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Developing an Effusion Cell to Measure Low Outgassing Rates from Europa Clipper Hardware

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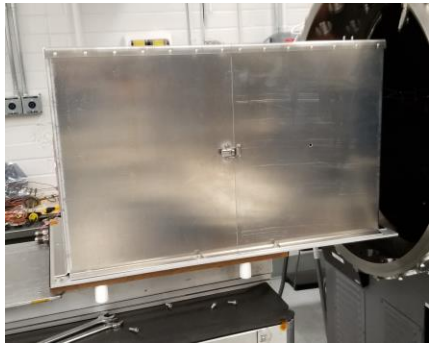
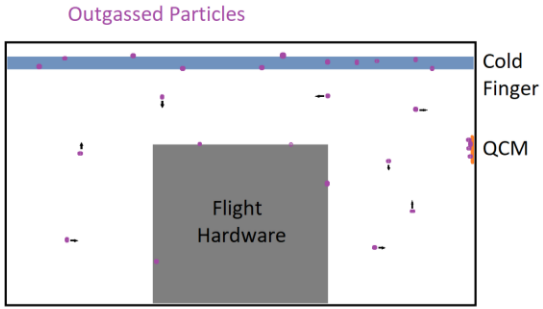
Introduction

What is the Effusion Cell?

The JPL effusion cell is a metallic box that encloses hardware during bakeout and outgassing measurement to direct outgassed molecules onto a Quartz Crystal Microbalance (QCM) sensor.

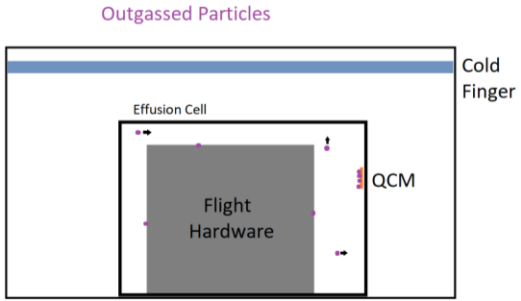


JPL Effusion Cell



Chamber without Effusion Cell

Outgassed particles collect on all cold surfaces (cold finger, QCM sensor head)



Chamber with Effusion Cell

Outgassed particles collect primarily on QCM sensor head

Europa Clipper Outgassing Requirements

Why do we need an Effusion Cell?

The Effusion Cell supports Clipper's outgassing rate measurements, which are critical to mission success

- Clipper's instruments have stringent molecular deposition requirements
- The JPL CC team has implemented outgassing rate requirements for every major Clipper component in order to support science return

Outgassing Rate Requirement

Each flight system surface shall have a pre-launch outgassing rate as defined below:

View Factor	Definition	Example Components	Outgassing Rate ($g/cm^2/sec$)	Outgassing Rate ($ng/cm^2/hr$)
High	Exposed	Solar Array, MLI	$1x10^{-14}$	0.036
Moderate	Underneath MLI	Prop Module Electronics	$5x10^{-14}$	0.18
Limited	Inside Vault	Vault Electronics	$1x10^{-12}$	3.6

- Outgassing rate requirement verification must involve a quantitative measurement of outgassing rate. In most cases, this involves a QCM measurement at the assembly level.
- Outgassing rate is measured with hardware at Europa flight temperature and QCM at -113°C (corresponding to Clipper sensitive surface temperature at Europa).

Effusion Cell Benefit

How does the Effusion Cell support Europa Clipper outgassing rate requirement verification?

Verification of the most stringent outgassing rate requirements would not be possible without directing a larger portion of outgassed molecules to the QCM head

When measuring hardware outgassing rate, the important factors are:

- Chamber background – hardware measurement on QCM must be at or above this value
- Hardware surface area – shrink wrap surface area; cannot change
- Transport factor – percentage of molecules that reach QCM sensor; can be changed

Example outgassing measurement of SRU Optical Head in ETL Chamber 18

	Without Effusion Cell	With Effusion Cell
Hardware Surface Area (cm^2)	4470	4470
Chamber Background	3 Hz/hr	3 Hz/hr
Transport Factor (% molecules impacting QCM sensor)	0.03%	1.21%
Sensitivity Floor* ($g/cm^2/s$)	~$3x10^{-13}$ $g/cm^2/sec$ or ~1.08 $ng/cm^2/hr$	~$1x10^{-14}$ $g/cm^2/sec$ or 0.036 $ng/cm^2/hr$
Able to verify most stringent Clipper requirement?	No	Yes

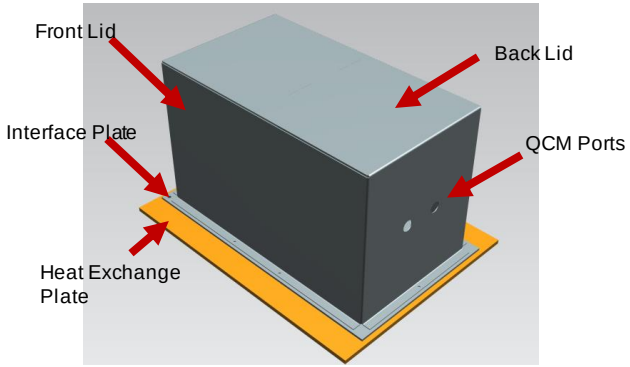
*hardware outgassing rate equivalent to chamber background QCM reading

Design Considerations

The Effusion Cell should:

- Fit within existing JPL chamber and interface with Environmental Test Lab (ETL) components
- Accommodate most Clipper hardware and provide a mounting interface for hardware of various shapes and handling constraints
- Constrain transport of outgassed particles between flight hardware and cryogenic QCM
  - Block views of other cold chamber surfaces
  - Remain warmer than hardware and CQCM
  - Minimize potential loss surfaces within box
- Maintain hardware at Europa operating temperature (-100°C to 50°C) for QCM verification

Effusion Cell Design in CAD

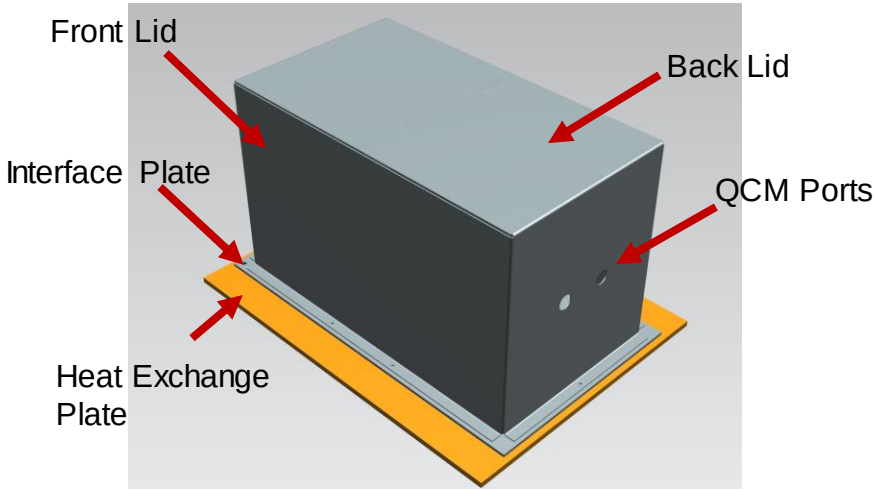


Effusion Cell Design

Effusion Cell Components

- Front Lid – removable half to install and uninstall hardware from the box
- Back Lid – removable half where the QCMs are mounted
- QCM Ports – opening for QCM heads to face hardware within box
- Interface Plate – mechanical and thermal interface for hardware
- Heat Exchange Plate – thermal control surface for the effusion cell

Effusion Cell Design in CAD



Effusion Cell #1 with Front Lid Removed

Effusion Cell – Sizing

The Effusion Cell is:

- Housed in ETL Chamber 18
- Sized to accommodate the largest expected components for QCM verification at JPL
  - Effusion Cell #1 fabricated to optimize height dimension inside chamber; designed for electronics boxes
  - Effusion Cell #2 fabricated to optimize width dimension inside chamber; designed for louvers

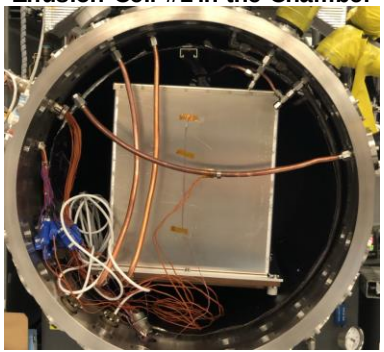
Component	Length	Width	Height
PCDA Box	55.0 cm	31.8 cm	38.0 cm
Battery Box	58.4 cm	34.2 cm	28.2 cm
Effusion Cell #1	**71.6 cm**	**39.5 cm**	**44.3 cm**
Louver	53.2 cm	39.7 cm	63.0 cm
Effusion Cell #2	**72.1 cm**	**48.3 cm**	**35.6 cm**

} Largest single electronics boxes

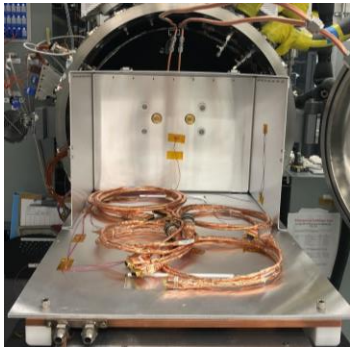
The Effusion Cell should:

- **Fit within chosen ETL chamber** and interface with ETL components
- **Accommodate most Clipper electronics boxes** and provide a mounting interface for hardware of various shapes and handling constraints
- Constrain transport of outgassed particles between flight hardware and CQCM
  - Block views of other cold chamber surfaces
  - Remain warmer than hardware and CQCM
  - Minimize potential loss surfaces within box
- Maintain hardware at Europa operating temperature (-110°C to 60°C) for QCM verification

Effusion Cell #1 in the Chamber



Effusion Cell #2 with Harness



Effusion Cell – Lids

- Front lid allows access to hardware and faces the chamber door
- Back lid holds the QCM mount and includes three 0.25” diameter mouseholes to support venting during pump down
- Lid flanges bolt to interface plate
- Lids latch together on sides and top to reduce gap
- Two lids allow for removal of front lid to access hardware without disturbing QCM mounting
- Lids are fabricated from aluminum sheet metal

The Effusion Cell should:

- Fit within chosen ETL chamber and **interface with ETL components**
- **Accommodate** most Clipper electronics boxes and provide a mounting interface for **hardware of various shapes and handling constraints**
- Constrain transport of outgassed particles between flight hardware and CQCM
  - **Block views of other cold chamber surfaces**
  - Remain warmer than hardware and CQCM
  - **Minimize potential loss surfaces within box**
- Maintain hardware at Europa operating temperature (-110°C to 60°C) for QCM verification

Effusion Cell #1 with Front Lid Removed

Effusion Cell – QCM Ports

The Effusion Cell accommodates two QCMs.

- QCM ports on the back lid face of the effusion cell
- Sensors are CrystalTek CQCMs
- Stand mounts QCMs to effusion cell
- Thermal standoffs isolate the QCMs from the effusion cell
- QCM heads at the port plane reduce loss areas around the QCM ports

The Effusion Cell should:

- Fit within chosen ETL chamber and **interface with ETL components**
- Accommodate most Clipper electronics boxes and provide a mounting interface for hardware of various shapes and handling constraints
- **Constrain transport of outgassed particles between flight hardware and CQCM**
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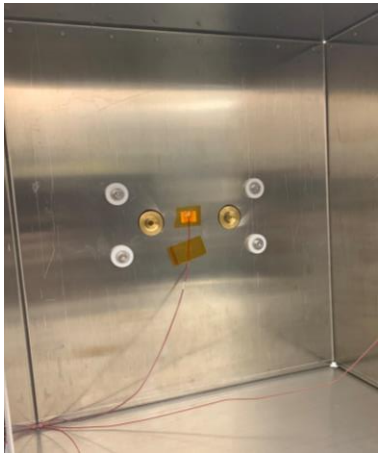
QCM Port Dimensions

Component	Diameter
QCM Port	1.25”
QCM Head	1.15”
QCM Collector	0.25”

QCMs on Mounting Interface (with Heat Exchange) on Effusion Cell Exterior

QCM Sensors on Effusion Cell Interior



Effusion Cell – Interface Plate

The interface plate is a mechanical and thermal interface for the hardware.

- Bolts to the heat exchange (HX) plate to control hardware temperature
- Provides a mounting interface for the hardware; can be customized for GSE

Design:

- 2 bolts to the HX plate
- 3 bolts per effusion cell lid half
- Aluminum sheet metal
- Custom bolt pattern for GSE if requested

The Effusion Cell should:

- Fit within chosen ETL chamber and **interface with ETL components**
- Accommodate most Clipper electronics boxes and **provide a mounting interface for hardware of various shapes and handling constraints**
- Constrain transport of outgassed particles between flight hardware and CQCM
  - Block views of other cold chamber surfaces
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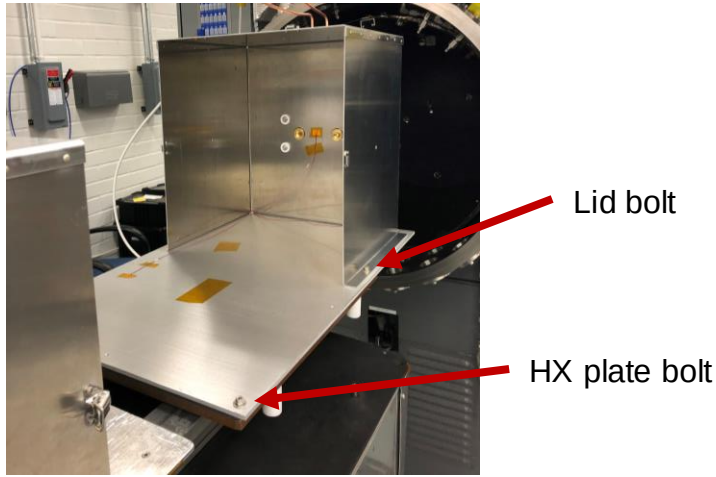
  - Minimize potential loss surfaces within box
- **Maintain hardware at Europa operating temperature (-110°C to 60°C) for QCM verification**

Interface Plate of Open Effusion Cell



Effusion Cell – Heat Exchange Plate

- Custom copper heat exchange plate designed for the effusion cell
  - Interface plate bolts to front of HX plate
  - Uses insulative feet to standoff from chamber shroud
  - Double back tube design to improve thermal control
  - Supports measurements at Europa operating temperatures

The Effusion Cell should:

- Fit within chosen ETL chamber and **interface with ETL components**
- Accommodate most Clipper electronics boxes and provide a mounting interface for hardware of various shapes and handling constraints
- Constrain transport of outgassed particles between flight hardware and CQCM
  - Block views of other cold chamber surfaces
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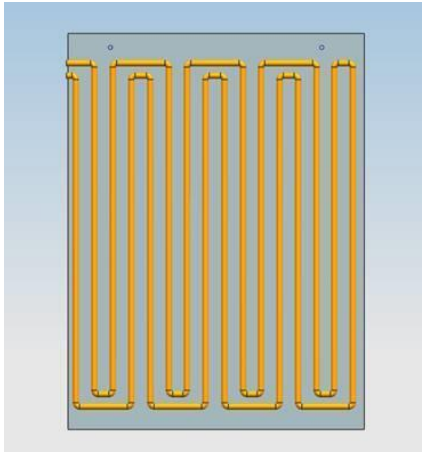
  - Minimize potential loss surfaces within box
- **Maintain hardware at Europa operating temperature (-110°C to 60°C) for QCM verification**

Heat Exchange Plate Design in CAD



Effusion Cell – Thermal Considerations

To reflect outgassed particles to collect on the QCMs, the effusion cell walls and interface plate must be warmer than the QCMs.

Thermocouples are typically placed:

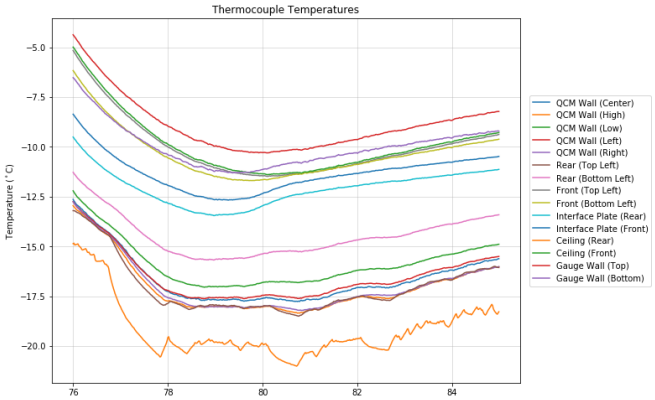
- On the interface plate
- On the right wall of the back lid
- On the back wall of the back lid
- On the front wall of the front lid
- On the hardware (as appropriate)

The effusion cell temperature should remain warmer than the QCMs for the outgassed material to collect on the QCMs. Ideally, it should also remain warmer than the hardware being measured.

The Effusion Cell should:

- Fit within chosen ETL chamber and **interface with ETL components**
- **Accommodate** most Clipper electronics boxes and provide a mounting interface for **hardware of various shapes and handling constraints**
- Constrain transport of outgassed particles between flight hardware and CQCM
  - Block views of other cold chamber surfaces
  - **Remain warmer than hardware and CQCM**
  - Minimize potential loss surfaces within box
- **Maintain hardware at Europa operating temperature (-110°C to 60°C) for QCM verification**

Thermocouple Temperatures during Thermal Gradient Characterization (Interface Plate set to -10°C)



Effusion Cell – Pressure Considerations

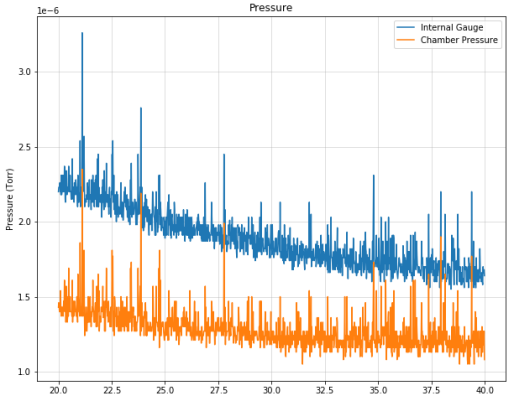
To reflect outgassed particles to collect on the QCMs and bake out hardware, the interior of the effusion cell should have a minimal pressure differential from the chamber, which is kept at or below 1e-5 Torr.

An ion gauge was mounted to Effusion Cell #1 to measure the internal pressure. The internal pressure was found to be higher than the chamber pressure but still ≤1e-5 Torr.

The Effusion Cell should:

- Fit within chosen ETL chamber and **interface with ETL components**
- Accommodate most Clipper electronics boxes and provide a mounting interface for hardware of various shapes and handling constraints
- Constrain transport of outgassed particles between flight hardware and CQCM
  - Block views of other cold chamber surfaces
  - Remain warmer than hardware and CQCM
  - Minimize potential loss surfaces within box
- Maintain hardware at Europa operating temperature (-110°C to 60°C) for QCM verification

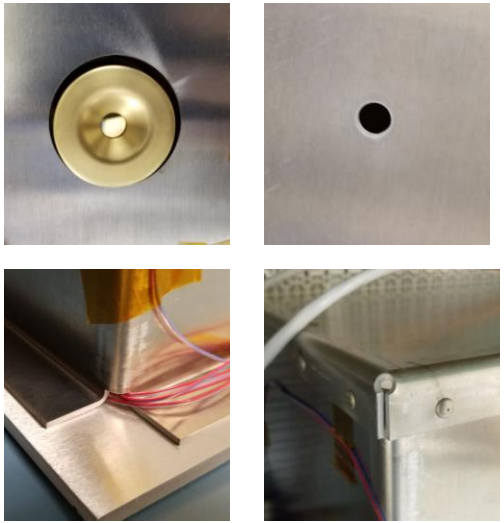
Pressure during Internal Pressure Test (Interface Plate set to 90°C)



Ion Gauge Mounted to Effusion Cell #1 Exterior

Effusion Cell – Area Fraction

Loss Surface	Dimensions	Area
QCM Port (x2)	32 mm diameter	16.1 cm^2
Mouseholes (x3)	7 mm diameter	1.2 cm^2
Corner Holes (x8)	4 mm diameter (upper) 7 mm x 7 mm (lower)	0.5 cm^2 2.0 cm^2
Lid Seam	0.5 mm width	6.4 cm^2
	Total Loss Area	26.1 cm^2
Collector Surface	**Dimensions**	**Area**
QCM Head	0.25 in. diameter	0.317 cm^2
	Area Fraction	**0.0121**



Area fraction: fraction of the QCM sensor head area (collection area) over the total loss area

Area fraction is used as an estimate for the transport factor inside the effusion cell. This can be used when the interior of the effusion cell is warm and can be assumed to be reflected outgassed molecules to the QCM sensor heads.

Conclusion

- Clipper JPL CC Team has developed and tested an effusion cell to support hardware outgassing rate measurements
  - Effusion cell design constrains view factor to the QCMs
  - Effusion cell is sized to be used by multiple pieces of hardware
- Effusion cell design achieves sensitivity required by Clipper's most stringent outgassing requirements
  - Area fraction is used to estimate transport factor from hardware to QCMs
  - Effusion cell temperatures support area fraction assumptions for transport factor in outgassing analysis
- Effusion cell has successfully verified the outgassing rate for ~15 Clipper components and test samples

JPL Clipper Effusion Cell successfully supports the measurement of Clipper's outgassing rate requirements.

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