reservoir: Teflon
	PTFE cover with fittings: Teflon
	O-rings: Viton (FKM)
	Quart Cylinder: Quartz
	Sensor Holder: Anodized Aluminium
	Plastic case: PLA
	Viton (FKM)
Maximum Dimensions	(L x W x H): 6 x 7 x 6 cm
Weight	~ 90 g

Sensors and core sensor	Next
Number of sensors	Single quartz resonator sensor
Quartz sensors	5 MHz and 10 MHz , 14 mm blank diameter, - wrapped (single sided contacting)
Frequency Range	5 and 10 MHz : 1 to 50 MHz

QCM Measurement Specification	
Electronics Interface	Network analyser
Physical quantities	Frequency and dissipation
Measurement mode	Multi - overtones 5 MHz: up to 9th overtone 10 MHz up to 5th overtone
Minimum sampling time	~ 150 ms for each harmonic

Power	
Main electronics	5 VDC

Introduction to e-QCM Module

Integrating QCM and Electrochemistry

The e-QCM module represents a significant advancement in analytical instrumentation, designed to bridge the gap between Quartz Crystal Microbalance (QCM) technology and electrochemical measurements. This innovative module provides researchers and industry professionals with a flexible platform for investigating interfacial processes and molecular interactions with unprecedented precision and versatility.

The Power of Combined QCM and Electrochemistry

Quartz Crystal Microbalance (QCM) and electrochemistry are two analytical techniques that, when integrated, offer unique insights into various physicochemical processes. QCM provides highly sensitive mass measurements based on the piezoelectric properties of quartz crystals, while electrochemistry allows for the study of electron transfer reactions and interfacial phenomena.

By facilitating the combination of these technologies, our e-QCM module enables simultaneous measurement of mass changes and electrochemical processes at an electrode surface. This integration allows researchers to correlate mass transfer with charge transfer in real-time, distinguish between faradaic and non-faradaic processes, and characterize electrode modifications in situ.

e-QCM Module: Features and Compatibility

It is crucial to understand that the e-QCM module itself does not provide electrochemical analysis capabilities. Instead, it is specifically designed to be compatible with a wide range of commercially available potentiostats. This design philosophy offers several key advantages:

1. **Flexibility:** Researchers can use the e-QCM module with their existing electrochemical equipment, eliminating the need for additional specialized instrumentation.

2. **Compatibility:** The module is engineered to work seamlessly with most common potentiostats on the market, ensuring broad applicability across different laboratory setups.

3. **Cost-effectiveness**: By leveraging existing electrochemical equipment, laboratories can add QCM capabilities without the need for a complete system overhaul.

4. **Customization:** Researchers have the freedom to choose the most appropriate potentiostat for their specific experimental needs, while still benefiting from integrated QCM measurements.

5. Seamless integration with QCM technology. Full compatibility with openQCM Q-1.

6. High-precision QCM measurements that can be correlated with electrochemical data.

7. User-friendly interface for QCM data acquisition and analysis.

The e-QCM module supports various electrochemical methods, including cyclic voltammetry, chronoamperometry, and electrochemical impedance spectroscopy, provided by the connected potentiostat. This approach gives researchers maximum flexibility in combining QCM and electrochemical techniques.

Applications Across Multiple Fields

The versatility and compatibility of the e-QCM module make it an invaluable tool across various scientific and industrial domains:

- **Energy Storage:** Study ion insertion/extraction processes in battery materials and characterize supercapacitor performances.
- **Corrosion Science:** Monitor corrosion rates in real-time and evaluate the effectiveness of corrosion inhibitors.
- **Biosensors:** Develop and characterize label-free immunosensors and study protein-surface interactions.
- **Electroactive Materials:** Investigate the growth and properties of conducting polymers and other electroactive films.
- **Surface Modification:** Analyze the formation of self-assembled monolayers and characterize layer-by-layer assembly processes.

Advancing Research and Development

By enabling the correlation of high-resolution QCM data with electrochemical processes, the e-QCM module empowers researchers to gain deeper insights into complex interfacial phenomena. This capability is crucial for advancing fundamental research and accelerating the development of new materials and technologies in fields ranging from energy storage to biomedical devices.

The e-QCM module's design philosophy of compatibility and flexibility represents a significant step forward in analytical instrumentation. It offers researchers a powerful and adaptable tool to explore the intricate relationships between mass transfer and electron transfer at interfaces, all while leveraging their existing electrochemical equipment. As we continue to push the boundaries of materials science and electrochemistry, the e-QCM module stands ready to play a crucial role in driving innovation and discovery, providing researchers with the flexibility and capability they need to tackle complex scientific challenges.

Key Aspects of Electrochemical Module

Before proceeding with assembly

This section provides essential preliminary guidance for assembling the electrochemical module designed for integration with third-party potentiostats.

⚠️ **SAFETY WARNING**

Exercise extreme caution when handling the quartz reservoir during assembly. While the device has been engineered for durability, improper handling or excessive force may result in breakage, potentially causing injury.

IMPORTANT:

Always handle the quartz components with gentle, controlled movements. Never apply excessive pressure or force during assembly. Follow all safety guidelines provided in this manual

DISCLAIMER: Novaetech assumes no liability for any damage or injury resulting from failure to follow these safety guidelines and proper handling procedures.

The module specifically designed to be compatible with openQCM Q-1 device, enables simultaneous QCM and electrochemical measurements by providing a specialized cell that interfaces with external potentiostats while maintaining high-precision QCM capabilities. Proper assembly is critical for achieving reliable measurements and protecting sensitive components, particularly the quartz crystal sensor which serves as both the QCM resonator and working electrode.

The following protocol details the step-by-step assembly process, with each stage documented through clear photographs and specific instructions. Users should familiarize themselves with all components and verify their workspace is clean and properly organized before beginning the assembly. Special attention must be paid to the orientation of the quartz crystal and the sealing elements to ensure proper electrical contact and prevent any liquid leakage that could compromise the measurements or damage the electronics.

An overview of the electrochemistry module

The electrochemical module (Fig. 2) represents an interface engineered to bridge QCM instrumentation with third-party potentiostats, enabling advanced electroanalytical studies. At its core, the module features a precision-engineered PTFE top cover equipped with multiple integrated fittings. These ports are designed to accommodate standard 4mm/6mm electrochemical probes for reference and counter electrodes, with custom port sizes available upon request to accommodate different probe dimensions, subject to the cell's spatial constraints. The cover also incorporates fluid handling ports that enable controlled electrolyte exchange, all constructed from chemical-resistant PTFE to ensure compatibility with aggressive media and organic solvents.

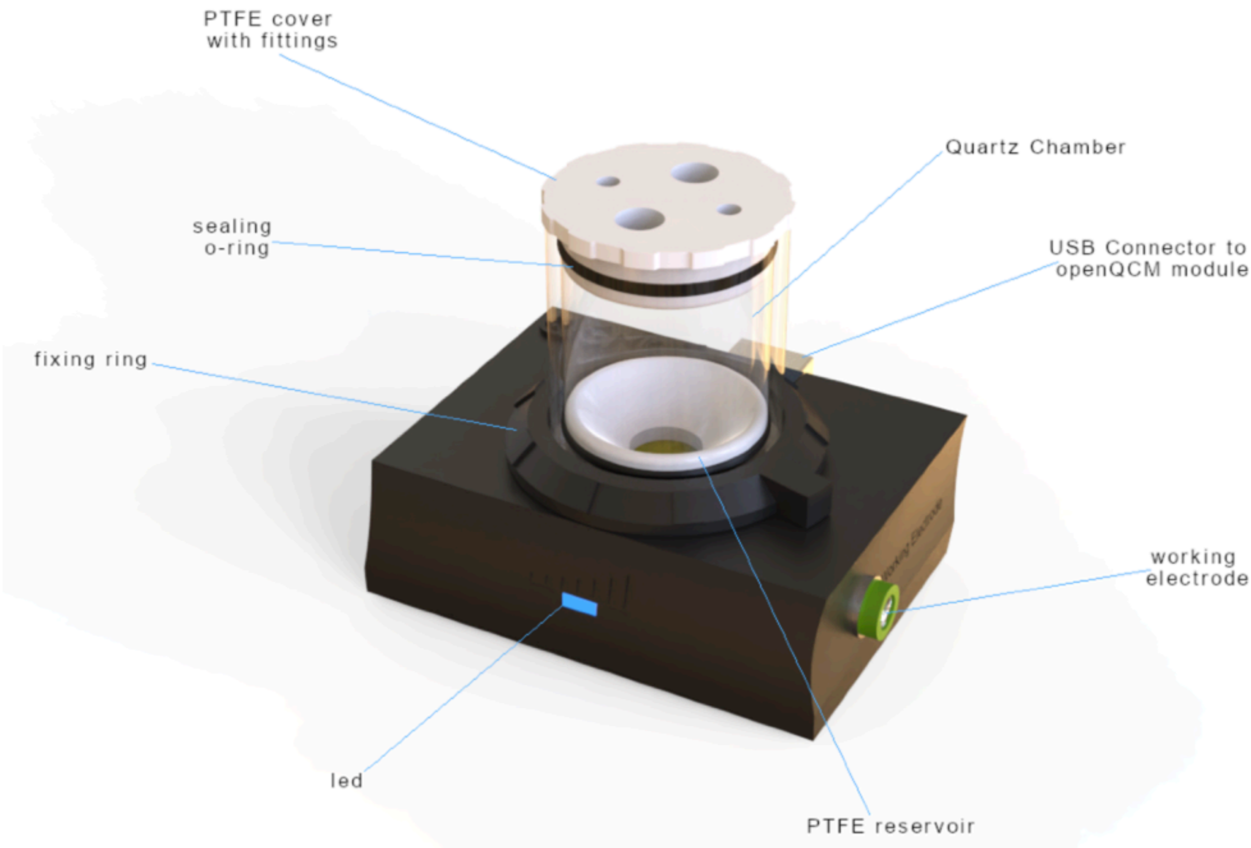


***Fig. 2:** Exploded view of the QCM electrochemical cell assembly.*

The module's sealing system employs a high-performance fluoroelastomer (FKM) O-ring, carefully designed to create a hermetic seal between chamber components while maintaining chemical compatibility with a broad range of electrolytes. This sealing mechanism prevents solution leakage.

A transparent cylindrical quartz chamber forms the central component of the module, allowing real-time visual monitoring of experiments. Its precisely engineered dimensions create optimal electrode spacing and controlled internal volume, minimizing solution requirements while accommodating the electrodes. The chamber's geometry has been optimized to ensure uniform current distribution throughout the cell.

The working electrode interface provides direct connection to the QCM sensor's electrode through a professional-grade electrical contact system. Featuring a banana plug connector for potentiostat integration, the interface incorporates low-noise signal pathway design optimized for both QCM and electrochemical measurements. The PTFE reservoir, constructed from chemically inert material.

Additional integrated features include an LED status indicator that verifies proper connectivity between the module and the QCM monitoring electronics. USB interface for QCM system connectivity, and a robust fixing ring mechanism. Base-mounted stabilizers ensure secure positioning during experiments, while the modular design facilitates easy maintenance and component replacement when necessary.

The module's architecture enables seamless integration with commercial potentiostats while maintaining QCM measurement capability. The design provides easy access for electrode positioning and maintenance, with reliable electrical isolation between QCM and electrochemical circuits.

This versatile platform finds application across numerous research areas, including electrochemical deposition studies, corrosion monitoring, battery material research, electroactive polymer investigations, biosensor development, surface modification analysis, and combined electrochemical impedance studies with QCM-D. The module's robust construction and adaptable design make it an invaluable tool for researchers seeking to combine electrochemical techniques with QCM measurements, advancing capabilities in materials science, electrochemistry, and surface analysis research.

Assembly of the Electrochemical QCM Cell

Comprehensive step-by-step Guide for Module Assembly and Integration

The following section outlines the essential steps for assembling and integrating the openQCM electrochemical module. Each procedure has been carefully detailed to ensure proper component assembly and system integration, enabling optimal performance for your electrochemical measurements. Before proceeding with the assembly, please ensure all components are present and the workspace is properly prepared.

1) Placing the Sensor: Precise Alignment

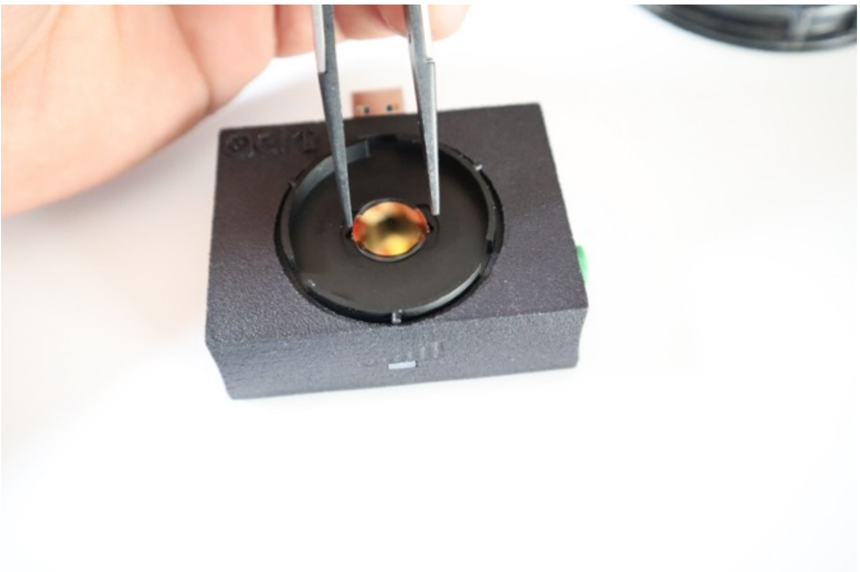


Fig. 3: *placing the sensor.*

This critical step requires careful attention to the orientation of the quartz crystal sensor. As shown in the reference image, the quartz crystal has two distinct sides:

- The top side features a larger gold electrode (sensing side) which must face upward as it will serve as the working electrode for electrochemical measurements

- The bottom side shows a smaller electrode pattern that will interface with the electrical contacts

The correct orientation is crucial for two main reasons:

1. To ensure the larger electrode faces the solution and acts as the working electrode for electrochemical experiments

2. To maintain proper electrical connection with the contact pins in the holder

Using plastic-tipped tweezers (Fig. 3), carefully place the quartz crystal into its designated socket in the holder. The crystal orientation is crucial - ensure the larger electrode faces up and the notch pattern matches the reference image. Proper alignment within the socket is essential, as misalignment could lead to crystal breakage when installing the PTFE reservoir in subsequent steps.

- Important precautions:
- Only handle the crystal with plastic-tipped tweezers
- Verify the crystal sits completely flat in its socket
- Double-check the electrode orientation before proceeding
- Ensure no lateral movement of the crystal in its housing
- Keep the sensing surface clean and free from contamination

Understanding QCM Sensor Orientation and Placement

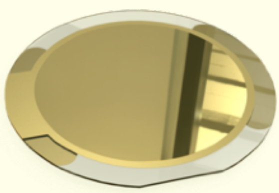
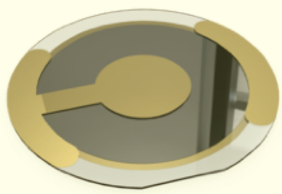
Before proceeding with the electrochemical cell setup, it is essential to understand the fundamental aspects of QCM sensors, particularly their orientation requirements. This section provides crucial information about sensor identification and proper positioning within the device, ensuring optimal performance and measurement accuracy.

The correct orientation of the QCM sensor is a critical parameter that directly influences both the quality of measurements and the longevity of the sensor itself. Understanding these preliminary aspects will significantly facilitate the assembly process and help prevent potential damage to the sensitive components.

This following description specifically addresses QCM sensors optimized for liquid sensing applications, characterized by an asymmetric electrode design - featuring a larger exposed electrode on the sensing side compared to the rear contact electrode. While this description focuses on our standard configuration, the assembly principles and orientation guidelines apply equally to all QCM sensors sharing this geometric design, regardless of their electrode materials or resonant frequencies.

Note: The asymmetric electrode configuration is specifically engineered to optimize performance in liquid environments while maintaining robust electrical connections. The larger sensing electrode design minimizes edging effects - a common phenomenon where electric field fringing at the electrode edges can lead to unwanted frequency shifts and measurement artifacts. This optimized geometry ensures that the active sensing area is well-defined and the mass-sensing response is primarily confined to the central region of the crystal, resulting in more accurate and reliable measurements.

All openQCM devices use quartz sensors with wrapped contact electrodes. The electrical contacts are therefore only arranged on one side. As such, it is important to check the correct orientation of the quartz sensor and, above all, to ensure that the contact is made on the correct side.

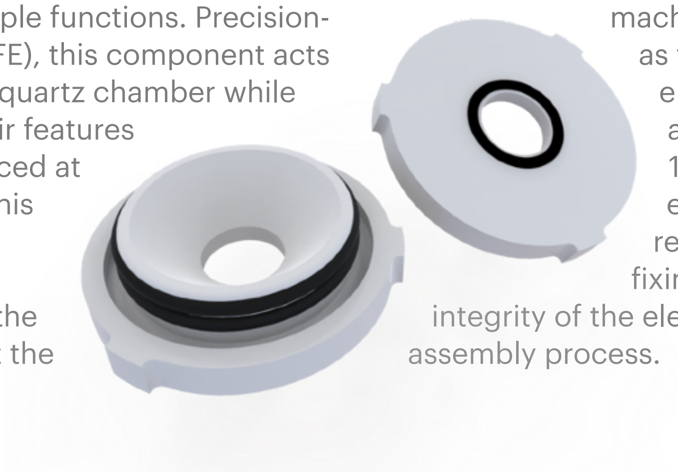
	Top side (sensing side)	Bottom side (to be interfaced to contacts)
Quartz sensor for liquid biosensing		

The correct orientation of the quartz crystal should match the configuration shown in Figure 4.

Fig. 4: *orientation of the quartz sensor.*

2) *Inserting the PTFE reservoir and Quartz Cylinder*

The PTFE reservoir serves as the foundational element of the electrochemical cell assembly, engineered to provide multiple functions. Precision-machined from high-grade polytetrafluoroethylene (PTFE), this component acts as the primary support structure for the cylindrical quartz chamber while ensuring essential sealing functions. The PTFE reservoir features an innovative three-wing design with projections spaced at 120-degree intervals around its circumference. This engineered anti-rotation mechanism prevents the reservoir from turning during the tightening of the fixing ring, ensuring proper alignment and maintaining the integrity of the electrical contacts and sealing surfaces throughout the assembly process.



Key Features and Functions:

The reservoir's primary role is to create a secure mounting platform for the QCM sensor crystal while establishing a liquid-tight environment for electrochemical measurements. Its carefully engineered design includes:

- A precision-machined circular recess that accommodates the QCM sensor with exact dimensional tolerances
- An integrated O-ring groove system that ensures proper compression and sealing when the quartz crystal is installed
- A raised rim that precisely aligns with the quartz cylinder, creating a stable and sealed interface
- Chemical resistance inherent to PTFE, making it compatible with a wide range of electrolytes and organic solvents
- A thermally stable structure that maintains dimensional integrity during temperature variations

Sealing Mechanism: The reservoir's sophisticated design incorporates a dual-sealing approach:

1. A primary seal between the reservoir and the QCM sensor, preventing any liquid ingress to the electronic contacts
2. A secondary seal at the interface with the quartz cylinder, containing the electrolyte within the measurement chamber

This dual-seal configuration is crucial for:

- Protecting the sensitive electronic components beneath the sensor
- Maintaining a defined electrochemical cell volume

- Ensuring reproducible experimental conditions
- Preventing solution leakage during extended measurements

Before integrating the PTFE reservoir with the electrochemical module, the quartz cylinder must be properly installed following specific safety protocols. This procedure requires careful attention to both personal safety and precise handling techniques to protect the delicate quartz component.

Fig. 5: *how to place the quartz cylinder*

Safety Considerations and Preparation Prior to beginning the assembly, ensure appropriate personal protective equipment is in place. Wear laboratory-grade protective gloves to safeguard against potential glass fragments in the unlikely event of breakage. Safety glasses are mandatory to protect against any unforeseen glass debris. The assembly must be performed on a clean, stable laboratory surface with adequate illumination for proper visual inspection of components.

Assembly Protocol Position the PTFE reservoir on a clean, level surface, maintaining sufficient distance from the workbench edge to ensure stability during assembly. Before proceeding, thoroughly inspect both the quartz cylinder and PTFE reservoir for any structural defects, contamination, or debris that could compromise the assembly.

With the PTFE reservoir properly sthbilized, carefully position the quartz cylinder directly above the reservoir's seating rim, maintaining precise vertical alignment. Gradually lower the cylinder onto the reservoir, allowing it to self-align with the circular seating surface. The cylinder should descend smoothly into position with minimal applied force.

Critical Precautions It is imperative to avoid applying excessive force during this procedure. The assembly should proceed with minimal resistance; any significant impediment to smooth installation indicates potential misalignment or obstruction. In such cases, immediately halt the procedure, carefully remove the cylinder, and investigate the cause. Avoid any twisting or lateral forces that could introduce stress to the quartz structure.

The successful completion of this assembly step is characterized by smooth component integration with minimal applied pressure. This careful approach ensures the integrity of both the quartz cylinder and PTFE reservoir while establishing a proper foundation for subsequent electrochemical cell assembly steps.

4) Installing the Pre-assembled PTFE Reservoir Unit

The integration of the pre-assembled PTFE reservoir unit with the electrochemical module base requires precise alignment and careful handling to preserve the integrity of all components, particularly the QCM sensor crystal. This critical assembly step demands methodical execution to ensure proper component seating while maintaining the established electrical and mechanical connections.

Begin by visually inspecting the quartz holder's receiving slots, ensuring they are free from any debris that might impede proper alignment with the PTFE reservoir's anti-rotation wings. These three precisely machined slots, positioned at 120-degree intervals, are engineered to accept the reservoir's corresponding wings while preventing any rotational movement during final assembly.

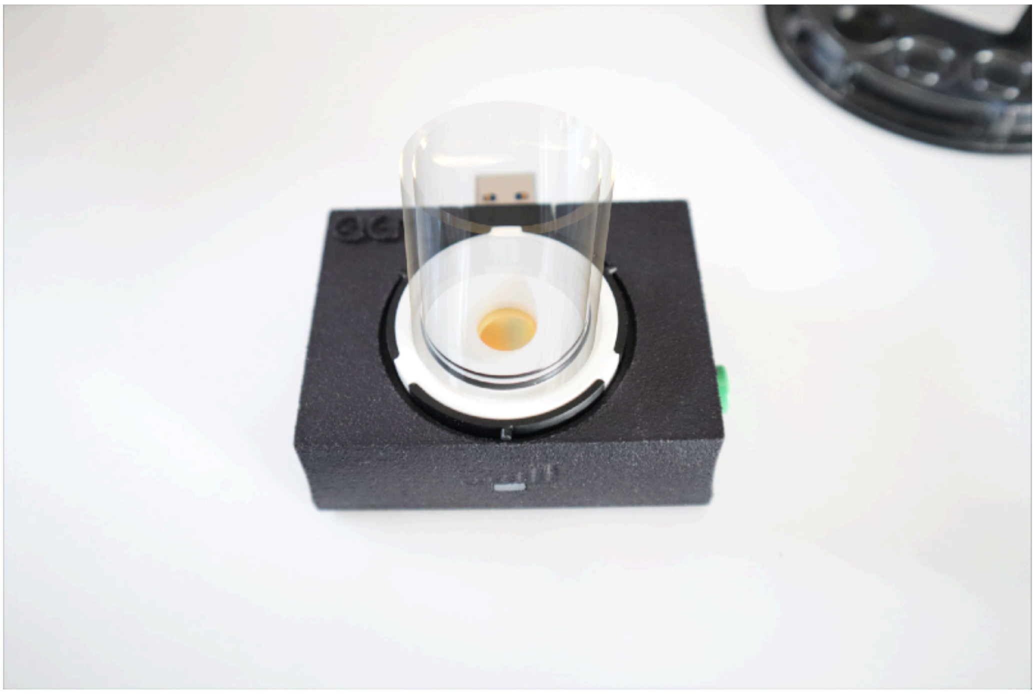


Fig. 6: *how to place the quartz cylinder*

Holding the pre-assembled reservoir unit steadily by its outer edges, position it above the quartz holder, maintaining a clear view of both the alignment wings and their corresponding slots. Before making contact, ensure the unit is oriented so that the wings align with their respective slots. This preliminary alignment is crucial for preventing any lateral forces that could disturb the QCM sensor's position.

Carefully lower the reservoir unit, maintaining its horizontal orientation to ensure uniform descent. The alignment wings should begin to engage with their slots with minimal resistance. If any resistance is encountered, immediately halt the descent and recheck the alignment - forcing the components together could result in sensor misalignment or damage.

⚠️ Critical Consideration: During this procedure, it is essential to maintain the pre-established position of the QCM sensor crystal. Any displacement could compromise electrical contact with the spring pins or affect the sealing surfaces, potentially leading to measurement errors or system failure.

As the reservoir unit approaches its final position, verify that all three wings are descending evenly into their slots. The unit should settle naturally into place with minimal guidance. Once seated, perform a gentle rotational test - the anti-rotation mechanism should prevent any circular movement, confirming proper installation.

Upon successful installation, the PTFE reservoir unit should sit flush with the quartz holder surface, with all wings fully engaged in their respective slots. This configuration establishes the foundation for the subsequent fixing ring installation, which will secure the entire assembly.

This precise integration ensures optimal alignment of all components while maintaining the critical positioning of the QCM sensor, ultimately contributing to the system's measurement accuracy and operational reliability.

4) Installing the Fixing Ring: Securing and Sealing the Cell Assembly

The fixing ring employs a precision-engineered bayonet locking mechanism designed to secure and stabilize the entire cell assembly. This component requires specific handling and installation procedures to ensure proper seating and optimal system performance.

Installation protocol begin by visually identifying the bayonet slots at the base of the fixing ring and their corresponding alignment pins on the quartz holder. Carefully introduce the fixing ring through the quartz cylinder, preliminarily orienting the slots toward the alignment pins. Allow it to descend smoothly along the cylinder's outer surface, maintaining this approximate alignment as it approaches its designated seating position.

Gently position the fixing ring near its final location and execute small bi-directional rotational movements (clockwise and counterclockwise). This manipulation allows the pre-aligned bayonet slots to precisely locate and engage with the quartz holder's positioning pins. When proper alignment is achieved, the fixing ring will naturally settle into its designated position, indicating correct preliminary engagement.

Final Securing Once the fixing ring has seated properly, apply the final securing motion by rotating the ring counterclockwise. During this operation, it is crucial to exercise appropriate restraint - complete tightening is neither necessary nor recommended. Instead, rotate the ring until you encounter moderate resistance, which indicates optimal compression of the sealing elements.

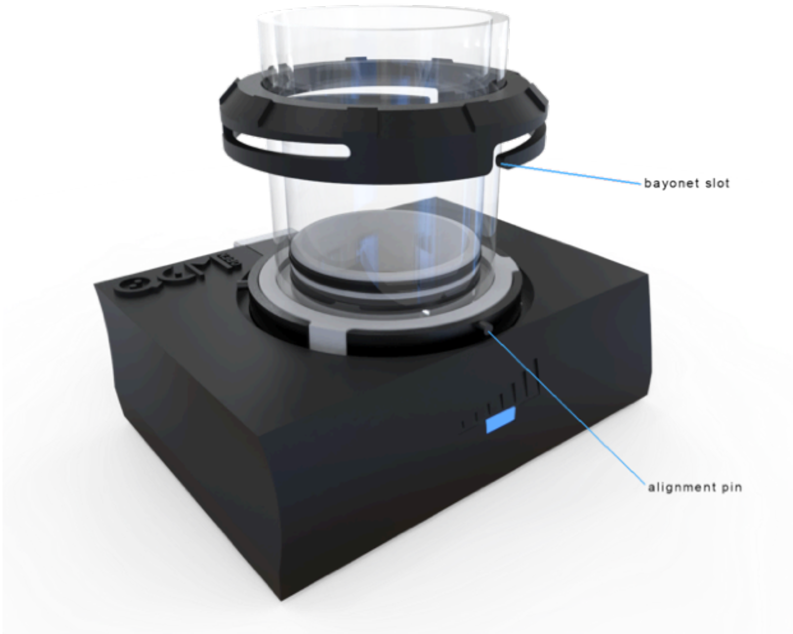


***Fig. 7:** how to insert the fixing ring*

⚠️ Technical Note: Over-tightening the fixing ring can introduce unnecessary stress to the assembly components. The system is designed to achieve proper sealing and stability with moderate securing force. When you encounter the initial resistance during counterclockwise rotation, this indicates that appropriate sealing pressure has been achieved.

This carefully controlled installation process ensures proper sealing and stability while preserving the

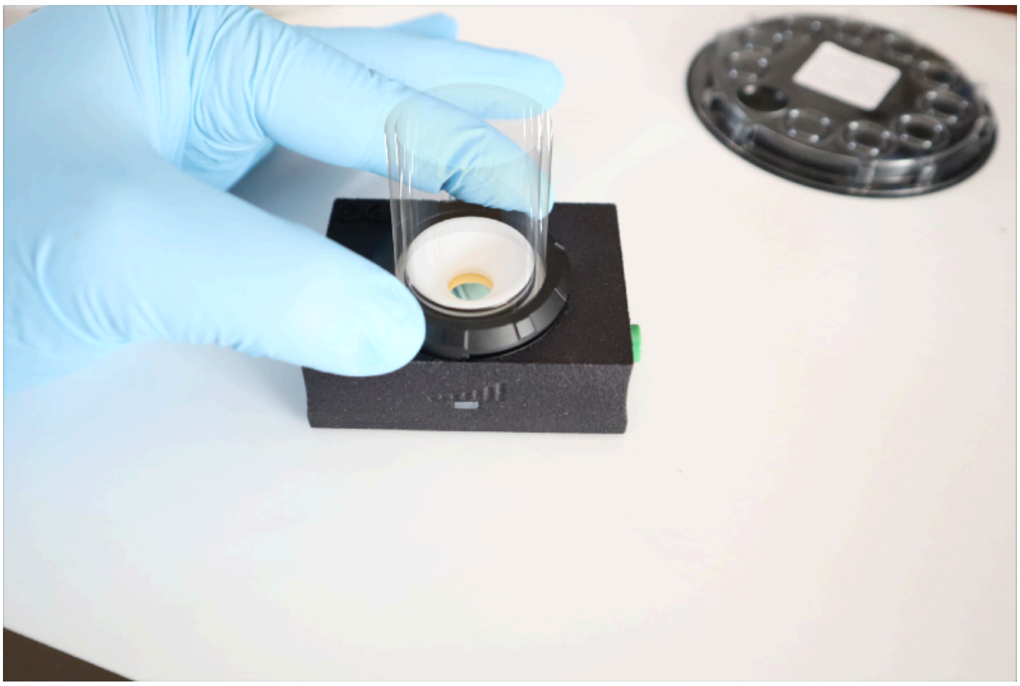


***Fig. 8:** Rotate the fixing ring counterclockwise to secure the assembly*

integrity of all system components.

5) Installing the PTFE Cover: Final Assembly

Installing the PTFE cover represents the final mechanical step in the electrochemical cell assembly. The cover is precision-machined from PTFE with two primary ports (6.2 mm diameter) specifically designed to accommodate standard reference and counter electrodes. Two additional smaller auxiliary ports are integrated into the design to enable fluid handling capabilities, allowing for electrolyte exchange and facilitating continuous flow experiments when needed. The module comes equipped with two Fitting Adapters designed for 4 mm and 6 mm electrochemical probes, which provide enhanced flexibility for accommodating longer electrodes while maintaining proper sealing and positioning within the cell.

Carefully lower the PTFE cover onto the quartz cylinder, applying gentle and uniform pressure. While maintaining vertical alignment, slowly press down until the cover is fully seated.

⚠ CAUTION: Exercise restraint during this operation. The cover should slide smoothly into position with minimal force. If you encounter any resistance, stop immediately and check for misalignment. Excessive force could damage the quartz cylinder or compromise the sealing surfaces.

Recognizing diverse research requirements, the PTFE cover can be customized to meet specific experimental needs. Researchers can either commission custom-designed covers through our service

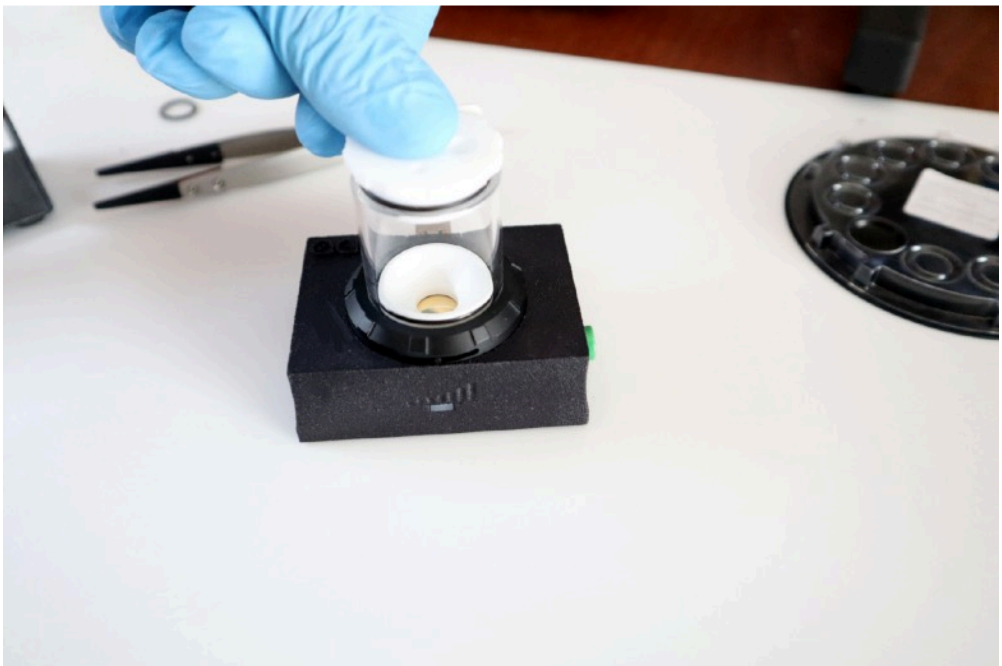


Fig. 9: *Carefully lower the PTFE cover onto the quartz cylinder, applying gentle and uniform pressure. While maintaining vertical alignment, slowly press down until the cover is fully seated.*

or fabricate their own using the provided dimensional specifications and technical drawings. This design flexibility ensures compatibility with various electrode configurations and experimental setups while maintaining the integrity of the electrochemical cell. Detailed dimensional drawings are included in this manual (Fig. 10) to facilitate custom modifications while preserving critical sealing interfaces and maintaining proper electrode spacing.

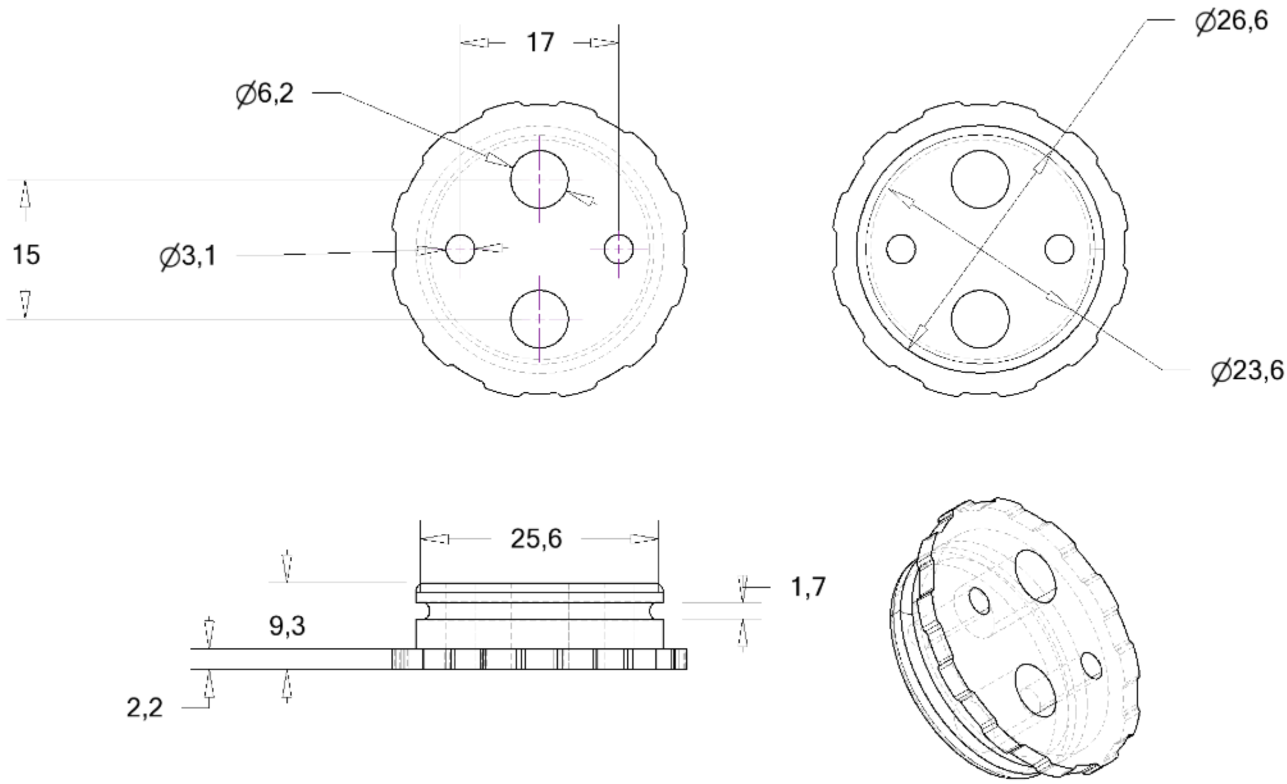


Fig. 10: *2D drawing of the PTFE cover (units: mm)*

6) Completing the System Integration and the Electrical Connectivity

The electrochemical module is specifically engineered for seamless integration with the openQCM Q-1 platform. Users can easily replace the standard sensor module of openQCM Q-1 with the electrochemical module using the same mounting interface. The successful electrical connection between openQCM Q-1's central unit and the electrochemical module is visually confirmed by the illumination of a blue LED indicator on the electrochemical module.

Interconnection between components is achieved through standard USB3 connectors.

⚠ IMPORTANT: The module must only be connected to the openQCM Q-1 central unit, never directly to a PC or other USB ports, as this could result in electrical damage to the module. The choice of USB connectors was implemented to ensure ready availability of replacement parts for users undertaking independent module assembly.

Fig. 11: *Fully assembled electrochemical QCM system ready for combined measurements. The completed setup shows proper integration of all components: electrochemical module mounted on openQCM Q-1 platform*

The electrochemical module is designed for compatibility with third-party potentiostats. Counter and reference electrodes are accommodated through the designated fittings in the PTFE cover. For working electrode connections, the module features a 2mm Green Female Banana Socket mounted on its side panel. The package includes a 2mm Green Male Banana Plug that can be soldered to a cable for connection to the potentiostat's working electrode terminal.

Upon completion of these connections, the system is fully configured for simultaneous QCM and electrochemical measurements, enabling comprehensive interfacial analysis through combined techniques.

7) *Complete Cell Filling: A Critical Requirement*

Proper cell preparation and maintenance are fundamental to obtaining reliable, high-quality data in QCM-electrochemistry experiments. Among the various operational parameters, correct cell filling stands out as one of the most critical yet often overlooked aspects.

CRITICAL NOTE: After assembly completion, it is absolutely essential to completely fill the cell up to the electrochemical probe insertion ports. Complete filling is crucial for several key reasons:

1. Signal Stability

- Any free surface (air-liquid interface) within the cell will introduce significant baseline noise in QCM signals
- Fluid movements at this interface can create spurious oscillations that interfere with measurements
- These disturbances can mask or distort the actual phenomena being studied

2. Additional Important Considerations:

- Ensure no air bubbles are trapped during filling, as they can cause similar interference effects
- Maintain consistent temperature during measurements, as thermal fluctuations can affect fluid density and cause unwanted convection
- Consider using a degassed solution to minimize the risk of bubble formation during experiments
- Regular verification of filling level is recommended, especially for long-duration experiments where evaporation might occur

3. Best Practices:

- Fill slowly and methodically to avoid bubble entrapment
- Use slightly positive pressure when filling to help displace any trapped air
- Consider implementing a sealed system to maintain consistent filling levels
- Document the filling procedure as part of your experimental protocol

This requirement for complete filling is fundamental to achieving reliable and reproducible QCM measurements by eliminating noise sources that could compromise data quality.

Cleaning

How to properly clean the removable parts of the electrochemistry module

Regular cleaning of the electrochemical module components is essential for maintaining measurement accuracy and system longevity. The module can be disassembled following the reverse order of the assembly steps (5 through 1) to access individual components for cleaning.

⚠ IMPORTANT: Before beginning the cleaning procedure, ensure all electrical connections are disconnected and the system is completely powered down.

Cleaning Protocol:

- PTFE Cover and Fittings: Clean with deionized water or mild laboratory detergent. For stubborn residues, isopropyl alcohol can be used. Avoid aggressive organic solvents which might degrade the sealing surfaces.
- Quartz Cylinder: Handle with extreme care. Clean with deionized water and, if necessary, mild laboratory detergent. Dry thoroughly with lint-free tissues. Never use abrasive materials or excessive force.
- PTFE Reservoir: Clean all sealing surfaces and ensure the anti-rotation wings are free from debris. Pay particular attention to the O-ring grooves.
- O-rings: Inspect for wear or damage during each cleaning. Clean with mild detergent and water. Replace if any signs of degradation are observed.
- Sensor Holder: Clean the electrical contact area with isopropyl alcohol using lint-free swabs. Ensure the contact springs are free from corrosion or debris.

Alternative Ultrasonic Cleaning: All removable components (O-rings, PTFE reservoir and cover, quartz cylinder, and fixing ring) can be efficiently cleaned using an ultrasonic bath with isopropyl alcohol (IPA), too.

Recommended ultrasonic cleaning procedure:

1. Place components in the ultrasonic bath with IPA at room temperature
2. Run two consecutive 5-minute cycles
3. Rinse thoroughly with deionized water
4. For drying:
    - Use filtered compressed air or nitrogen gas for rapid drying of PTFE components

- Allow the quartz cylinder to air dry in a dust-free environment or use a laboratory oven at 40°C for 30 minutes

- Thoroughly dry O-rings at room temperature before reinstallation

⚠ CAUTION: Never use acetone or aggressive organic solvents on any components, as these may damage the sealing surfaces or compromise the material integrity.

After cleaning, allow all components to reach room temperature and ensure they are completely dry before reassembly. Inspect each part for damage or wear before rebuilding the cell following the assembly instructions detailed in sections 1 through 5.