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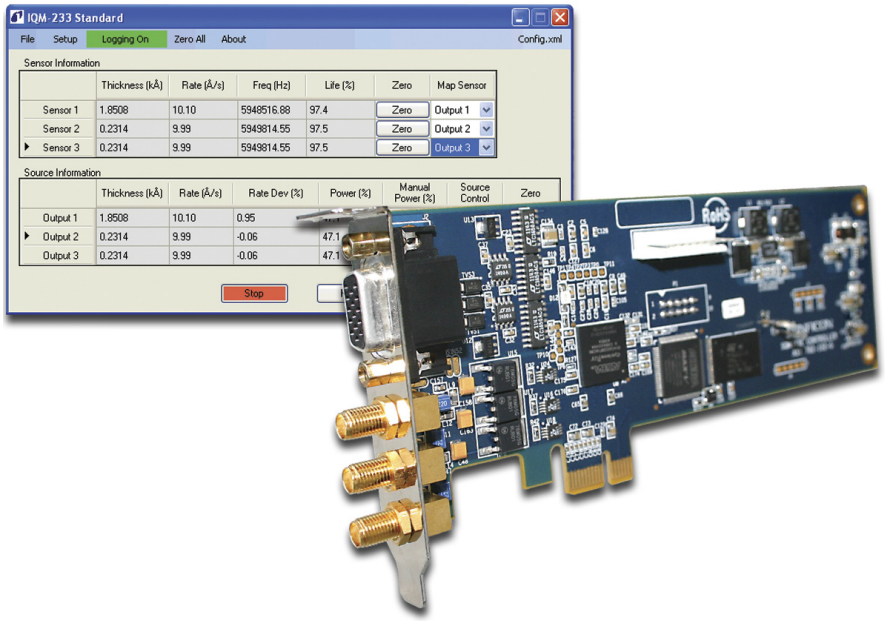

IQM-233™

Thin Film Deposition Controller

PN 074-584-P1B

INFICON

O P E R A T I N G M A N U A L

IQM-233™

Thin Film Deposition Controller

PN 074-584-P1B

INFICON Instruments for Intelligent Control®

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DECLARATION OF CONFORMITY

This is to certify that this equipment, designed and manufactured by:

INFICON Inc.
Two Technology Place
East Syracuse, NY 13057
USA

Meets the essential safety requirements of the European Union and is placed on the market accordingly. It has been constructed in accordance with good engineering practice in safety matters in force in the Community and does not endanger the safety of persons, domestic animals or property when properly installed and maintained and used in applications for which it was made.

Equipment Description: **IQM-233 Thin Film Deposition Controller**

Applicable Directives:
2014/35/EU (LVD)
2014/30/EU (General EMC)
2011/65/EU (RoHS2)

Applicable Standards:

Safety:	EN 61010-1: 2010 3.0 Edition
Emissions:	EN 61326-1: 2013 (Radiated & Conducted Emissions) (EMC – Measurement, Control & Laboratory Equipment) CISPR 11/EN 55011 Edition 2009-12 Emission standard for industrial, scientific, and medical (ISM) radio RF equipment FCC Part 15 Class A emissions requirement (USA)
Immunity:	EN 61326-1: 2013 (Industrial EMC Environments) Immunity per Table 2 (EMC – Measurement, Control & Laboratory Equipment)
RoHS2:	Fully Compliant

CE Implementation Date: November 2013 (REVISED 5/29/15)

Authorized Representative: Steven Schill

Steven Schill

Thin Film Business Line Manager
INFICON, Inc.

ANY QUESTIONS RELATIVE TO THIS DECLARATION OR TO THE SAFETY OF INFICON'S PRODUCTS SHOULD BE DIRECTED, IN WRITING, TO THE AUTHORIZED REPRESENTATIVE AT THE ABOVE ADDRESS.

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NOTE: These instructions do not provide for every contingency that may arise in connection with the installation, operation or maintenance of this equipment. Should you require further assistance, please contact INFICON.

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Chapter 1
Introduction and Specifications

1.1 Introduction

The IQM-233 card is a thin film deposition controller that installs into a PCI Express slot within a standard or small form factor computer that runs on the Windows® XP, Windows 7, or Windows 8 operating system. See Figure 1-1.

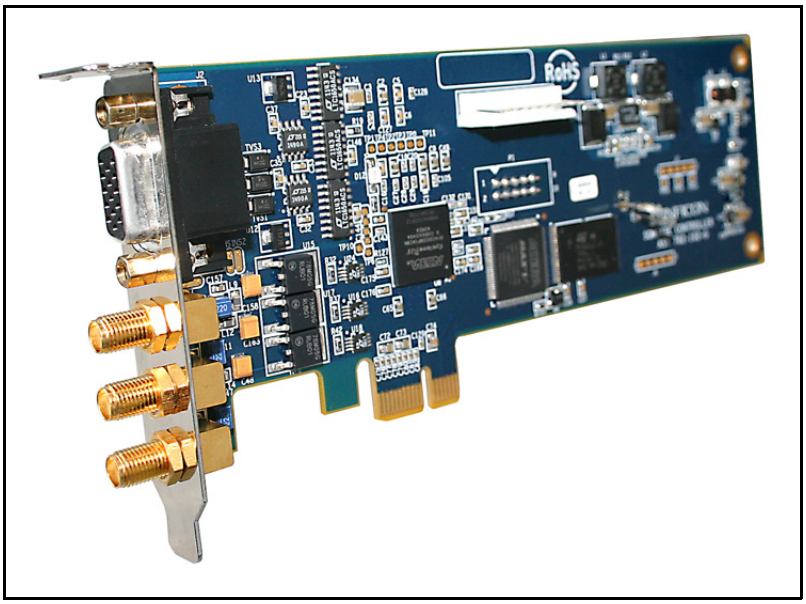
Basic features for one IQM-233 card, or one SQM-242 card, are provided with the IQM-233 Standard software.

NOTE: Advanced features for up to two IQM-233 cards, or two SQM-242 cards, are provided by the optional IQS-233 Codeposition software.

For designing custom software, the Windows Dynamic Link Library (DLL) file allows up to six IQM-233 cards or up to six SQM-242 cards to be used.

A LabVIEW™ VI sample is provided to demonstrate programming techniques.

Figure 1-1 IQM-233 card



1.1.1 IQM-233 Card Features

- Three sensor inputs for 5 MHz or 6 MHz quartz crystal sensors
- Three analog source outputs
- Compatible with the PN 782-900-010 oscillator used with the SQM-242 card

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1.1.2 IQM-233 Standard Software Features

- Basic setup and control of one IQM-233 card or one SQM-242 card (SAM-242 card not supported)
- Single layer process setup
- Single layer monitoring of up to three quartz crystal sensors (up to four sensors for SQM-242)
- Single layer codeposition of up to three sources (up to two sources for SQM-242)
- Compatible with all INFICON non-shuttered single sensors**:** Front Load, Cool Drawer, Bakeable, and Sputtering

  NOTE: Shuttered sensors require a PLC and IQS-233 Codeposition software for automatic shutter control.

  NOTE: Not compatible with CrystalSix, Crystal12, and RSH-600 rotary sensors.

  NOTE: Not compatible with the CrystalTwo switch.

1.1.3 IQS-233 Codeposition Software Features

- Advanced setup and control of up to two IQM-233 cards or two SQM-242 cards (SAM-242 card not supported)
- Multi-layer process setup
- Codeposition of up to six sources (up to four sources for SQM-242 card)
- Easy PLC integration for event-selectable relay functions and shutter control
- Compatible with all INFICON single and dual sensors: Front Load, Cool Drawer, Bakeable, Sputtering

  NOTE: Shuttered sensors require a PLC for automatic shutter control.

  NOTE: Not compatible with CrystalSix, Crystal12, and RSH-600 rotary sensors.

  NOTE: Not compatible with the CrystalTwo switch.

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1.1.4 Related Operating Manuals

PN 074-154 . . . . . Bakeable Crystal Sensor

PN 074-156 . . . . . Front Load Single and Dual Sensors

PN 074-157 . . . . . Sputtering Crystal Sensor

PN 074-609 . . . . . Cool Drawer Single and Dual Sensors

PN 074-585 . . . . . IQS-233 Codeposition Software

NOTE: Sensor operating manuals are available on the Thin Film Manuals CD included with the IQM-233 card. Other related documentation can be downloaded from www.inficon.com.

1.2 Instrument Safety

1.2.1 Definition of Notes, Cautions and Warnings

When using this manual, please pay attention to the NOTES, CAUTIONS and WARNINGS found throughout. For the purposes of this manual they are defined as follows:

NOTE: Pertinent information that is useful in achieving maximum IQM-233 card efficiency when followed.

CAUTION

Failure to heed these messages could result in damage to the IQM-233 card or the loss of data.

WARNING

Failure to heed these messages could result in personal injury.

WARNING - Risk Of Electric Shock

Dangerous voltages are present which could result in personal injury.

1.2.2 General Safety Information

WARNING - Risk Of Electric Shock

The IQM-233 card does not have any user serviceable components.

WARNING - Risk Of Electric Shock

Dangerous voltages may be present whenever the computer is turned on or external connections are present.

WARNING - Risk Of Electric Shock

The computer in which the IQM-233 card is installed must be connected to earth ground through a sealed three-conductor power cable plugged into a socket outlet with protective ground terminal.

Extension cables must have three conductors including a protective earth ground.

WARNING

Failure to operate the IQM-233 card in the manner intended by INFICON can circumvent the safety protection provided by the IQM-233 card and may result in personal injury.

CAUTION - Static Sensitive Device

The IQM-233 card contains circuitry which is susceptible to transient voltages or static.

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1.3 How To Contact INFICON

Worldwide customer support information is available under **Contact >> Support Worldwide** at www.inficon.com

- Sales and Customer Service
- Technical Support
- Repair Service

If you are experiencing a problem with your IQM-233 card or software, please have the following information readily available:

- The Sales Order or PO number for the IQM-233 card purchase, if calling about the IQM-233 card.
- The software version, if calling about IQM-233 Standard or IQS-233 Codeposition software.
- A description of the problem.
- An explanation of any corrective action already attempted.
- The exact wording of any error messages received.

1.3.1 Returning Your IQM-233 Card to INFICON

Do not return any component of your IQM-233 card to INFICON without first speaking with a Customer Support Representative and obtaining a Return Material Authorization (RMA) number.

Packages delivered to INFICON without an RMA number will be held until the customer is contacted. This will result in delays in servicing the IQM-233 card.

If returning an IQM-233 card with a crystal sensor, or other component potentially exposed to process materials, prior to being given an RMA number you will be required to complete a Declaration Of Contamination (DOC) form. DOC forms must be approved by INFICON before an RMA number is issued. INFICON may require that the component be sent to a designated decontamination facility, not to the factory.

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1.4 IQM-233 Specifications

1.4.1 Measurement

Crystal Frequency Range	4.000 MHz to 6.100 MHz
Frequency Resolution	0.05 Hz @ 6 MHz (0.50 s measurement period)
Reference Frequency Stability	±50 ppm (0 to 50°C)
Thickness Resolution	0.0613 Å/s/measurement, (density = 1.00, Z-Ratio = 1.000, measurement period = 0.5 s, crystal frequency = 6.0 MHz)
Thickness Accuracy	Dependent on process conditions, especially sensor location, material stress, temperature, and density
Measurement Period	0.1 to 2 s
Measurement Technique	Active Oscillation
Number of Sensors	3

1.4.2 Source Outputs

Number of Outputs	3
Output Connector	15-pin high-density D-sub
Output Voltage	0 to ±10 V(dc)
Output Impedance	50 Ω
Output Resolution	15-bit plus sign

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1.4.3 Computer Requirements

Processor	1.5 GHz CPU minimum
RAM	2 GB RAM minimum
Memory	200 MB hard disk space minimum
Operating System	Windows XP SP3, Windows 7 32/64-bit, Windows 8 32/64-bit
Screen Resolution	800 x 600 minimum
IQM-233 Card Interface	PCI Express x1, x4, x8, x16
Computer Case	Standard or small form factor
Communication Interface	RS-232C communications are required when interfacing an external PLC to the optional IQS-233 Codeposition software **NOTE:** If the computer does not have an available RS-232 port, a USB-Serial Adapter can be used instead.

1.4.4 General Specifications

IQM-233 Card Type	PCIe x1
IQM-233 Cards/Computer	One card with IQM-233 Standard software. Two cards maximum with IQS-233 Codeposition software. Six cards maximum with customer-designed software using included Windows DLL.
Power Consumption	<2 W per card

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1.4.5 Operating Environment

Usage . . . . . Indoor only

Temperature . . . . . 0 to 50°C (32 to 122°F)

Humidity . . . . . 0 to 80% RH @ 31°C, non-condensing

Altitude . . . . . 0 to 2000 m (0 to 6561 ft.)

Pollution Degree. . . . . 1 per EN 61010-1

1.4.6 Storage Temperature

Storage Temperature . . . . . –10 to 60°C (14 to 140°F)

1.4.7 Warm Up Period

Warm Up Period. . . . . For maximum stability allow five minutes.

1.4.8 Size

1.4.8.1 IQM-233 Card (without bracket) H x L

6.9 x 18.0 cm (2.7 x 7.1 in.)

1.4.8.2 IQM-233 Card (standard) H x L x W

12.2 x 18.0 x 2.3 cm (4.8 x 7.1 x 0.9 in.)

1.4.8.3 IQM-233 Card (Small Form Factor) H x L x W

8.1 x 18.0 x 2.3 cm (3.2 x 7.1 x 0.9 in.)

1.4.9 Connector Clearances

SMA cable installation/removal . . . . 7.6 cm (3.0 in.) from IQM-233 card bracket

D-sub cable installation/removal . . . 7.6 cm (3.0 in.) from IQM-233 card bracket

1.4.10 Weight

782-IQM-233-G1 Kit. . . . . 0.18 kg (0.40 lb.)

782-IQM-233-G2 Kit. . . . . 0.16 kg (0.35 lb.)

IQM-233 Card (standard). . . . . 0.10 kg (0.22 lb.)

IQM-233 Card (small form factor) . . 0.08 kg (0.18 lb.)

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1.5 Unpacking and Inspection

CAUTION - Static Sensitive Device

Observe proper ESD procedures when handling the IQM-233 card.

1. If the IQM-233 card has not been removed from its packaging, do so now. Do not discard the packing materials until you have read this section and successfully completed the installation of the IQM-233 card and software as described by Chapter 2, Installation and Interfaces.
2. Carefully examine the IQM-233 card for damage that may have occurred during shipping. This is especially important if you notice obvious rough handling on the outside of the container. *Immediately report any damage to the carrier and to INFICON.* Refer to section 1.3 on page 1-5.
3. Take an inventory of your order by referring to the order invoice and the information contained in section 1.6.

   For additional information or technical assistance, contact INFICON. Refer to section 1.3 on page 1-5.

   To install the IQM-233 card and software, see Chapter 2, Installation and Interfaces.

1.6 Configurations and Accessories

1.6.1 IQM-233 Card Configurations

- IQM-233 Card (standard) PN 782-IQM-233-G1

  or

- IQM-233 Card (small form factor) PN 782-IQM-233-G2

Both IQM-233 configurations include:

- Thin Film Manuals CD containing IQM-233 Standard software, Windows DLL, IQM-233 VI sample, IQM-233 Operating Manual, and sensor operating manuals.
- SMA/BNC Adapter Cable, PN 600-1441-P1. One adapter cable is included with each IQM-233 card.
- 15-pin male high-density D-sub connector and housing.

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1.6.2 Accessories

1.6.2.1 Software (Optional)

IQS-233 Codeposition Software . . . . . PN 782-IQS-233

1.6.2.2 Cables and Oscillator Kits

SMA/BNC Adapter Cable . . . . . PN 600-1441-P1

Oscillator Kit (3.0 m (10 ft.) cable) . . . . . PN 782-934-003-10

Oscillator Kit (7.6 m (25 ft.) cable) . . . . . PN 782-934-003-25

Oscillator Kit (15.2 m (50 ft.) cable) . . . . . PN 782-934-003-50

Oscillator Kit (30.5 m (100 ft.) cable) . . . . . PN 782-934-003-99

NOTE: One oscillator kit and one SMA/BNC adapter cable are required for each crystal sensor that will be connected to the IQM-233 card.

1.6.2.3 Crystal Sensors

NOTE: "X" represents feature selections. Contact INFICON for assistance.

Front Load Single Sensor . . . . . PN SL-XXXXX

Front Load Dual Sensor . . . . . PN DL-AXXX

Front Load UHV Bakeable Sensor . . . . . PN BK-AXF

Cool Drawer Single Sensor . . . . . PN CDS-XXFXX

Cool Drawer Dual Sensor . . . . . PN CDD-XFXX

Sputtering Sensor . . . . . PN 750-618-G1

NOTE: Shuttered sensors require a solenoid valve (PN 750-420-G1), a PLC, and optional IQS-233 Codeposition software for shutter control. See section 2.1.2.5, Digital I/O Connections, on page 2-18.

NOTE: CrystalSix, Crystal12, and RSH-600 rotary sensors are not compatible with the IQM-233 card.

NOTE: The CrystalTwo switch is not compatible with the IQM-233 card.

CAUTION

For proper performance of the IQM-233 card, the crystal sensor in-vacuum cable (Front Load and Sputtering sensors) or electrical conduit tube (Cool Drawer and Bakeable sensors) should not exceed 78.1 cm (30.75 in.).

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Chapter 2
Installation and Interfaces

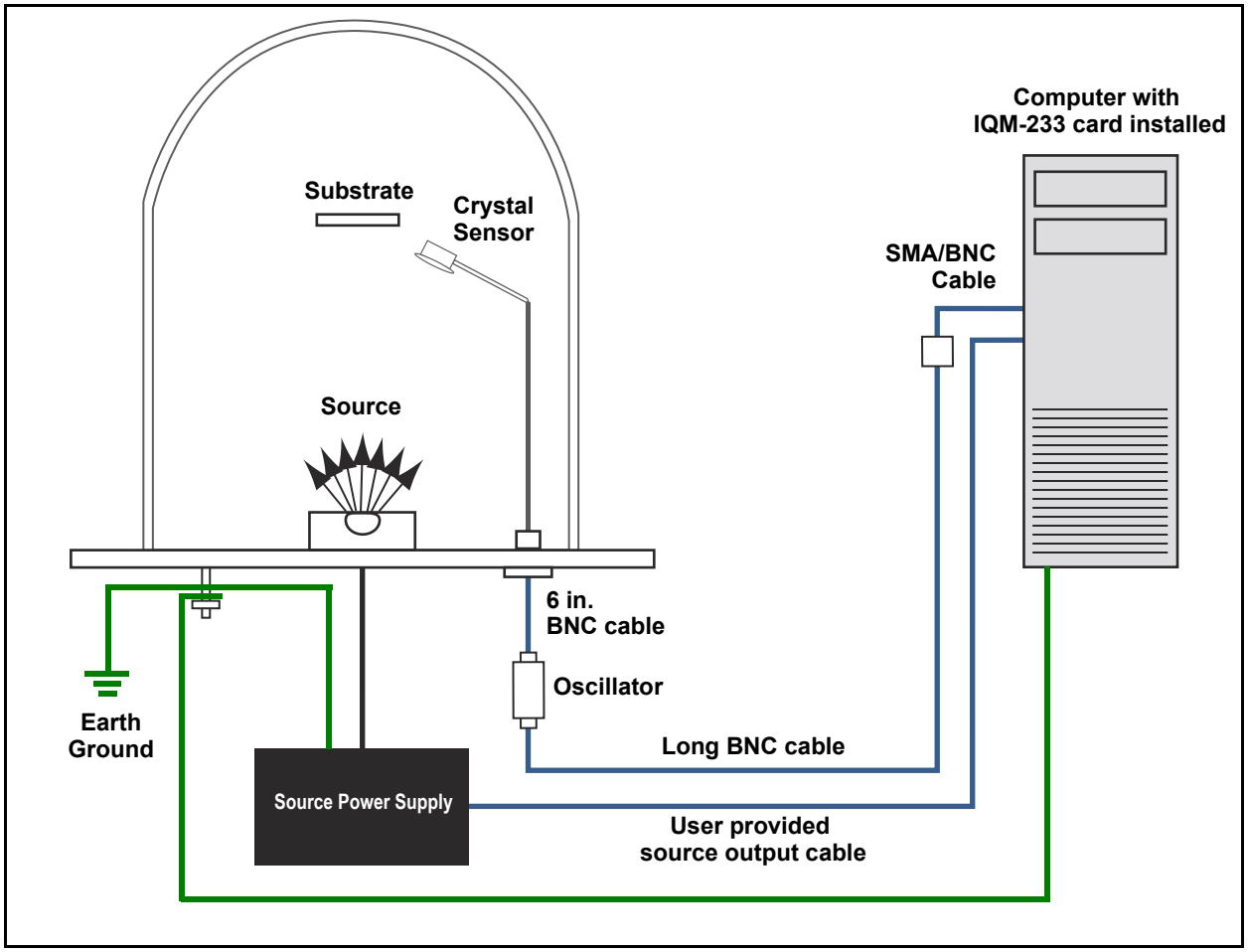
2.1 Installation

Figure 2-1 shows a typical IQM-233 card system installation.

Refer to the sensor's operating manual for sensor installation instructions.

To install the IQM-233 card, Dynamic Link Library (DLL), device driver, and IQM-233 Standard software, read the installation requirements in section 2.1.1, and then perform the installation procedure, starting at section 2.1.2 on page 2-5.

Figure 2-1 Typical system installation



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2.1.1 Installation Requirements

2.1.1.1 Computer Requirements

The computer must meet or exceed the specifications shown in section 1.4.3, Computer Requirements, on page 1-7.

Each IQM-233 card requires one empty PCI Express slot of any size.

2.1.1.2 Software Requirements

One IQM-233 card requires:

- IQM-233 Standard software, or
- optional IQS-233 Codeposition software, or
- customer-designed software using the included Windows DLL

Two IQM-233 cards in same computer require:

- IQS-233 Codeposition software, or
- customer-designed software using the included Windows DLL

Three to six IQM-233 cards in same computer require customer-designed software using the included Windows DLL.

2.1.1.3 Installation Precautions

CAUTION - Static Sensitive Device

Observe proper ESD procedures when handling the IQM-233 card.

CAUTION

Refer to the computer's operating manual for instructions regarding the installation of peripheral cards.

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2.1.1.4 Parts Requirements

- IQM-233 card(s).
- One to three crystal sensor(s) for each IQM-233 card. See section 1.6.2.3, Crystal Sensors, on page 1-10.
- Up to one user-provided source output cable for each IQM-233 card. A source output cable is not required if the card will be used only as a monitor. See section 2.1.2.3, Source Output Cable and Connection, on page 2-13.
- One SMA/BNC adapter cable for each crystal sensor.
- One oscillator kit for each crystal sensor. See section 1.6.2.2, Cables and Oscillator Kits, on page 1-10.
- IQM-233 Standard software (located on the Thin Film Manuals CD), or the optional IQS-233 Codeposition software.

CAUTION

For proper performance of the IQM-233 card, the crystal sensor in-vacuum cable (Front Load and Sputtering sensors) or electrical conduit tube (Cool Drawer and Bakeable sensors) should not exceed 78.1 cm (30.75 in.). Use only the short BNC cable (15.2 cm (6 in.)) included in the oscillator kit to connect the oscillator to the crystal sensor.

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2.1.1.5 Ground Requirements

Low impedance cables or straps must be used to connect the chassis of all control components to a common ground point on the vacuum chamber. The common ground point must be connected to earth ground. See section 2.1.1.5.1 on page 2-5 for the earth ground requirement.

Solid copper straps at least 12.7 mm (0.5 in.) wide and approximately 0.56 mm (0.022 in.) thick (as short as possible) are recommended where RF is present. This is particularly important in high-noise e-beam systems.

See Figure 2-2 for the recommended grounding method.

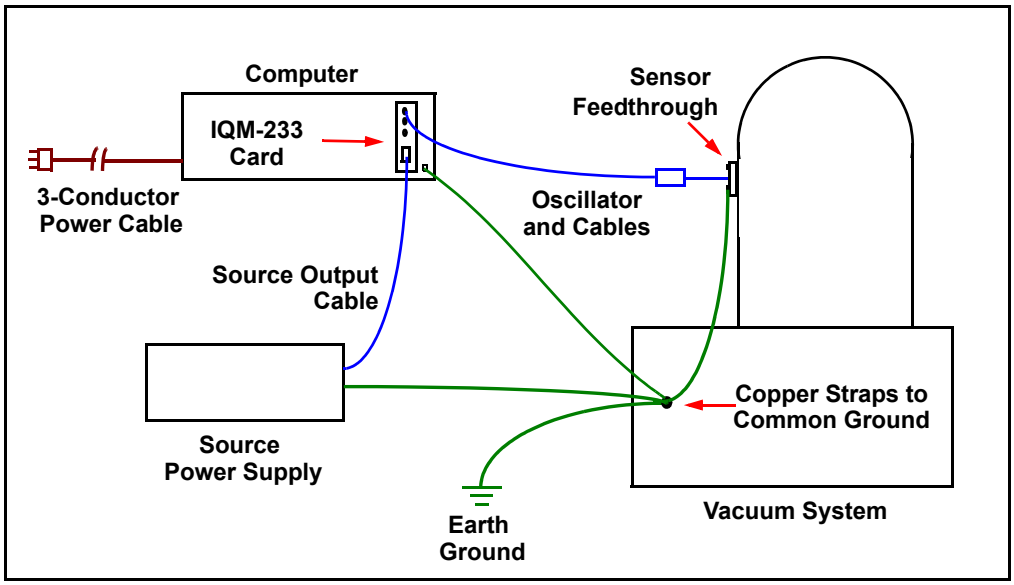
- The oscillator is grounded to the IQM-233 card and crystal sensor through the BNC cables and SMA/BNC adapter.
- The crystal sensor is typically grounded to the wall of the vacuum system. If the sensor feedthrough is not properly grounded to earth through the vacuum system, connect a copper strap between the feedthrough and the common ground point on the vacuum system.

WARNING - Risk Of Electric Shock

The computer in which the IQM-233 card is installed must be connected to earth ground through a sealed three-conductor power cable plugged into a socket outlet with a protective ground terminal. The computer must also be connected to the common ground point, shown in Figure 2-2.

Extension cables must have three conductors including a protective earth ground.

Figure 2-2 System grounding diagram



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2.1.1.5.1 Earth Ground

WARNING - Risk Of Electric Shock

It is imperative to follow local electrical regulations and codes.

If an earth ground is not established, the following grounding method is a recommendation; however, it is imperative to follow local electrical regulations and codes.

1. Install two 3.0 m (10.0 ft.) long copper-clad steel ground rods into the soil, spaced at least 1.9 m (6.2 ft.) apart. Ideally, the distance between the rods should be at least twice the rod length.
2. Pour a solution of magnesium sulfate or copper sulfate around each rod to reduce the resistance to earth ground.
3. Test the ground rods using a Ground Resistance Tester specifically designed for that purpose (a common ohmmeter is not recommended).
4. After verifying that a good earth ground has been achieved, connect the rods together using #6 AWG copper wire.

2.1.2 Installation Procedure

1. Install the DLL, device driver, and WinDriver. See section 3.2.1, DLL Installation, on page 3-1.
2. Install the IQM-233 Standard software. See section 3.2.2, IQM-233 Standard Software Installation, on page 3-5.
3. Start the IQM-233 Standard software.

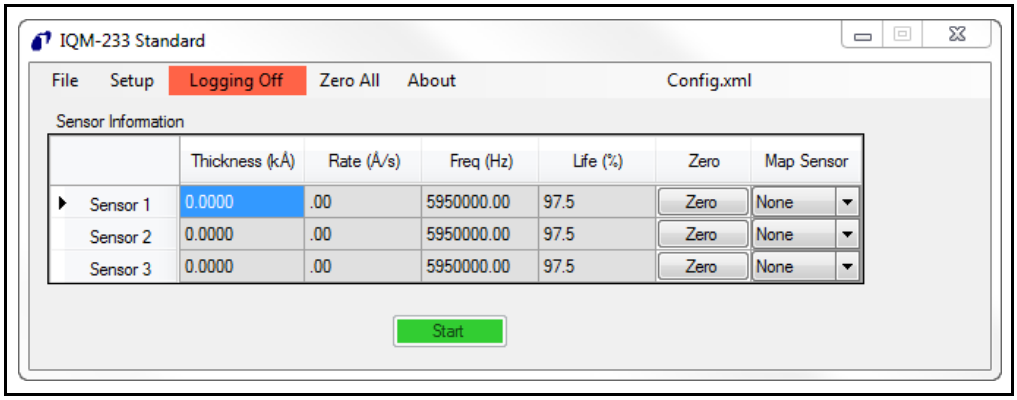
3a. Windows 7 users: Click **Start >> All Programs >> INFICON >> IQM-233 Standard**.

3b. Windows 8 users: In the **Start** window, click the **IQM-233 Standard** icon.

HINT: If the IQM-233 Standard icon is not visible, click **Search >> Apps**, and then type **IQM-233** in the **Search** box to locate the icon.

4. The **IQM-233 Standard** window will display. See Figure 2-3.

Figure 2-3 IQM-233 Standard window



2.1.2.1 IQM-233 Card Installation

WARNING - Risk Of Electric Shock

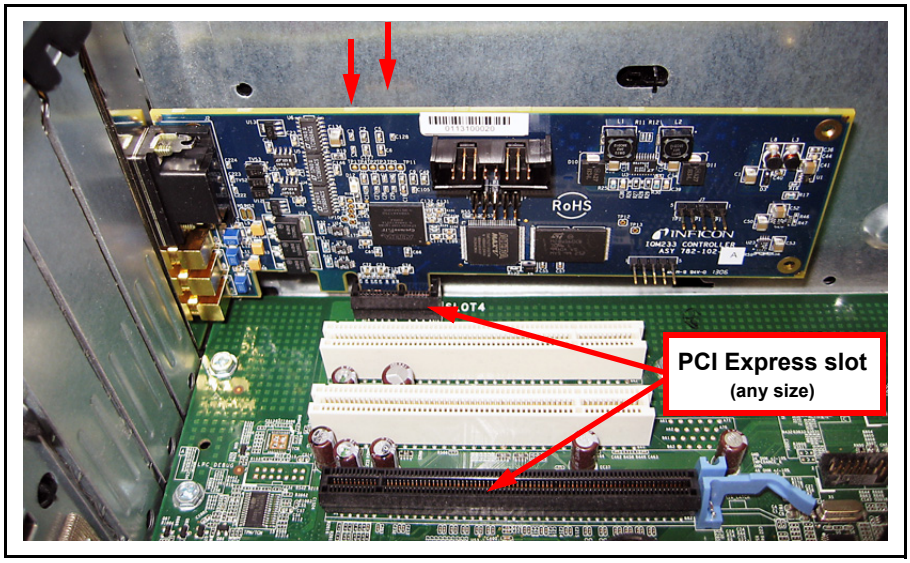
Turn off the computer and disconnect the power cord before continuing.

CAUTION - Static Sensitive Device

Follow proper ESD precautions.

1. Remove the computer's cover.
2. Remove the blank panel from the computer's rear panel adjacent to any empty PCI Express slot.
3. Align the IQM-233 card's gold-plated edge connector with the PCI Express slot while aligning the IQM-233 card's bracket with the opening in the computer's rear panel. See Figure 2-4.
4. Push down on the top of the IQM-233 card until the edge connector is fully inserted into the PCI Express slot.

Figure 2-4 IQM-233 card in PCI Express slot



5. Secure the IQM-233 card's bracket to the computer's rear panel.
6. Repeat steps 2 through 5 if additional IQM-233 cards are being installed.
7. Replace the computer's cover.
8. Connect the power cord and turn on the computer.
9. Start the IQM-233 Standard software.

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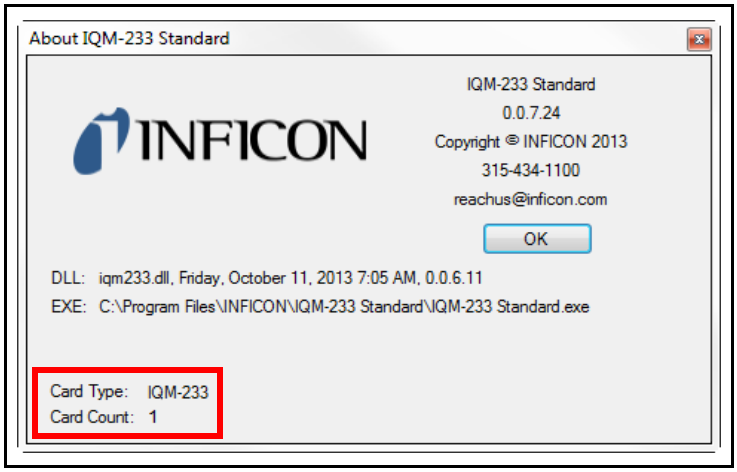
10 On the menu bar, click **Help >> About**.

11 In the **About IQM-233 Standard** window, verify that **Card Type** is **IQM-233** and **Card Count** is **1** for one installed card (see Figure 2-5). If the **Card Type** is **None** or the **Card Count** is **0**, see section 2.1.2.1.1.

NOTE: IQM-233 Standard software supports one IQM-233 or SQM-242 card; however, the Card Count will display the quantity of installed IQM-233 or SQM-242 cards (up to six cards of one type). If both IQM-233 and SQM-242 cards are installed, Card Count will display only the quantity of IQM-233 cards.

Figure 2-5 About IQM-233 Standard window

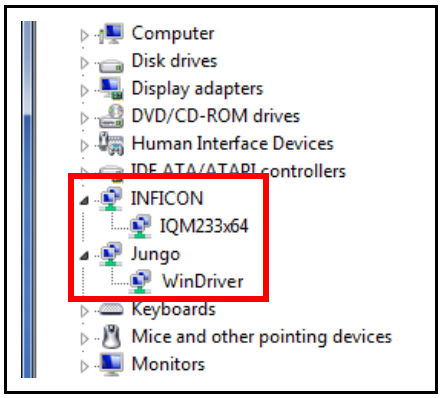


2.1.2.1.1 IQM-233 Card Installation Troubleshooting

If the IQM-233 card is not detected by the software (the **Card Type** is **None** or the **Card Count** is **0**):

- Make sure all installed cards are fully seated in their slots.
- Make sure the IQM-233 device driver and WinDriver™ are properly installed. In **Windows Device Manager**, click ▷ next to **INFICON** and **Jungo**, and verify that both drivers are present and no errors are displayed. See Figure 2-6.

Figure 2-6 Device manager - IQM233 device driver and WinDriver



- If the IQM-233 device driver and/or WinDriver are missing, install the DLL again. See section 3.2.1, DLL Installation, on page 3-1.
- If "!" or "X" is displayed next to IQM-233 device driver or WinDriver:

1. Right-click **IQM233x64** or **IQM233x86** and click **Uninstall** to remove the device driver.
2. Right-click **WinDriver** and click **Uninstall** to remove WinDriver.
3. Install the DLL again. See section 3.2.1, DLL Installation, on page 3-1.

If the problem cannot be resolved, contact INFICON. Refer to section 1.3, How To Contact INFICON, on page 1-5.

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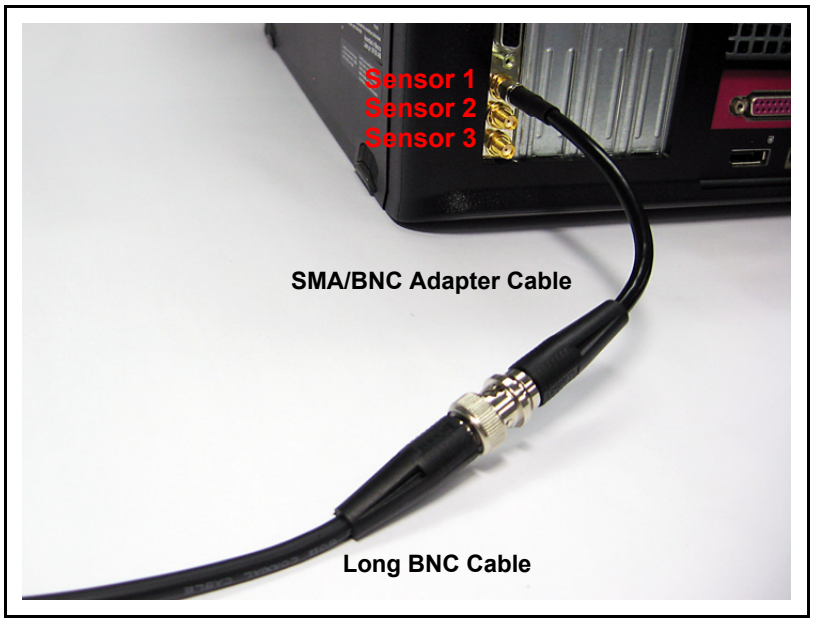
2.1.2.2 Sensor Connections

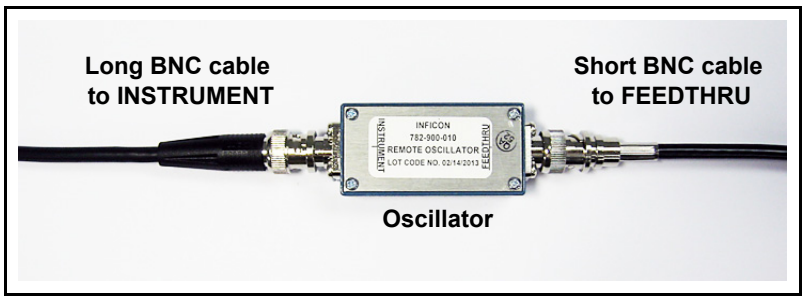
1. Connect the SMA/BNC adapter cable to the desired SMA connector on the IQM-233 card. See Figure 2-7.
2. Connect one end of the SMA/BNC adapter cable to the long BNC cable.

Figure 2-7 SMA/BNC adapter cable and long BNC cable



3. Connect the other end of the long BNC cable to the oscillator's **INSTRUMENT** BNC connector. See Figure 2-8.
4. Connect one end of the short BNC cable to the oscillator's **FEEDTHRU** BNC connector.

Figure 2-8 Cable connections to oscillator



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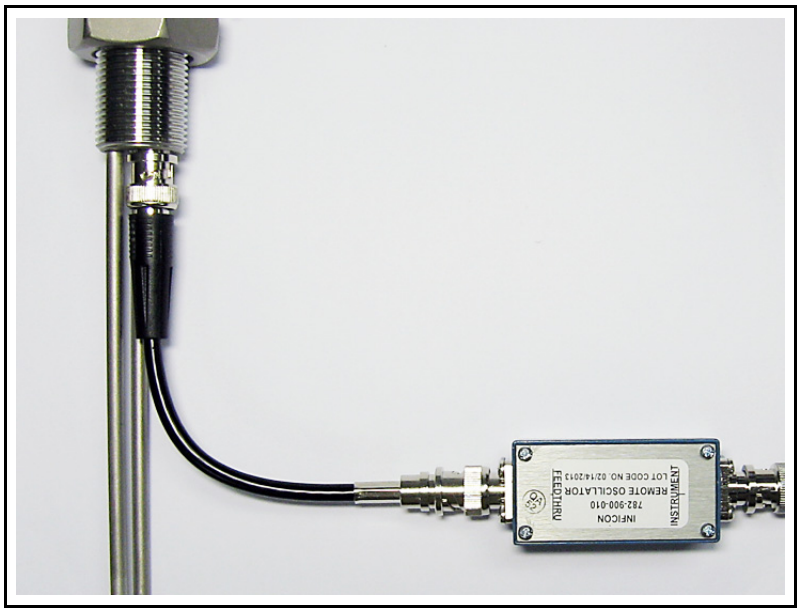
5 Connect the other end of the short BNC cable to the feedthrough of the crystal sensor. See Figure 2-9.

6 Install a new 5 MHz or 6 MHz crystal into the sensor.

NOTE: Refer to the sensor's operating manual for crystal installation instructions.

Figure 2-9 Oscillator connection to sensor feedthrough



CAUTION

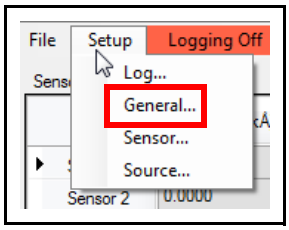
For proper performance of the IQM-233 card, the crystal sensor in-vacuum cable (Front Load and Sputtering sensors) or electrical conduit tube (Cool Drawer and Bakeable sensors) should not exceed 78.1 cm (30.75 in.). Use only the short BNC cable (15.2 cm (6 in.)) included in the oscillator kit to connect the oscillator to the crystal sensor.

7 Repeat steps **1** through **6** for any additional sensors to be connected to the IQM-233 card.

8 Start the IQM-233 Standard software.

9 In the IQM-233 Standard window, on the menu bar, click **Setup >> General**. See Figure 2-10.

Figure 2-10 Setup list



10 The **Setup** window displays. See Figure 2-11.

11 In the **Maximum Crystal Freq**, **Initial Crystal Freq**, and **Minimum Crystal Freq** boxes, select frequency values appropriate for a 5 MHz or 6 MHz crystal. See Table 2-1.

12 Make sure the **Enable Simulate** check box is clear.

13 Click **OK** to save the configuration.

Figure 2-11 Setup window

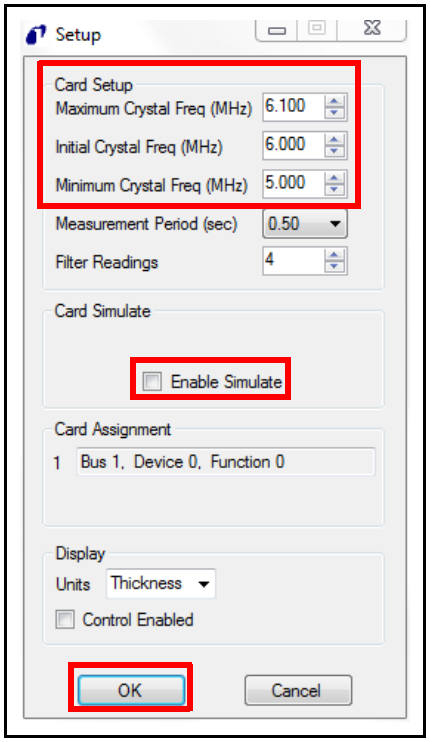


Table 2-1 Typical frequency settings

New Crystal Starting Frequency	Maximum Crystal Frequency	Initial Crystal Frequency	Minimum Crystal Frequency
5 MHz	5.100	5.000	4.000
6 MHz	6.100	6.000	5.000
5.5 MHz Test Crystal (included in oscillator kit)	6.100	6.000	5.000

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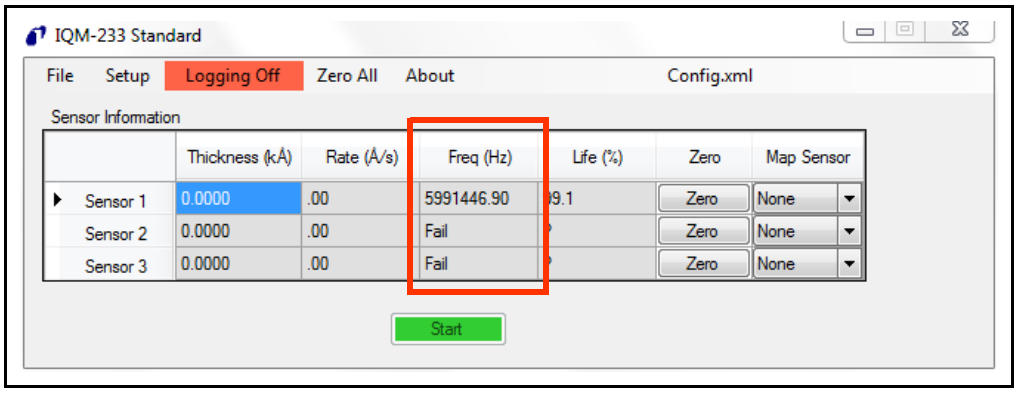
14 In the IQM-233 Standard window, verify that **Freq (Hz)** is approximately the starting frequency of the new crystal for all connected sensors (see Figure 2-12). If the Freq (Hz) reading is incorrect or Fail is displayed for a connected sensor, see section 2.1.2.2.1.

NOTE: Sensors do not need to be under vacuum for frequency verification.

NOTE: The **Freq** readout for Sensor channels not connected to a sensor should display **Fail**.

Figure 2-12 Freq (Hz) readout



2.1.2.2.1 Sensor Connection Troubleshooting

Perform the following steps if the reported frequency is not correct or if **Fail** is displayed for a Sensor channel connected to a sensor.

1 In the **Setup** window (refer to Figure 2-11), type or select values for **Maximum Crystal Freq**, **Initial Crystal Freq**, and **Minimum Crystal Freq** appropriate for a 5.5 MHz test crystal (refer to Table 2-1).

2 Click **OK** to save the configuration.

3 Disconnect the short BNC cable from the sensor feedthrough.

4 Connect the 5.5 MHz Test Crystal to the short BNC cable. See Figure 2-13.

- If the **Freq (Hz)** reading for the test crystal is close to 5.5 MHz, the sensor, feedthrough, or the sensor's crystal is the cause of the incorrect or failed reading. Refer to the sensor's operating manual for troubleshooting information.
- If the **Freq (Hz)** reading for the test crystal is not close to 5.5 MHz or the reading displays **Fail**, contact INFICON. Refer to section 1.3, How To Contact INFICON, on page 1-5.

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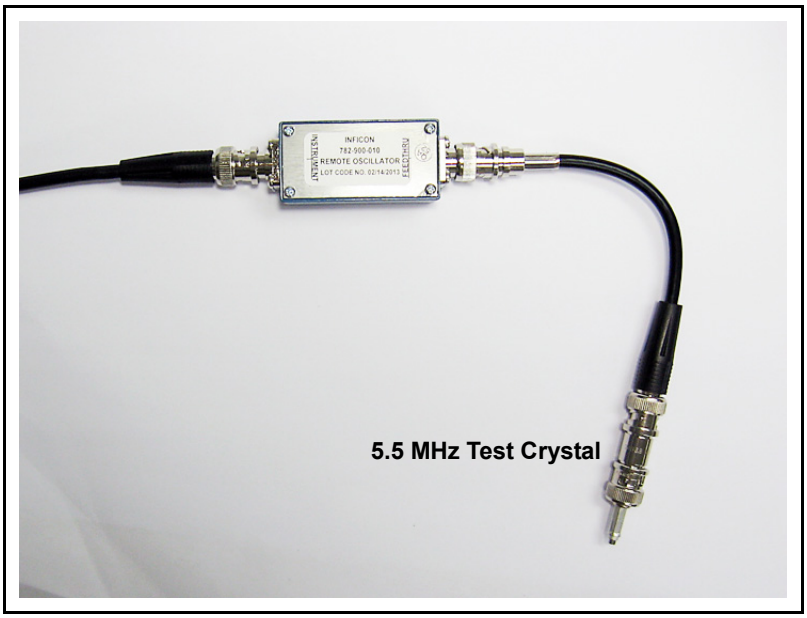
Figure 2-13 5.5 MHz test crystal



2.1.2.3 Source Output Cable and Connection

NOTE: Source output connections are not required if the IQM-233 card is used only as a monitor. In this case, the IQM-233 card installation is complete and the following procedure is not required.

1 Construct a source output cable for one, two, or three source output channels.

NOTE: The source output cable is user provided.

- A 15-pin male high-density D-sub connector is provided with the IQM-233 card, to be used for the source output cable connection to the IQM-233 card. See Table 2-2 and Figure 2-14 for the source output pin assignments.
- The connector type used for the other end of the cable depends upon the requirements of the source power supply or other equipment.

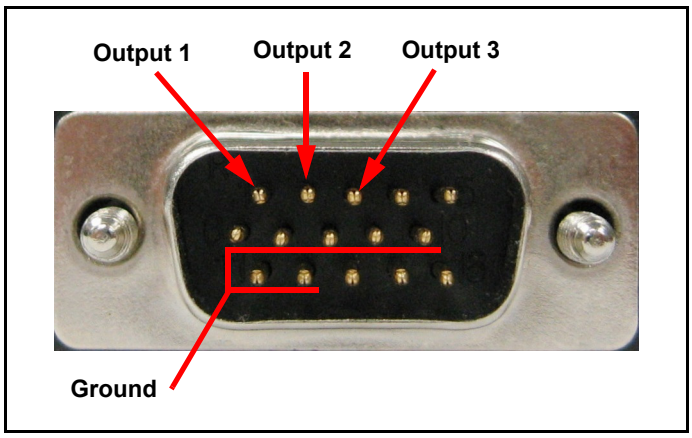
Table 2-2 Source output pin assignments

High-Density D-sub	Function
Pin 1	Output 1
Pin 2	Output 2
Pin 3	Output 3
Pin 4	Not Used
Pin 5	Not Used
Pin 6	Ground
Pin 7	Ground

Table 2-2 Source output pin assignments (continued)

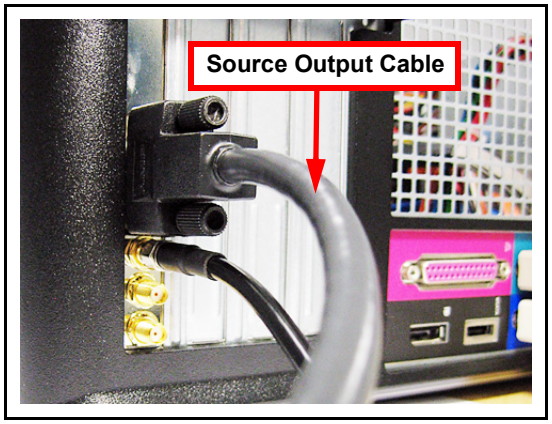
High-Density D-sub	Function
Pin 8	Ground
Pin 9	Ground
Pin 10	Ground
Pin 11	Ground
Pin 12	Ground
Pin 13	Not Used
Pin 14	Not Used
Pin 15	Not Used

Figure 2-14 Source output cable - 15-pin high-density male D-sub connector



2 Connect the D-sub connector end of the source output cable to the IQM-233 card. See Figure 2-15.

Figure 2-15 Source output cable



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3 Connect the other end of the cable to the source power supply or other equipment.

CAUTION

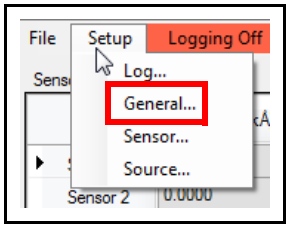
Care must be taken in connecting the IQM-233 card source outputs to the source power supply or other equipment. Failure to follow the equipment manufacturer's instructions can result in damage to the equipment and/or the IQM-233 card.

2.1.2.4 Source Output Configuration and Verification

NOTE: The following steps are not required if the IQM-233 card is used only as a monitor.

1 In the IQM-233 Standard window, click **Setup >> General**. See Figure 2-16.

Figure 2-16 Setup list



2 The **Setup** window is displayed. See Figure 2-17.

3 Select the **Control Enabled** check box.

4 Click **OK** to display the **IQM-233 Standard** window with **Sensor Information** and **Source Information** panes. See Figure 2-18.

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Figure 2-17 Setup - Control Enabled selected

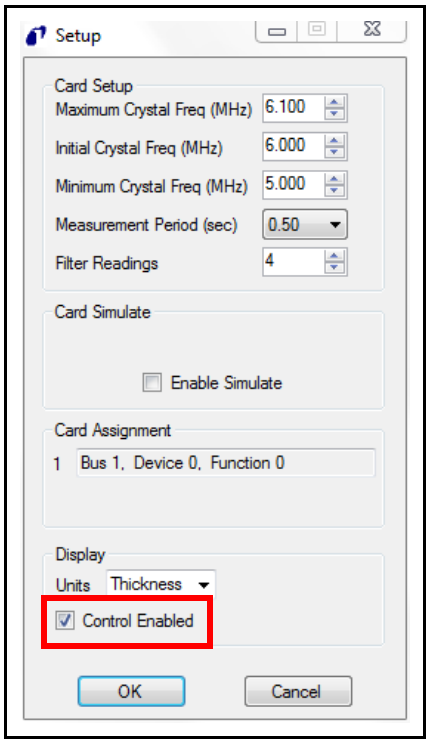
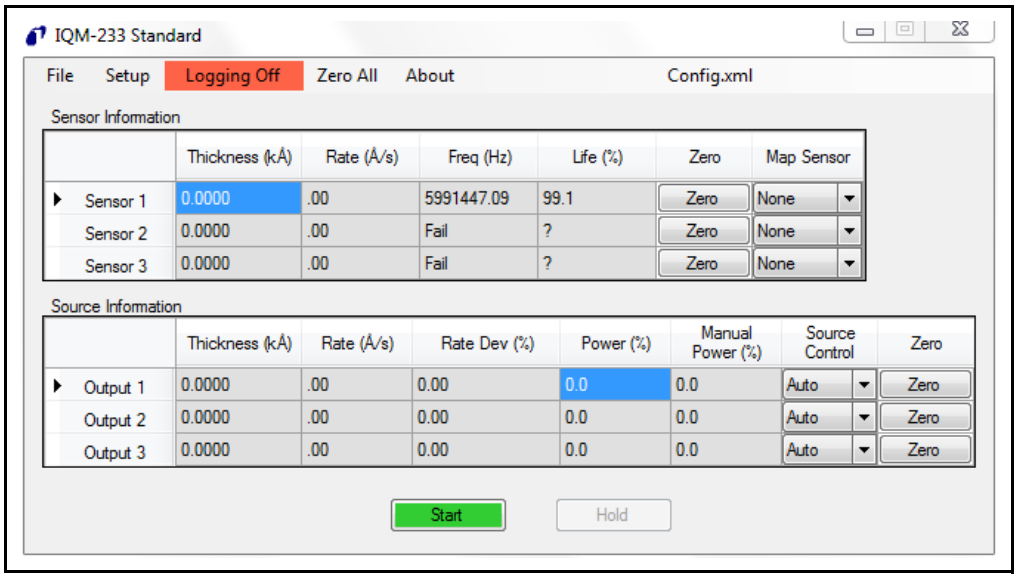


Figure 2-18 IQM-233 Standard window - Sensor Information and Source Information



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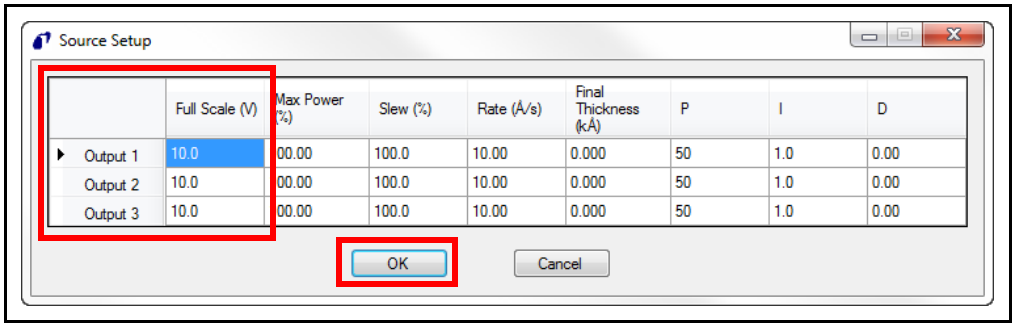
5 On the menu bar, click **Setup >> Source**.

6 The **Source Setup** window displays. See Figure 2-19.

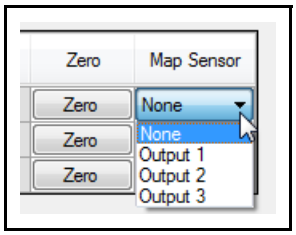
Figure 2-19 Source Setup window



7 For each source output connected to a source power supply, enter a value in the **Full Scale (V)** box(es) equal to the maximum input voltage allowed for the source power supply. Click **OK** to save the configuration. For detailed information, see section 3.3.3.1.4, Source, on page 3-14.

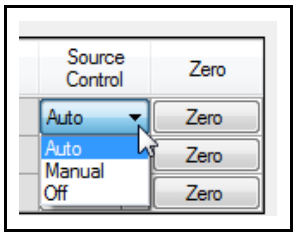
8 In the **Sensor Information** pane of the IQM-233 Standard window, select a connected **Output** from the **Map Sensor** list (see Figure 2-20). For detailed information, see section 3.3.3.2, Map Sensor, on page 3-15.

Figure 2-20 Map Sensor list



9 In the **Source Information** pane, select **Manual** from the **Source Control** list (refer to Figure 2-18). For detailed information, see section 3.3.4.4, Source Control Operating Functions, on page 3-23.

Figure 2-21 Source Control list



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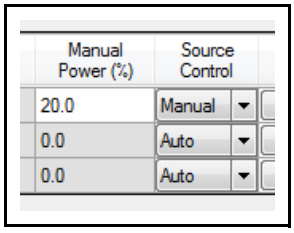
10 In the **Source Information** pane, adjust the value of **Manual Power (%)** for the connected output, and then check for an appropriate response from the source power supply (see Figure 2-22). For detailed information, see section 3.3.4.4, Source Control Operating Functions, on page 3-23.

11 Repeat steps 8, 9, and 10 for any additional source output channels connected to source power supplies.

Figure 2-22 Source Control - Manual



2.1.2.5 Digital I/O Connections

The IQM-233 card does not have the digital inputs and outputs needed for automatic control of source and sensor shutters, rotation of source pockets, etc. A Programmable Logic Controller (PLC) together with the optional IQS-233 Codeposition software can add this capability. The PLC is not available from INFICON. Refer to the IQS-233 Codeposition Software Operating Manual for information about interfacing a PLC with IQS-233 Codeposition software.

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Chapter 3
IQM-233 Standard Software

3.1 Introduction

IQM-233 Standard software is used to monitor or control a simple process using a single IQM-233 card or SQM-242 card.

Features include:

- Single layer or codeposition control of up to three materials.
- Output parameters for controlling source power supplies.
- Saving of setup parameters and deposition data.
- Simulation of deposition for developing and testing a deposition process.

3.2 How To Install IQM-233 Standard Software

3.2.1 DLL Installation

The Dynamic Link Library (DLL), device driver for the IQM-233 or SQM-242 card, and WinDriver are installed by the **IQM233 DLL** or the **SQM242 with IQM DLL** setup file. To install the DLL, device driver, and WinDriver:

NOTE: **IQM233 DLL** and **SQM242 with IQM DLL** cannot be installed together on the same computer.

NOTE: If IQM-233 and SQM-242 cards are installed together in the same computer, IQM-233 Standard software will detect only one IQM-233 card and ignore the SQM-242 card(s). The IQM-233 card(s) must be removed to use IQM-233 Standard software with an SQM-242 card.

1. If the operating system is Windows 7 or 8, click **Start >> Control Panel >> System**. Note the operating system size (32-bit or 64-bit) displayed under **System type**.

   If the operating system is Windows XP, click **Start >> Settings >> Control Panel >> System >> System Properties >> General tab**. Determine the operating system size from the operating system name displayed under **System**:

   - Windows XP Home, Windows XP Media Center Edition, and Windows XP Professional are 32-bit.
   - Windows XP Professional x64 Edition is 64-bit.

2. Insert the Thin Film Manuals CD into the computer's CD drive.

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3. Click **Windows Explorer or File Explorer >> Computer >> (CD drive letter:) INFICON Technical Documentation**.
   - If an IQM-233 card will be used with the IQM-233 Standard software, click **IQM-233 Card >> IQM-233 Drivers**.
   - If an SQM-242 card will be used with the IQM-233 Standard software, click **SQM-242 Card >> Current Software and Installation >> SQM-242 Drivers**.
4. Start the DLL installation:

   NOTE: If an error message prevents the DLL installation from being completed, see section 3.2.1.1 on page 3-3.

   - For an IQM-233 card and a 32-bit operating system, double-click **IQM233 DLL x86 vx.x.x.x Setup.exe**
   - For an IQM-233 card and a 64-bit operating system, double-click **IQM233 DLL x64 vx.x.x.x Setup.exe**
   - For an SQM-242 card and a 32-bit operating system, double-click **SQM242 with IQM DLL x86 vx.x.x.x Setup.exe**
   - For an SQM-242 card and 64-bit operating system, double-click **SQM242 with IQM DLL x64 vx.x.x.x Setup.exe**
5. The **InstallShield Wizard** window will display.
6. Click **Next**.
7. Click **I accept the terms in the license agreement**.
8. Click **Next**.
9. Type information into the **User Name** and **Organization** boxes.
10. Click **Next**.
11. Click **Install** to start the installation of the device driver for the IQM-233 or SQM-242 card and the DLL required by the IQM-233 Standard software.
12. When **Install Wizard Completed** is displayed, click **Finish** to close the InstallShield Wizard.

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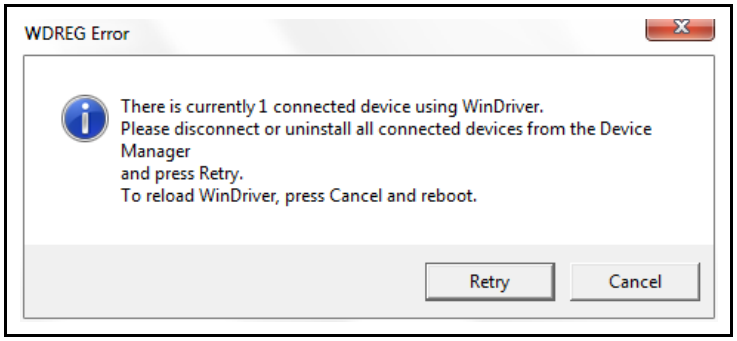
3.2.1.1 DLL Installation Troubleshooting

If the **WDREG Error** window displays (see Figure 3-1), an existing version of WinDriver is preventing the installation of the DLL.

Figure 3-1 WDREG Error



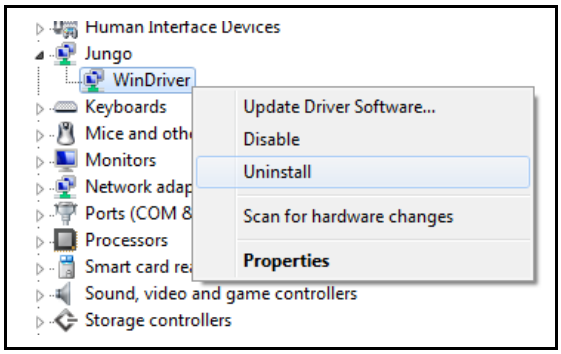
To remove the existing WinDriver and install the required WinDriver:

1. In **Windows Device Manager**, click ▷ next to **Jungo** to display **WinDriver**. See Figure 3-2.

Figure 3-2 Jungo and WinDriver

2. Right-click **WinDriver** and click **Uninstall**. See Figure 3-3.

Figure 3-3 Uninstall WinDriver



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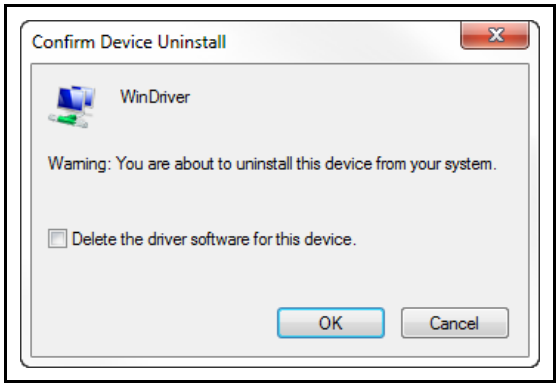
3 When the Confirm Device Uninstall window appears, click **OK** to uninstall WinDriver. See Figure 3-4.

Figure 3-4 Confirm Device Uninstall

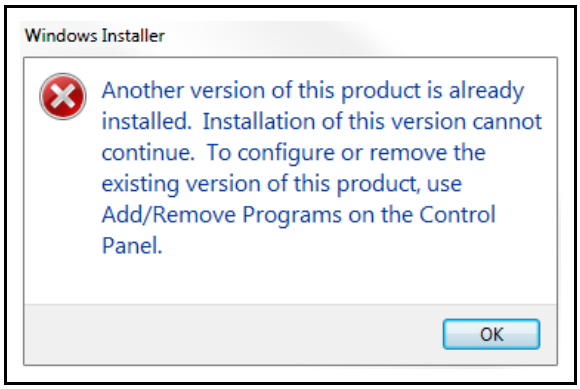


4 In the WDREG Error window, click **Retry** to continue with the DLL installation. Refer to Figure 3-1.

If the **Windows Installer** error message is displayed (see Figure 3-5), another DLL (**IQM233 DLL** or **SQM242 with IQM DLL**) is already installed.

NOTE: IQM233 DLL and **SQM242 with IQM DLL** cannot be installed together on the same computer.

Figure 3-5 Windows Installer Installation Error



- Click **OK** to keep the previously installed DLL.

  or

- To remove the previously installed DLL and install a different DLL:

  1 Click **OK** to close the Windows Installer window.

  2 Click **Control Panel >> Programs** to display a list of installed programs.

  3 Select the **IQM233 DLL** or the **SQM242 with IQM DLL** from the list.

  4 Click **Uninstall** to remove the selected DLL.

  5 Install the DLL again. Refer to section 3.2.1, DLL Installation, on page 3-1.

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3.2.2 IQM-233 Standard Software Installation

To update an existing installation of IQM-233 Standard software to a newer version, see section 3.2.3.

1. Click **Windows Explorer or File Explorer >> Computer >> (CD drive letter:) INFICON Technical Documentation >> IQM-233 Card >> IQM-233 Software**.
2. Double-click **IQM-233 Standard vx.x.x.x Setup.exe**.
3. The **InstallShield Wizard** will display.
4. Click **Next**.
5. Click **I accept the terms in the license agreement**.
6. Click **Next**.
7. Type information into the **User Name** and **Organization** boxes.
8. Click **Next**.
9. Click **Install** to start the software installation.
10. When **Install Wizard Completed** is displayed, click **Finish** to close the **InstallShield Wizard** window.

3.2.3 IQM-233 Standard Software Update

To update an existing installation of IQM-233 Standard software to a newer version:

1. Click **Control Panel >> Programs** to display a list of installed programs.
2. If the IQM-233 Standard software was used with an IQM-233 card, select **IQM233 DLL x86** or **IQM233 DLL x64** from the list.

   If the IQM-233 Standard software was used with an SQM-242 card, select **SQM242 with IQM DLL x86** or **SQM242 with IQM DLL x64** from the list.
3. Click **Uninstall** to remove the DLL.
4. Select **IQM-233 Standard** from the list.
5. Click **Uninstall** to remove the IQM-233 Standard software.
6. Install the latest version of DLL. Refer to section 3.2.1.
7. Install the latest version of IQM-233 Standard software. Refer to section 3.2.2.

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3.3 How To Use IQM-233 Standard Software

3.3.1 Starting the Software

3.3.1.1 Starting the Software in Windows XP or Windows 7

Click **Start >> All Programs >> INFICON >> IQM-233 Standard**.

- If this is the first time the software has been started, the **IQM-233 Standard** window with **Sensor Information** pane is displayed. See Figure 3-6.
- If the software has previously been configured to allow source control by selecting the **Control Enabled** check box in the **Setup** window, the **IQM-233 Standard** window with **Sensor Information** pane and **Source Information** pane is displayed. See Figure 3-7.

3.3.1.2 Starting the Software in Windows 8

1 In the **Start** window, click the **IQM-233 Standard** icon.

2 If the icon cannot be found:

2a Click **Search >> Apps**.

2b Type **IQM-233** in the **Search** text box.

2c Click the **IQM-233 Standard** icon.

- If this is the first time the software has been started, the **IQM-233 Standard** window with **Sensor Information** pane will display. See Figure 3-6.
- If the software has previously been configured to allow source control by selecting the **Control Enabled** check box in the **Setup** window, the **IQM-233 Standard** window with **Sensor Information** and **Source Information** panes will display. See Figure 3-7.

Figure 3-6 IQM-233 Standard window - Sensor Information pane

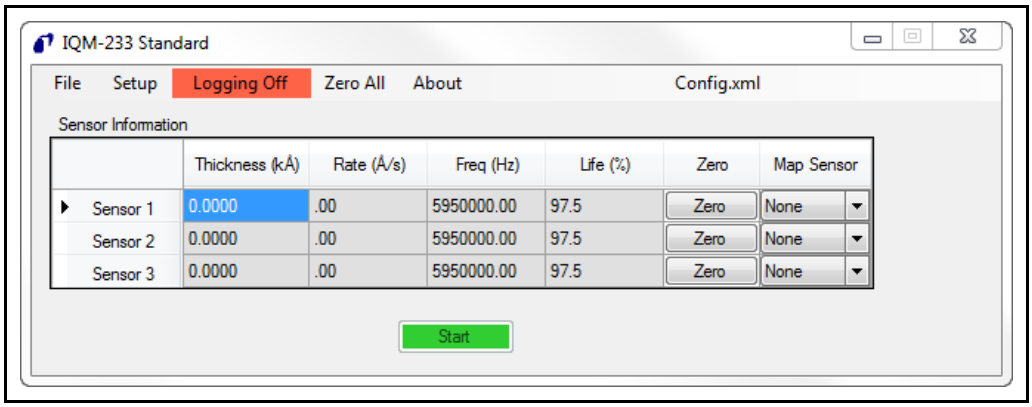

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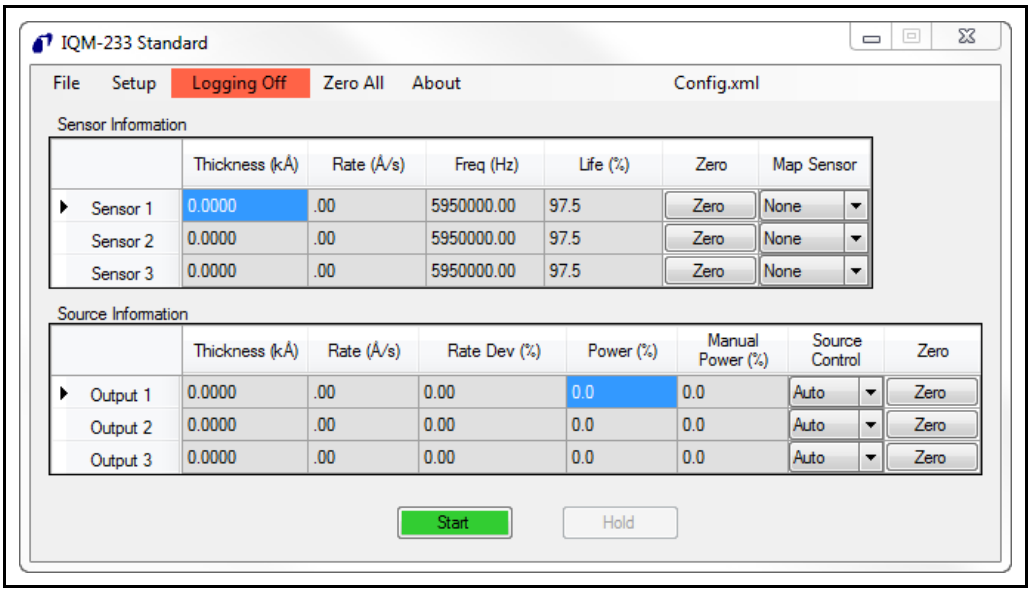
Figure 3-7 IQM-233 Standard window - Sensor Information and Source Information panes

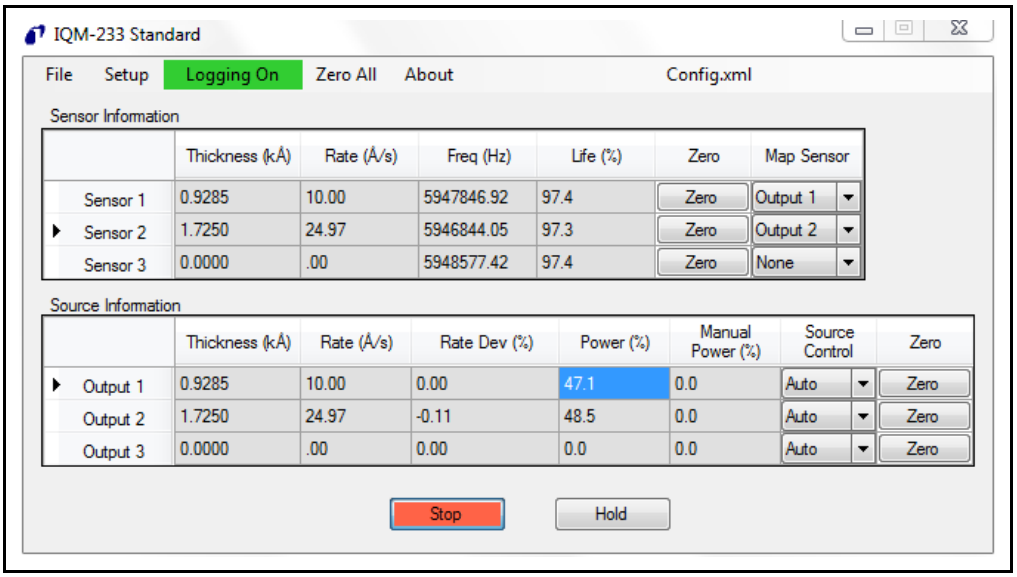


3.3.2 IQM-233 Standard Window Introduction

The **IQM-233 Standard** window contains a **Sensor Information** pane and a **Source Information** pane. See Figure 3-8.

NOTE: The **Source Information** pane is only available when the **Control Enabled** check box is selected in the **Setup** window. Refer to section 3.3.3.1.2, General, on page 3-10.

Figure 3-8 IQM-233 Standard window



The **Sensor Information** pane displays material thickness, deposition rate, crystal frequency, and estimated remaining life of the crystal, for up to three individual sensors. See section 3.3.4.1, Sensor Information Pane Readouts, on page 3-19.

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Operating functions allow data logging of thickness, rate, frequency, and life information, starting and stopping of the readout information, and zeroing of the thickness values. See section 3.3.4.3, Global Operating Functions, on page 3-22.

In addition to the information displayed by the **Sensor Information** pane, the **Source Information** pane displays material thickness, deposition rate, rate deviation, and source power, for up to three sources. See section 3.3.4.2, Source Information Pane Readouts, on page 3-21.

When the **Source Information** pane is displayed, additional operating functions allow selection of source control mode, starting and stopping of source power, holding and resuming of a process, and zeroing of the thickness values in the **Source Information** pane. See section 3.3.4.4, Source Control Operating Functions, on page 3-23.

NOTE: IQM-233 Standard software must be configured before monitoring or controlling a deposition. See section 3.3.3.

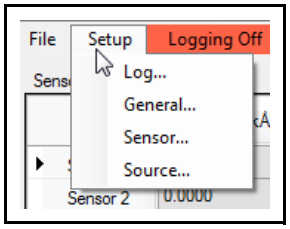
3.3.3 Software Configuration

Configure the **Setup** parameters (see section 3.3.3.1), **Map Sensor** parameters (see section 3.3.3.2), and **Source Control** parameters (see section 3.3.3.3). Save the configured parameters as a configuration file (see section 3.3.3.4).

3.3.3.1 Setup

On the menu bar, click Setup to access options to control Log, General, Sensor, and Source settings. See Figure 3-9.

Figure 3-9 Setup list



- Log, see section 3.3.3.1.1
- General, see section 3.3.3.1.2
- Sensor, see section 3.3.3.1.3
- Source, see section 3.3.3.1.4

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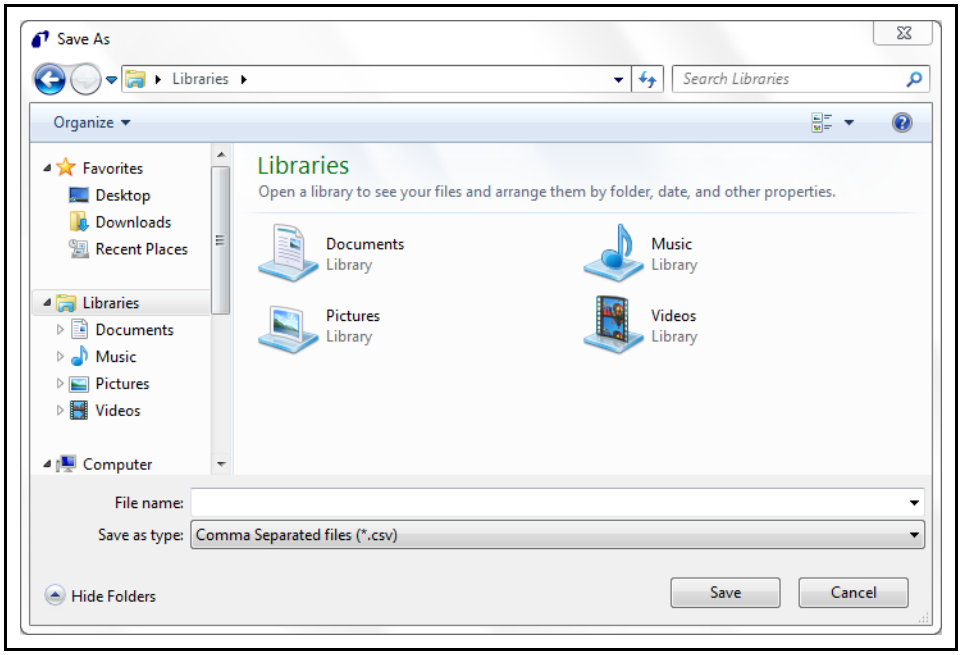
3.3.3.1.1 Log

Data logging (see section 3.3.4.3, Global Operating Functions, on page 3-22) allows rate, thickness, frequency, and life data, for individual sensors and multiple sensors mapped to outputs (sensor averaging), to be saved to a `.csv` format data log file.

Click **Setup >> Log** on the menu bar to display the **Save As** window. In the **File name:** text box, type a name for the data log file and browse for a suitable folder. Click **Save** to save the data log file. See Figure 3-10.

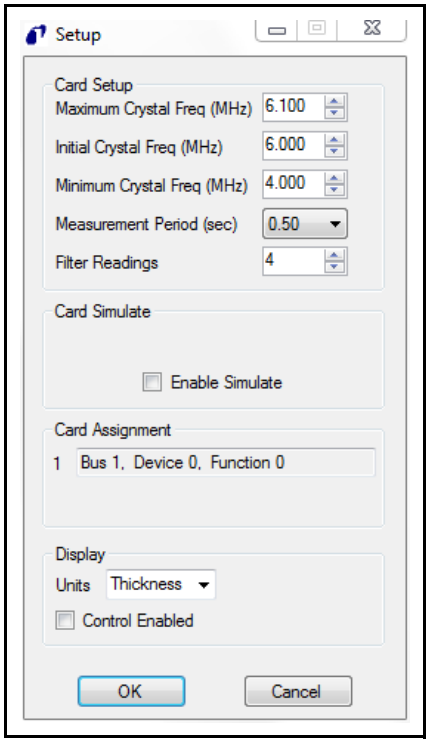
Figure 3-10 Log Save As window



3.3.3.1.2 General

Click **Setup >> General** on the menu bar to display the **Setup** window, allowing parameters to be configured for crystal measurement, simulation mode, display units, and source control. See Figure 3-11.

Figure 3-11 Setup window



Card Setup Pane

Maximum Crystal Freq (MHz) . 5.000 to 6.100 MHz

Enter the highest possible frequency of a new crystal. Frequencies above this value will display a crystal **Fail**.

Initial Crystal Freq (MHz) . . . . . 4.900 to 6.099 MHz

Enter the nominal frequency of a new crystal; usually 5 MHz or 6 MHz.

Minimum Crystal Freq (MHz). . 4.000 to 6.098 MHz

Enter the lowest desired crystal frequency before a crystal **Fail** message is displayed.

NOTE: Maximum Crystal Freq must be set at least 0.001 MHz higher than **Initial Crystal Freq**.

Initial Crystal Freq must be set at least 0.001 MHz higher than **Minimum Crystal Freq**.

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Measurement Period (sec) . . . .0.10, 0.25, 0.50, 1.00, 2.00 s

Indicates the time period needed for one measurement. Enter a longer measurement period to provide higher resolution, especially in low rate applications.

Filter Readings. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Indicates the number of unfiltered readings averaged (arithmetic mean) within the displayed rate. A higher value will help reduce rate noise. For example, a setting of 1 indicates no averaging while a setting of 10 indicates heavy averaging.

Card Simulate Pane

Enable Simulate

Select the check box to activate simulate mode, allowing a deposition process to be developed and tested without the need for an IQM-233 or SQM-242 card to be installed or sensors to be connected to an installed card. This check box is automatically selected when no cards are installed. See section 3.3.4.5, Simulate Mode, on page 3-24 for detailed information about Simulate mode.

Card Type IQM-233, SQM-242

Card Type is displayed only when the **Enable Simulate** check box is selected. Card Type allows an IQM-233 or SQM-242 card to be simulated. Click ▼ in the **Card Type** box and then select from the list the card to simulate. See section 3.3.4.5, Simulate Mode, on page 3-24 for detailed information about Simulate mode.

Card Assignment Pane

Bus, **Device**, **Function**

Read-only parameter that displays the computer bus, device, and function assignments for an installed IQM-233 or SQM-242 card. IQM-233 Standard software supports one card only. If multiple cards are installed, the displayed assignment is for the card automatically selected by the software. If IQM-233 and SQM-242 cards are installed together, the software will select an IQM-233 card.

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Display Pane

Units . . . . . Thickness, Mass

Click ▼ and then select from the list the unit of measure for the **Rate (Å/s)** and **Thickness (kÅ)** readouts in the IQM-233 Standard window (refer to Figure 3-8 on page 3-7).

If **Thickness** is selected:

- The **Rate (Å/s**) value is in units of **Å/s**
- The **Thickness (kÅ)** value is in units of **kÅ**

If **Mass** is selected:

- The **Rate (Å/s)** value is in units of **ng/cm^2/s**
- The **Thickness (kÅ)** value is in units of **ug/cm^2**

NOTE: The desired **Rate (Å/s)** and **Final Thickness (kÅ)** parameters in the **Source** window are not affected by the **Units** selection, and these values are entered as units of **Å/s** and **kÅ**, respectively. See section 3.3.3.1.4, Source, on page 3-14.

Control Enabled

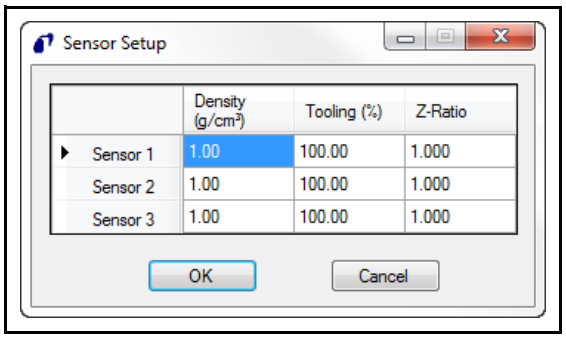
Select the check box to display the **Source Information** pane in addition to the **Sensor Information** pane on the **IQM-233 Standard** window (refer to Figure 3-8 on page 3-7). The **Source Information** pane provides additional operating functions and readouts for PID closed-loop control or manual control of up to three deposition sources.

NOTE: Click **OK** to save the **Setup** parameters.

3.3.3.1.3 Sensor

Click **Setup >> Sensor** on the menu bar to display the **Sensor Setup** window, where **Density** and **Z-Ratio** values specific to the material to be deposited, and a **Tooling** value to compensate for sensor/source geometry, are entered. See Figure 3-12.

Figure 3-12 Sensor Setup window



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Sensor Fields

The **Sensor 1**, **Sensor 2**, and **Sensor 3** fields correspond to the sensor(s) connected to the SMA connectors on the IQM-233 card, with **Sensor 1** corresponding to the SMA connector closest to the D-sub connector (refer to Figure 2-7 on page 2-9). Each sensor field contains the following parameters:

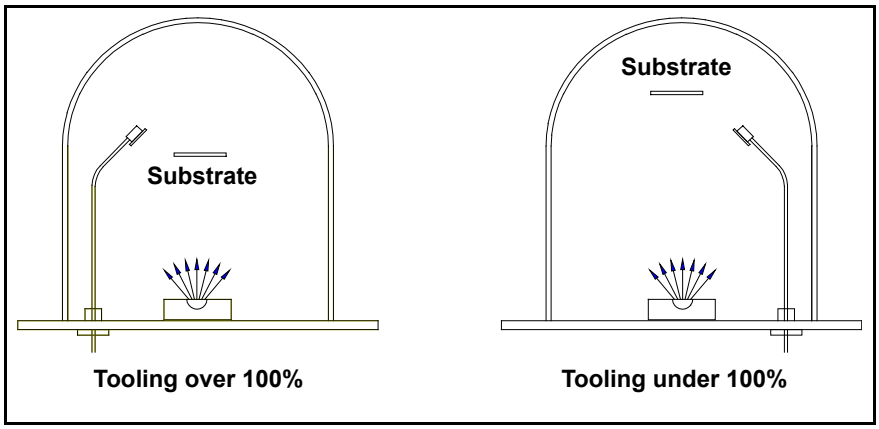
Density (g/cm^3) . . . . . 0.4 to 99.99 g/cm^3

Enter the density of the material to be deposited using the corresponding sensor. See Table A-1 for material density values. The default value is 1.00. If the density value is not available for a material, see section 6.2, Determining Density, on page 6-1.

Tooling (%) . . . . . 0.00 to 999.00

Enter a Tooling value to compensate for differences in the measured deposition rate and actual deposition rate at the substrate due to the sensor or substrate geometry (see Figure 3-13). The default value is 100.00. To determine the Tooling value, see section 6.3, Determining Tooling, on page 6-2.

Figure 3-13 Tooling settings



Z-Ratio . . . . . 0.100 to 9.999

Enter a Z-Ratio value specific to the material being deposited to compensate for the mechanical elasticity of the material to the quartz crystal. See Table A-1 for material Z-Ratio values.

If the Z-Ratio of a material is not known, enter the default value of 1.000 for Z-Ratio. Z-Ratio has a smaller effect when the crystal is relatively new. To determine Z-Ratio experimentally, see section 6.4, Determining Z-Ratio, on page 6-3.

NOTE: Click **OK** to save the **Sensor Setup** parameters.

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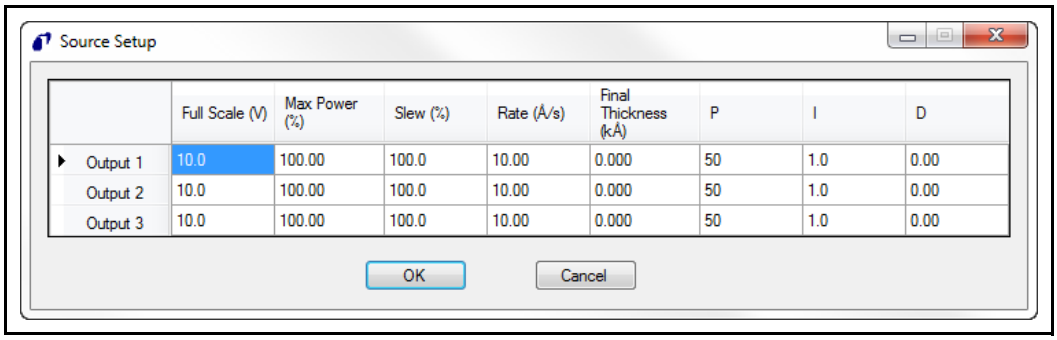
3.3.3.1.4 Source

Click **Setup >> Source** on the menu bar to display the **Source Setup** window where parameters related to the source power supply characteristics, the desired material rate, and final thickness can be configured. See Figure 3-14.

NOTE: The **Source** button is unavailable unless the **Control Enabled** check box is selected in the **Setup** window. Refer to Figure 3-11.

Figure 3-14 Source Setup window



Output Fields

The **Output 1**, **Output 2**, and **Output 3** fields correspond to the source power supply or supplies connected to the D-sub connector on the IQM-233 card (refer to Table 2-2 on page 2-13). Each Output field contains the following parameters:

Full Scale (V). . . . . 0 to ±10 V

Enter the desired value for the source output voltage for 100% power. This value can be from -10.0 to +10.0 (the + sign is not required), but must not exceed the maximum input voltage allowed for the equipment connected to the source output.

Max Power (%) . . . . . 0 to 100%

Enter the maximum voltage allowed for the corresponding IQM-233 card source output, as a percentage of the **Full Scale (V)** setting. For example, if -10 is entered for **Full Scale (V)** and 75 is entered for **Max Power (%)**, the IQM-233 card source output voltage will not exceed 75% of –10 V, or –7.5 V.

Slew (%) . . . . . 0 to 100%

Enter the maximum percentage of **Full Scale (V)** change allowed per second for a source output using PID closed-loop control.

Rate (Å/s) . . . . . -999.9 to 999.9 Å/s

Enter the rate at which the deposition is to be controlled.

Final Thickness (kÅ) . . . . . 0.00 to 999.90 kÅ

Enter the value that when reached, will set all source output voltages to zero, ending the deposition.

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P . . . . . 0 to 9999

P is the proportional term that sets the gain of the control loop. A value of 0 makes this function unavailable. Enter a high gain for a faster responding (but potentially unstable) control loop, and a lower gain for a slower responding control loop. Enter a value of 25, and then gradually increase or decrease the value to respond as desired to rate step changes. See section 6.5, Tuning the Control Loop, on page 6-5.

I . . . . . 0 to 999.9

I is the integral term that controls the time constant of the loop. A value of 0 makes this function unavailable. Enter a small I Term, such as 0.5 to 1 second, to smooth the response and minimize overshoot to rate step changes. See section 6.5, Tuning the Control Loop, on page 6-5.

D . . . . . 0 to 99.9

D is the derivative term that determines how quickly the control loop responds to changes. A value of 0 makes this function unavailable. Enter 0 or a very small value to avoid rate oscillations, especially with fast sources, such as electron beam guns. Slow sources, such as resistively heated sources, may require a large D value. See section 6.5, Tuning the Control Loop, on page 6-5.

NOTE: Click **OK** to save the **Source Setup** parameters.

3.3.3.2 Map Sensor

Map Sensor . . . . . None, Output 1, Output 2, Output 3

Unavailable (default is **None**) unless the **Control Enabled** check box is selected in the **Setup** window. Refer to Figure 3-11.

Select **None** if monitoring a deposition, or select an **Output** if controlling a deposition by PID closed-loop or manual source control.

Each sensor can be mapped to a different output for codeposition.

Multiple sensors can be mapped to the same output for rate averaging. The Rate readouts in the Source Information pane display an aggregate rate when multiple sensors are mapped to an output. Rate readouts in the Sensor Information pane are not affected by the Map Sensor configuration and display Rate only for the individual sensors. If a sensor's rate becomes erratic during deposition, the sensor can be turned off by changing the **Output** to **None**. If any sensor fails, its measurement is automatically excluded from the aggregate rate.

Click ▼ to view the Map Sensor list. See Figure 3-15.

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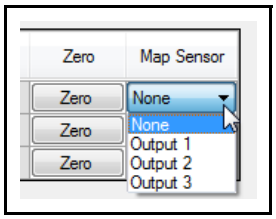
Figure 3-15 Map Sensor list



- Select **None** if no output will be mapped to the corresponding sensor. This sensor will only monitor the deposition.
- Select **Output 1**, **Output 2**, or **Output 3** to map the output to the corresponding sensor.

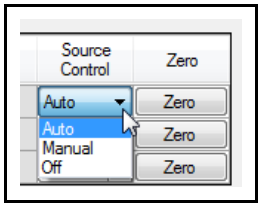
NOTE: If the **Control Enabled** check box is cleared in the **Setup** window after a Map Sensor output is selected, the Map Sensor buttons become unavailable and display the selected configuration.

3.3.3.3 Source Control

Source Control . . . . . Auto, Manual, Off

Click ▼ to view the Source Control list. See Figure 3-15.

Figure 3-16 Source Control list



- Select **Auto** for PID closed-loop control of the source power supply.
- Select **Manual** for manual control of the source power supply.
- Select **Off** to make the source output unavailable. Sensors mapped to that output will monitor the deposition.

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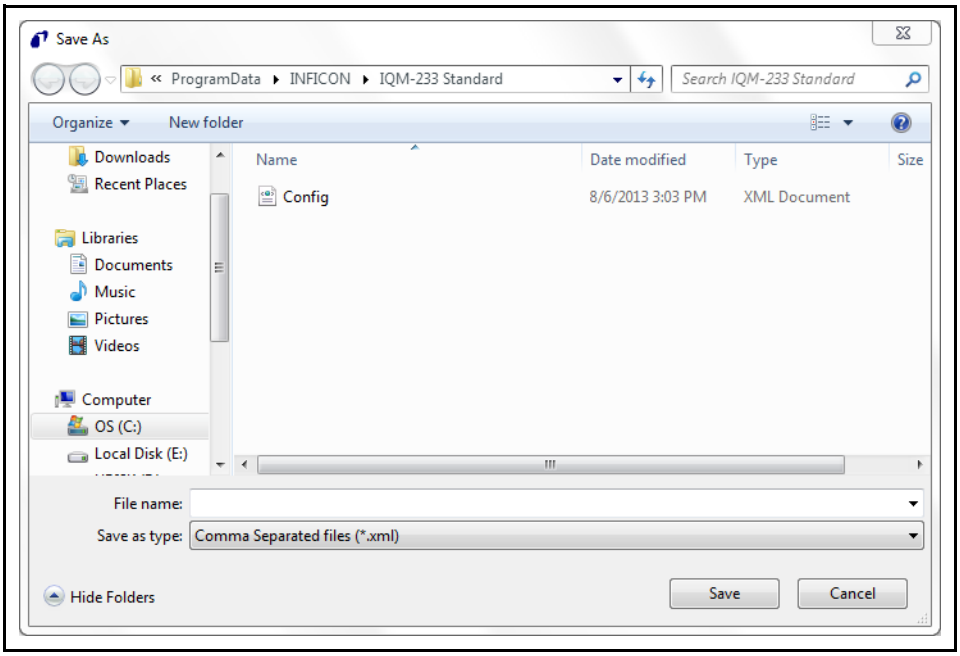
3.3.3.4 File

File . . . . . Load, Save As

The parameters for **Setup**, **Map Sensor**, and **Source Control** can be saved to an .xml format configuration file.

Click **File >> Save As** on the menu bar to display the **Save As** window. Type a name for the configuration file and browse for a folder to save the file to. Click **Save** to save the configuration file. See Figure 3-17.

Figure 3-17 Save As window

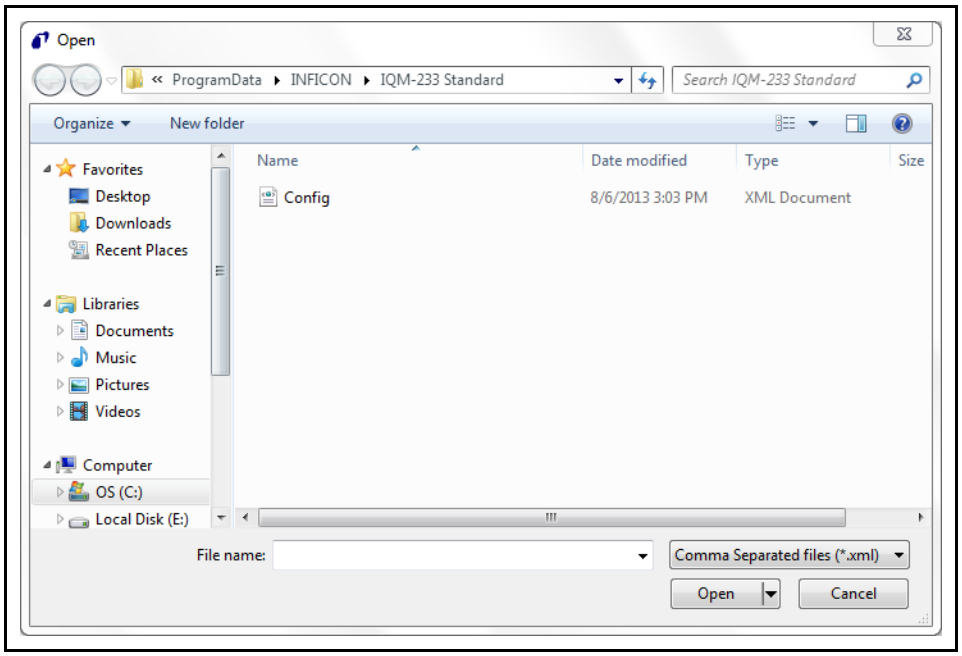


A previously saved .xml format configuration file can be loaded into the IQM-233 Standard software.

Click **File >> Load** to display the **Open** window. Browse for the folder where a configuration file was previously saved to. Click the name of the configuration file to be loaded, and then click **Open** to load the configuration to the software. See Figure 3-18.

NOTE: Each time the IQM-233 Standard software is started, factory-default parameter values in a configuration file named **Config.xml** are automatically loaded. The factory-default parameter values will be overwritten if changes are made to the parameter values and the new parameters are saved to the **Config.xml** file, or if the check box next to **Save any changes to Config.xml** is selected upon exiting the software.

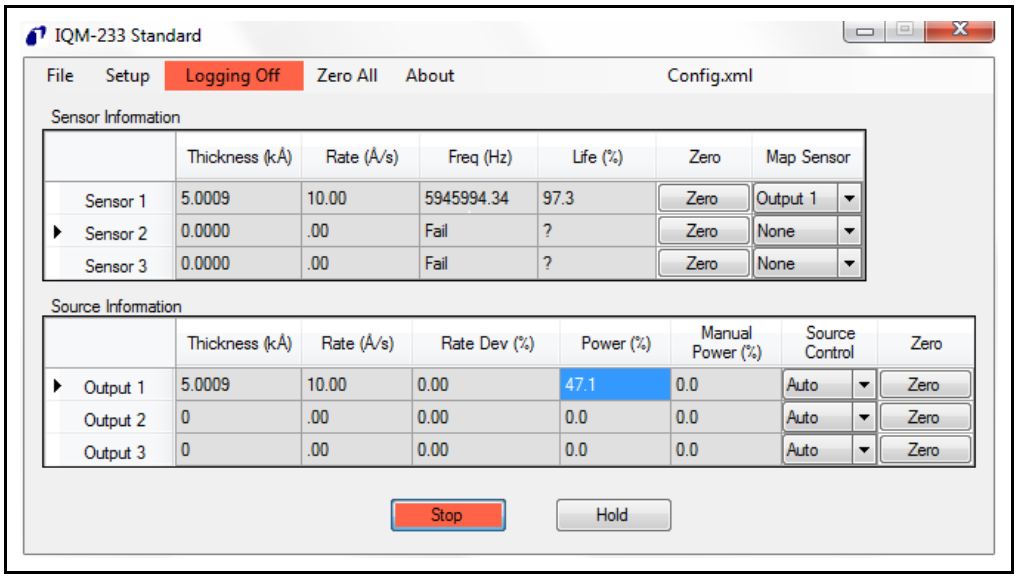
Figure 3-18 Open window



3.3.4 IQM-233 Standard Window Description

In the IQM-233 Standard window (see Figure 3-19), only the **Sensor Information** pane is displayed when the **Control Enabled** check box is cleared in the **Setup** window (refer to Figure 3-11 on page 3-10). This pane allows a deposition to be monitored only.

Figure 3-19 IQM-233 Standard window



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The **Source Information** pane is displayed below the **Sensor Information** pane when the **Control Enabled** check box is selected in the **Setup** window. This pane allows a deposition to be controlled using PID closed-loop or manual source control.

The readouts on the **Sensor Information** pane are described by section 3.3.4.1, Sensor Information Pane Readouts, on page 3-19.

The readouts on the **Source Information** pane are described by section 3.3.4.2, Source Information Pane Readouts, on page 3-21.

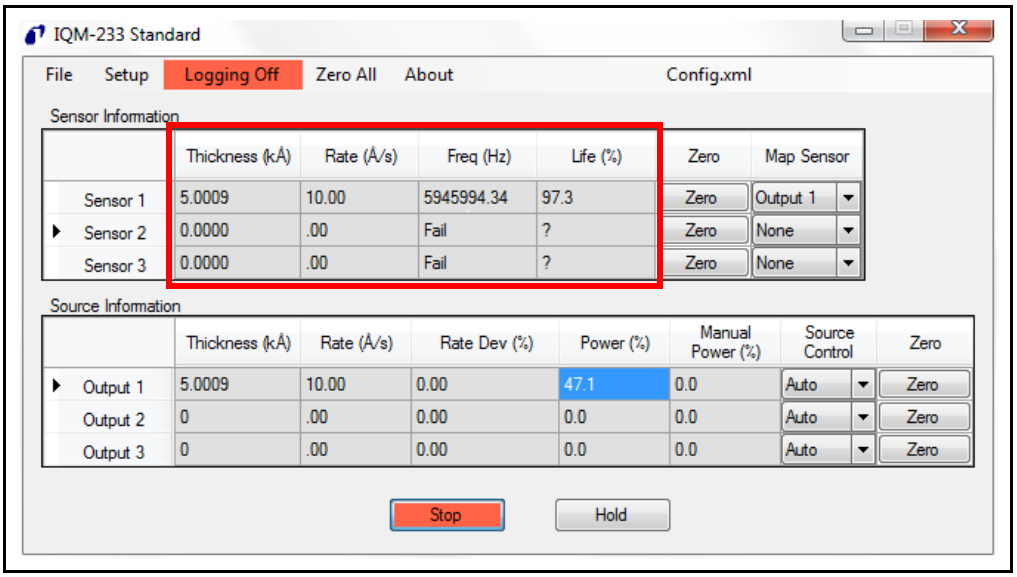
The operating functions on the **IQM-233 Standard** window are described by section 3.3.4.3, Global Operating Functions, on page 3-22 and section 3.3.4.4, Source Control Operating Functions, on page 3-23.

The **About IQM-233 Standard** window provides software and hardware information. See section 3.3.4.6, About IQM-233 Standard Window, on page 3-25.

The IQM-233 Standard software is configured by the **Setup** list on the menu bar, the **Map Sensor** list in the Sensor Information pane, and the **Source Control** list in the Source Information pane. Refer to section 3.3.3, Software Configuration, on page 3-8.

3.3.4.1 Sensor Information Pane Readouts

Figure 3-20 Sensor Information pane - readouts



Sensor Fields

The **Sensor 1**, **Sensor 2**, and **Sensor 3** fields correspond to the crystal sensor(s) connected to the SMA connector(s) on the IQM-233 card, with **Sensor 1** corresponding to the SMA connector closest to the D-sub connector. Each Sensor field displays the following readouts:

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Thickness (kÅ) . . . . . 0.0000 to 999.90 kÅ

The calculated thickness of material deposited on the substrate, based on the thickness measured by the corresponding sensor. The thickness calculation is affected by the **Density**, **Z-Ratio**, and **Tooling** values displayed in the **Sensor Setup** window. Refer to Figure 3-12 on page 3-12.

Rate (Å/s) . . . . . –999.9 to 999.9 Å/s

The calculated rate of deposition at the substrate. The rate calculation is affected by the **Density**, **Z-Ratio**, and **Tooling** values in the **Sensor Setup** window (refer to Figure 3-12 on page 3-12) and the **Measurement Period** and **Filter Readings** values displayed in the **Setup** window (refer to Figure 3-11 on page 3-10).

Freq (Hz) . . . . . 4000000.00 to 6100000.00 Hz, Fail

The fundamental frequency of the crystal. **Fail** is displayed when no sensor is connected, no frequency is detected, or the frequency is not within the limits of the **Crystal Frequency** settings in the **Setup** window. Refer to Figure 3-11 on page 3-10.

Life (%) . . . . . 0 to 100%

Represents the maximum possible percentage of crystal life remaining before a crystal **Fail** is displayed by the **Freq (Hz)** readout. The Life (%) value is dependent on material properties and process conditions, and is affected by the **Crystal Frequency** settings in the **Setup** window (refer to Figure 3-11 on page 3-10). The Life (%) value for a new crystal is at or near 100. When **Fail** is displayed by the **Freq (Hz)** readout, "**?**" is displayed by **Life (%)**.

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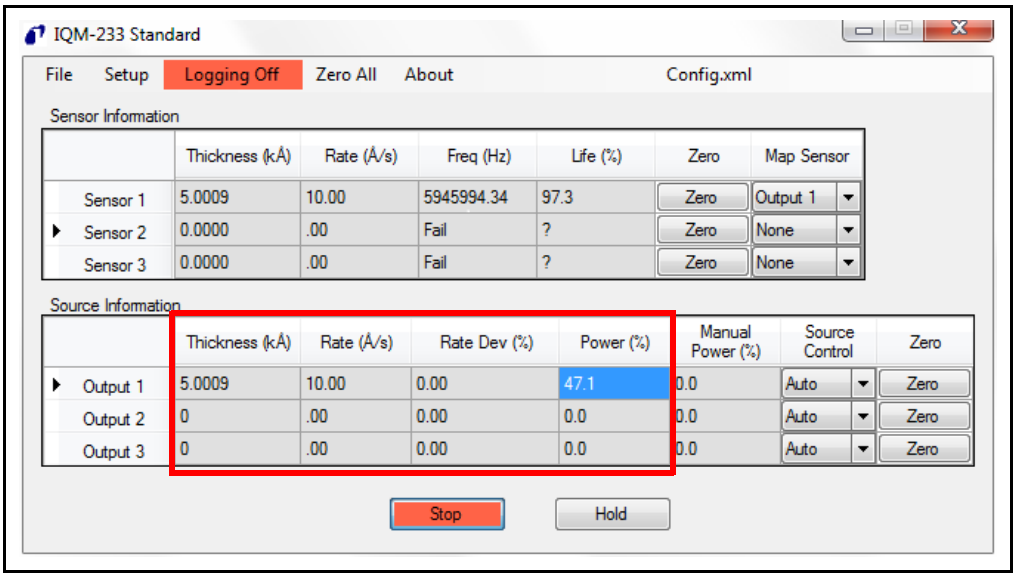
3.3.4.2 Source Information Pane Readouts

Figure 3-21 Source Information pane - readouts



Output Fields

The **Output 1**, **Output 2**, and **Output 3** fields display the following readouts:

Thickness (kÅ) . . . . . 0.0000 to 999.90 kÅ

The thickness of material deposited on the substrate, based on the thickness measured by the sensor, or sensors, mapped to the corresponding output. If multiple sensors are mapped to an output, the thickness readout is an average of the mapped sensor thicknesses.

Rate (Å/s). . . . . –999.9 to 999.9 Å/s

The rate of deposition at the substrate, based on the rate measured by the sensor, or sensors, mapped to the corresponding output. If more than one sensor is mapped to an output, the output's displayed rate is an average of the mapped sensor rates.

Rate Dev (%) . . . . . –100% to 100%

The percentage deviation of the **Rate (Å/s)** display from the desired rate setting in the **Source Setup** window.

Power (%) . . . . . 0 to 100%

The percentage of source output voltage relative to the **Full Scale (V)** voltage setting for the corresponding output channel.

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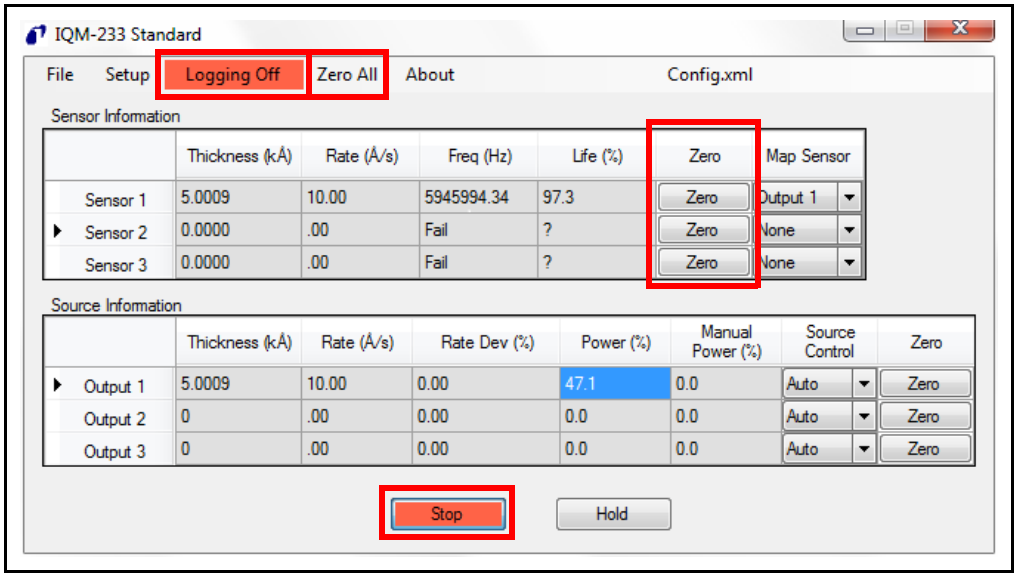
3.3.4.3 Global Operating Functions

The following operating functions are always available. See Figure 3-22.

Figure 3-22 Operating functions



Logging Off, Logging On

The data log function saves Rate, Thickness, Frequency, and Life data, for individual sensors and outputs in .csv format. Refer to section 3.3.3.1.1, Log, on page 3-9.

Click **Logging Off**, which changes to **Logging On**, to activate data logging. Data logging may be activated with **Start** or **Stop** displayed; however, data is not collected until **Stop** is displayed. If data logging was not previously configured, the **Save As** window will be displayed to allow selection of a data log path and file name (refer to section 3.3.3.1.1).

Click **Logging On**, which changes to **Logging Off**, to make data logging unavailable.

Start, Stop

Click **Start**, which changes to **Stop**, to zero the thickness readouts of all sensors, and start the thickness and rate readings. If the **Source Information** pane is displayed, source power will be applied if an **Output** is selected for **Map Sensor** and **Auto** or **Manual** are selected for **Source Control**.

Click **Stop**, which changes to **Start**, to freeze the values in the thickness and rate readouts. If the **Source Information** pane is displayed, source power will be set to zero in addition to freezing the thickness and rate readouts.

Zero All

Click **Zero All** to zero all thickness readouts in the **Sensor Information** and **Source Information** panes.

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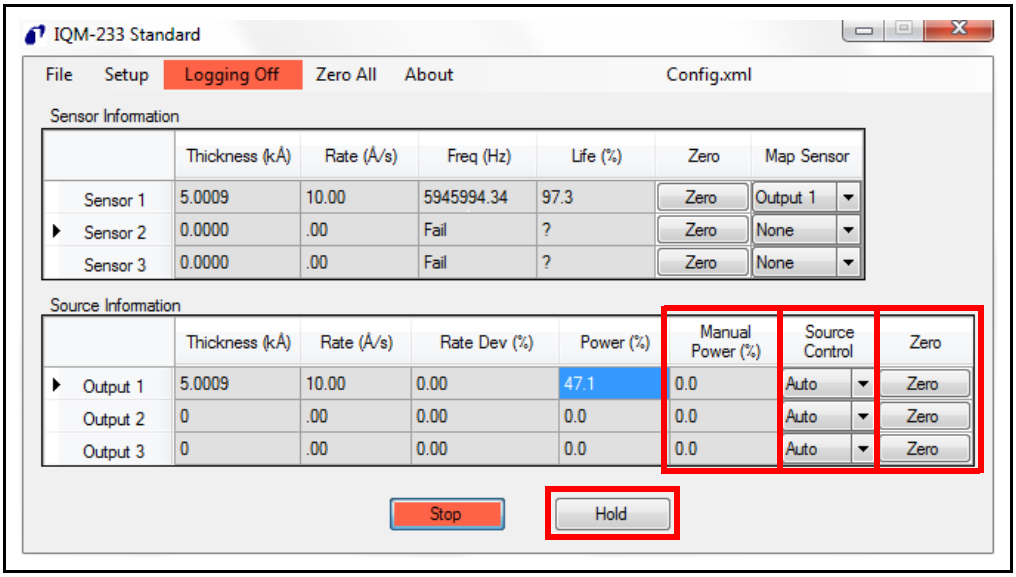
Zero

Click **Zero** in the **Sensor Information** pane to zero the thickness readout of the corresponding sensor. If an output is mapped to this sensor, the effect of the zero function on the corresponding thickness readout in the **Source Information** pane is determined by the sensor mapping (refer to section 3.3.3.2, Map Sensor, on page 3-15).

3.3.4.4 Source Control Operating Functions

In addition to the operating functions described by section 3.3.4.3, the following operating functions are available when the **Source Information** pane is displayed. See Figure 3-23.

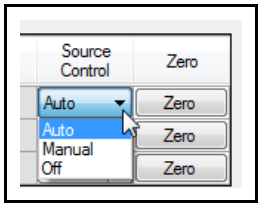
Figure 3-23 Operating functions - source control



Source Control . . . . . Auto, Manual, Off

Click ▼ to view the **Source Control** list. See Figure 3-24.

Figure 3-24 Source Control list



- Select **Auto** for PID closed-loop control of the source power supply.
- Select **Manual** for manual control of the source power supply.
- Select **Off** to make the source output unavailable. Sensors mapped to that output will monitor the deposition.

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Manual Power (%) . . . . . 0 to 100%

Manual must be selected in the **Source Control** list to use this function.

In the **Manual Power (%)** cell of the corresponding output field, type or select a value, and then click another cell or press **Enter** to accept the value. The source output voltage and **Power (%)** will remain at zero until **Start** is clicked.

Zero

Click **Zero** in the **Source Information** pane to zero the thickness readout in the corresponding output field and zero the thickness readout(s) in the sensor information pane for any sensor mapped to that output.

Hold, Resume

Hold is available only when **Stop** is displayed. Click **Hold**, which changes to **Resume**, to freeze all thickness values and set all source output power levels to zero.

Click **Resume**, which changes to **Hold**, to continue the deposition from the previously frozen thickness value.

3.3.4.5 Simulate Mode

Simulate mode allows a deposition process to be developed and tested without the need for an IQM-233 or SQM-242 card to be installed or sensors to be connected to an installed card. Simulated values are provided for the thickness, rate, rate deviation, frequency, life, and power readouts.

To activate and configure Simulate mode:

1. On the menu bar, click **Setup >> General**.
2. The **Setup** window will display. See Figure 3-25.
3. Select the **Enable Simulate** check box. This check box is automatically selected when no cards are installed.
4. In the **Card Type** box, click ▼ and then select from the list the card type to be simulated (**IQM-233** or **SQM-242**).
5. Simulation of a deposition process requires the **Source Information** pane for source control. Select the **Control Enabled** check box if the Source Information pane is not displayed in the IQM-233 Standard window.
6. Click **OK** to save the parameters.

NOTE: The simulated Rate and Thickness will remain at zero until the **Power (%)** readout increases to approximately 50%.

NOTE: The factory-default PID values of **P = 5**, **I = 2.0**, and **D = 0.00** provide a stable simulated rate. The simulated rate may become unstable if the PID values are changed. Refer to section 3.3.3.1.4, Source, on page 3-14 for information on configuring the PID values.

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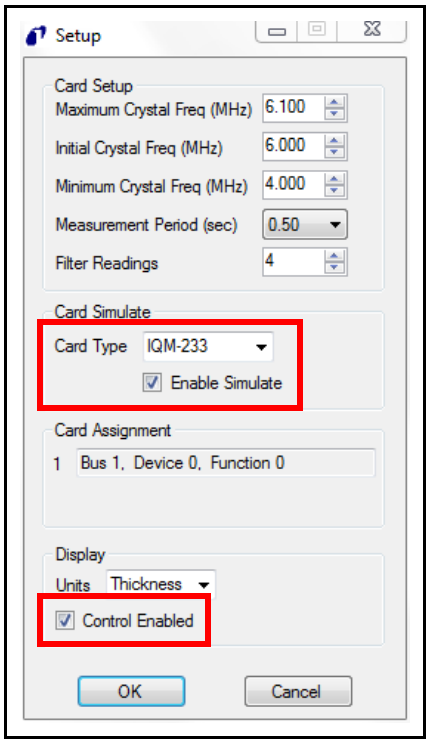
Figure 3-25 Setup window - simulate settings



3.3.4.6 About IQM-233 Standard Window

On the menu bar, click **About** to display the **About IQM-233 Standard** window, which displays the IQM-233 Standard software version, DLL version, software installation path, installed **Card Type** (None, IQM-233, SQM-242), and installed **Card Count** (0 to 6). See Figure 3-26.

NOTE: IQM-233 Standard software supports one IQM-233 or SQM-242 card; however, the Card Count will indicate the quantity of installed IQM-233 or SQM-242 cards (up to six cards of one type).

Figure 3-26 About IQM-233 Standard window

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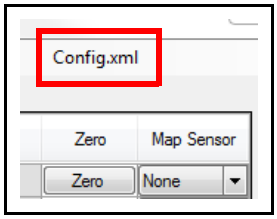
3.3.4.7 Current Configuration File

The name of the currently used configuration file is displayed on the menu bar (see Figure 3-27). The **Config.xml** configuration file, containing the factory-default software configuration parameters, is automatically loaded when the IQM-233 Standard software is started. Other previously saved configuration files can then be loaded using **File >> Load** (refer to section 3.3.3.4, File, on page 3-17).

Figure 3-27 Configuration file



CAUTION

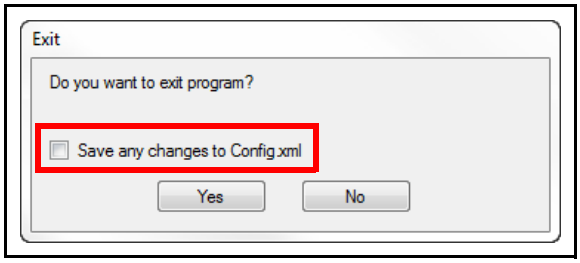
If the Config.xml file is not found by the IQM-233 software upon starting, an error will occur and the software will close. Do not move this file to another folder location or change the name of this file.

NOTE: Initially, the **Config.xml** file contains factory-default parameter values; however, the factory-default parameter values can be overwritten if changes are made to the parameter values and the new values are saved to the **Config.xml** file, either by using **File >> Save** (refer to section 3.3.3.4, File, on page 3-17), or by selecting the check box next to **Save any changes to Config.xml** upon exiting the IQM-233 Standard software (see section 3.3.4.8).

3.3.4.8 Exit Window

When exiting the IQM-233 Standard software, changes made to the current configuration parameter values can be saved by selecting the **Save any changes to (name).xml** check box and clicking **Yes**. See Figure 3-28.

Figure 3-28 Exit window - Save any changes



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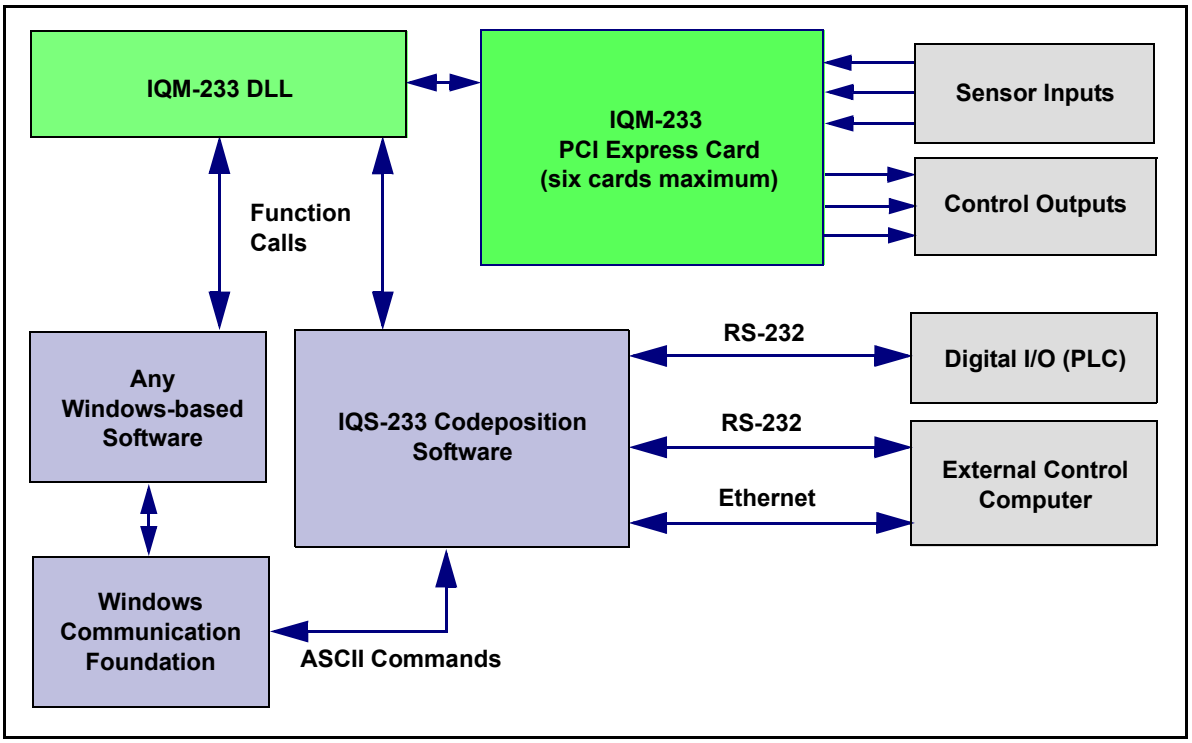
Chapter 4
Remote Communications

4.1 Introduction

Figure 4-1 illustrates basic concepts for interfacing to the IQM-233 card.

Figure 4-1 Communications diagram



Communications with the IQM-233 card are through a provided 32-bit or 64-bit DLL, placed in the Windows system directory. A description of each DLL function is listed in section 4.2, DLL Functions, on page 4-2.

A LabVIEW VI sample is provided on the Thin Film Manuals CD to demonstrate the syntax for calling the DLL. See section 4.3, LabVIEW VI Sample, on page 4-7.

The optional IQS-233 Codeposition software can be used as the user interface. This software provides multi-layer processes, graphing, data logging, and digital I/O (with external PLC). IQS-233 Codeposition software can be controlled from customer-designed software by ASCII text commands. Contact INFICON for more information regarding the optional IQS-233 Codeposition software.

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4.2 DLL Functions

In the function descriptions below, *long* indicates a 32 bit integer, *double* indicates a double precision real. Array parameters require a pointer to the first element of the array (standard C calling convention).

NOTE: These function definitions are for IQM233.DLL, which supports up to six IQM-233 or six SQM-242 cards. Contact INFICON for information on interfacing to the older SQM242.DLL (refer to section 1.3, How To Contact INFICON, on page 1-5).

`Sif142Startup2 (long Mode, long CardStatus (0 to 7))`

Loads the DLL and initializes the card. Must be called with Mode=0 before any other function. The card status parameter is an array that returns card installation status information

Mode . . . . . -1 unloads the DLL, any other value loads the DLL.

CardStatus(0) . . . . . DLL and card installation status. Values >900 are errors.

CardStatus (1 to 6) . . . . . Firmware revision of card 1 to 6. **Zero** indicates no card found.

`Sif142Init (double Xfmax, double Xfmin, double Xinit, double Period)`

Initializes the measurement engine. Must be called before readings are taken.

Xfmax. . . . . Maximum crystal frequency (6.1 MHz Max). Any measurement greater than this value will return a crystal failure.

Xfmin . . . . . Minimum crystal frequency (4.0 MHz minimum). Any measurement less than this value will return a crystal failure.

Xinit . . . . . Initial frequency of a new crystal. Usually either 6.00 MHz or 5.00 MHz. Must be between Xfmax and Xfmin.

Period . . . . . Sets the time period to collect one measurement between 0.1 and 2 seconds.

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`Sif142Simulate (long Mode)`

Sets the operating mode. Normal mode requires the IQM-233 card(s), sensors, and a source power supply for proper operation. In simulate mode, no IQM-233 card is required. The DLL simulates the frequency readings and power output required for PID loop control. The initial sensor frequency is fixed at 5.95 MHz and approximately 50% output power is required to start simulating deposition.

Mode . . . . . 1 turns on simulate mode
0 turns on normal mode

`Sif142StartMeas ()`

Starts the card measuring frequency and zeros the sensor thickness reading.

`Sif142ZeroSensor (long SensorNum)`

Sets a sensor (0 to 23) thickness reading to zero.

`Sif142Zero2 (long OutputNum)`

Sets a control output (0 to 17) thickness reading for each assigned sensor to zero.

`Sif142Material (long Sensor, double Density, double Zfact, double Tooling)`

Sets up the material-specific parameters for each sensor.

Sensor . . . . . A bit-weighted value for sensor(s). The three lowest bits determine the selected sensor(s). Add the bits to select multiple sensors, for example, send 111 to select all three sensors.
001 = Sensor 1
010 = Sensor 2
100 = Sensor 3

Density. . . . . Sets the density of the material. Values are from 0.4 to 99.99 g/cm^3. Refer to Appendix A, Material Table.

Zfact. . . . . Z-Ratio (Z-Factor) of the material. This number has no units, and can be found in Appendix A, Material Table. Values are from 0.100 to 9.999.

Tooling. . . . . Accounts for the difference in deposition rate at the sensor vs. the substrate. Values are a range from 0 to 9.99, representing 0 to 999%. Refer to section 6.3, Determining Tooling, on page 6-2.

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`Sif142GetMaterial (double SensorParams (0 to 23, 0 to 2), double SystemParams (0 to 4)`

Read material parameters: Density, Z-Ratio, and Tooling (0 to 23, 0 to 2) and system parameters: max freq, min freq, init freq, period, norm/sim (0 to 4)

`Sif142FullScale (long Output, double FullScaleVolts, double MaxPwr, double SlewRate)`

Sets the source output operating parameters.

Output . . . . . The output of these parameters 0 to 17.

FullScaleVolts. . . . . Maximum scaled voltage for the output when the output is at 100% power. Values from -10 to +10 are valid.

MaxPwr . . . . . Maximum power that the loop is allowed to output, expressed as 0.0 to 1.0, representing 0% to 100%.

SlewRate . . . . . Maximum rate of change of the output, expressed as the percent of Full Scale times 0.01 second.

`Sif142Auto (long Output)`

Exits manual power control and starts the control loop running on the indicated output channel.

Output . . . . . 0-17, indicating the output to place in PID control.

`Sif142Loop2 (double Rate, double P, double I, double D, long Output)`

Sets the control loop parameters for an output. The sensors specified in **Sif142MapSensors** are averaged to provide the input parameters to the PID loop.

Rate . . . . . Specifies the rate to control, from -999.9 to 999.9 Å/s.

P. . . . . Proportional (gain) term of the PID loop, from 0 to 9999. This number has no units.

I . . . . . Integral term, from 0 to 999.9, expressed in seconds.

D. . . . . Derivative term, from 0 to 99.9, expressed in seconds.

Output . . . . . The output (0 to 13) to which the parameters apply.

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Sif142SetPower (long Output, double Power)

Sets the control voltage value in Manual mode. If an output was in Auto mode, turns off PID control and places the output in Manual mode.

Output . . . . . Specifies the output, from 0 to 17.

Power. . . . . Between 0.0 and 1.0, representing 0 to 100% of Full Scale.

Sif142MapSensors (long SensLoop(0 to 23))

An array that associates each sensor (0 to 23) with an output (0 to 17) for PID control. An output value of -1 for a sensor causes the sensor to continue to monitor deposition, but have no effect on output control.

SensLoop (). . . . . Array (0 to 23) of sensor to output assignments (0 to 17).

Sif142GetReadings (double SensorArray(0 to 23, 0 to 2), double OutputArray (0 to 17))

Fills two arrays with measurement data. In the second dimension of the SensorArray the elements are Rate (Å/s), Thickness (Å), and Frequency (Hz). Negative frequency values indicate a sensor error. OutputArray is output power, 0 to 1.

If a 0 is returned, there are no new readings available. A non-zero value indicates there is new data, with the returned value indicating the number of readings in the buffer. The buffer is 10 readings long. To flush the buffer, keep reading until there is no new data.

Sif142GetPower (double PowerArray(0 to 17))

Fills the array with the current output powers. Unlike Sif142GetReadings OutputArray, the value is an instantaneous unbuffered value.

SqmSimulate (long Type)

Sets the type of card to simulate.

Type . . . . . Type of board to emulate
1 = SQM-242
2 = IQM-233

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`SqmSystemState (long *CardTypeInstalled, long *ActiveCardType, long *NumCardsInstalled, long *NumOutputsTotal, long *NumSensorsTotal, long *NumOutputsPerCard, long *NumSensorsPerCard, long *Sim, long *NumActiveCards)`

Sets the material-specific parameters for each of the sensors.

CardTypeInstalled. . . . . Type of card physically installed
0 = No card
1 = SQM-242
2 = IQM-233

ActiveCardType . . . . . Type of card currently being run or emulated
1 = SQM-242
2 = IQM-233

NumCardsInstalled. . . . . Number of actual cards installed

NumOutputsTotal . . . . . Total outputs for all cards, either physical or emulated

NumSensorsTotal. . . . . Total sensors for all cards, either physical or emulated

NumOutputsPerCard . . . . . Number of outputs per card

NumSensorsPerCard. . . . . Number of sensors per card

Sim. . . . . Current simulation mode
0 = Not in simulation mode
1 = SQM-242
2 = IQM-233

NumActiveCards . . . . . Number of cards currently running, either real or emulated

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```
IqmGetReadings (double SensorArray(0 to 23, 0 to 2),
double OutputArray (0 to 17), double *Time)
```

SensorArray . . . . . Elements are Rate (Å/s), Thickness (Å), and Frequency (Hz)

Negative frequency values indicate a sensor error.

OutputArray . . . . . Output power, 0 to 1

Time . . . . . Time since midnight when measurement readings were taken. If a 0 is returned, no new readings are available. A non-zero value indicates there is new data, with the returned value indicating the number of readings in the buffer. The buffer is 10 readings long. To flush it, keep reading until there is no new data.

4.3 LabVIEW VI Sample

A LabVIEW VI sample file for use with LabVIEW is provided on the Thin Film Manuals CD. The LabVIEW VI sample aids in creating user-developed software, and interfacing the IQM-233 card with other devices.

4.3.1 Getting Started With The LabVIEW VI Sample

Requirements for the LabVIEW VI sample:

- **LabVIEW** software version 6 or higher must be installed on the computer.
- The **IQM233 DLL** must be installed on the computer. Refer to section 3.2.1, DLL Installation, on page 3-1.

1. Insert the Thin Film Manuals CD into the computer's CD drive.
2. Click **Windows Explorer or File Explorer >> Computer >> (CD drive letter:) INFICON Technical Documentation >> IQM-233 Card >> IQM-233 Samples**.
3. Extract the contents of the **IQM-233 VI Sample.zip** folder.
4. Double-click the **IQM233.vi** file to display the **IQM-233 VI Sample** window. See Figure 4-2.
5. Click **Load DLL** and then click **Run** in LabVIEW software. The **DLL LOADED** indicator should now be illuminated.
6. In the **Card Setup** pane, the **Normal Mode** indicator is illuminated when the IQM-233 VI is interfaced to an installed IQM-233 card. To simulate an IQM-233 card, whether or not a card is installed, click **Simulate** (**Simulate Mode** indicator illuminates).

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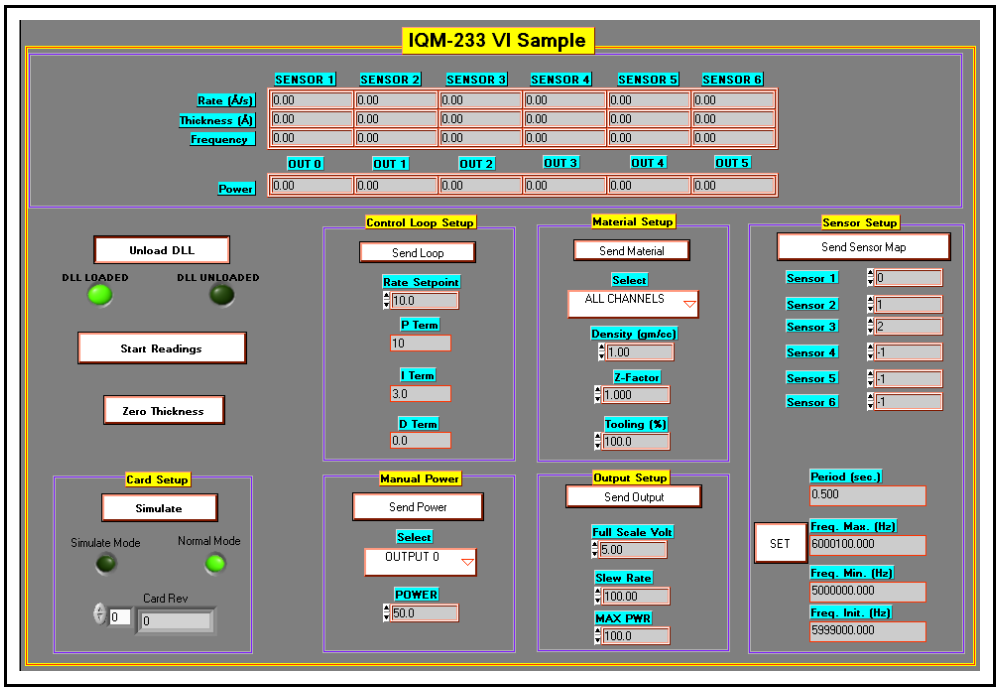
7 Click **Start Readings** to obtain **Sensor** readings for **Rate (Å/s)**, **Thickness (Å)**, and **Frequency (Hz)**, and to apply power at the IQM-233 card's source outputs.

8 Click **Unload DLL** before exiting the IQM-233 VI Sample window; otherwise, a Windows error will occur.

Figure 4-2 IQM-233 VI Sample window



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Chapter 5
Troubleshooting and Maintenance

5.1 Troubleshooting Guide

If the IQM-233 card does not function as expected, or appears to have diminished performance, the following Symptom/Cause/Remedy charts may be helpful (see Table 5-1). Additional troubleshooting information can be found in the operating manuals for sensors, located on the Thin Film Manuals CD. If the problem cannot be resolved, contact INFICON (refer to section 1.3, How To Contact INFICON, on page 1-5).

CAUTION

The IQM-233 card has no user serviceable components.

Refer all maintenance to qualified INFICON personnel.

CAUTION - Static Sensitive Device

Use ESD precautions when handling the IQM-233 card.

WARNING - Risk Of Electric Shock

Potentially lethal voltages are present when the line cord, Inputs or Outputs are connected.

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Table 5-1 Symptom/Cause/Remedy Chart

SYMPTOM	CAUSE	REMEDY
Freq (Hz) displays unstable or drifting frequency.	Temperature of the crystal is unstable (an AT-cut crystal may drift as much as 10 Hz/°C).	Control the vacuum chamber temperature. Move the crystal farther away from the source (at least 25.4 cm (10 in.) from source). Check sensor water cooling for correct flow and temperature. Clean or replace the crystal holder. Use SPC-1157-G10 thermal shock crystals designed to minimize frequency shifts due to heat load.
	Humidity level on the crystal is changing. Moisture being absorbed or exuded from the crystal surface.	Avoid condensation by turning off cooling water to sensor before opening the vacuum chamber to air, and then flow heated water above the room's dew point through the sensor when the chamber is open.
	Defective in-vacuum cable or coax cables.	Use an ohmmeter to check electrical continuity and isolation.
	Check crystal and crystal holder's crystal seating surface for scratches or contamination.	Replace crystal. Clean or replace crystal holder.
Freq (Hz) displays unstable and incorrect frequency.	Excessive cable length between oscillator and crystal causes a self-oscillation condition.	Use no longer than a 78.1 cm (30.75 in.) in-vacuum cable. Use only the 15.2 cm (6 in.) cable between oscillator and feedthrough.

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Table 5-1 Symptom/Cause/Remedy Chart (continued)

SYMPTOM	CAUSE	REMEDY
Freq (Hz) displays Fail.	Failed or defective crystal, or no crystal in sensor.	Install a new crystal.
	Two crystals were installed or crystal is upside down.	Remove extra crystal. Reverse crystal orientation. Inspect crystal for scratches; if scratched, replace with new crystal.
	Built-up material at crystal holder aperture is touching the crystal.	Clean or replace the crystal holder.
	Crystal frequency is not within the frequency range settings in software.	Use a 5 MHz or 6MHz crystal. Check the crystal frequency range settings in software.
	Excessive cable length between oscillator and crystal.	Use no longer than a 78.1 cm (30.75 in.) in-vacuum cable. Use only the 15.2 cm (6 in.) cable between oscillator and feedthrough.

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Table 5-1 Symptom/Cause/Remedy Chart (continued)

SYMPTOM	CAUSE	REMEDY
Freq (Hz) displays Fail.	Sensor not connected, or bad electrical connection in sensor head or feedthrough, or bad cables.	Check sensor connections. Use an ohmmeter to check electrical continuity / isolation of sensor head, feedthrough, in-vacuum cable, SMA/BNC adapter cable, and BNC cables. Refer to the sensor's operating manual for detailed troubleshooting information. Substitute a 5.5 MHz test crystal or a known good sensor for the suspect sensor. Refer to section 2.1.2.2.1, Sensor Connection Troubleshooting, on page 2-12.
	Bad coax cable between feedthrough and oscillator, or bad coax cable between oscillator and IQM-233 card.	Use an ohmmeter to check electrical continuity / isolation. Substitute a known good coax cable.
	IQM-233 card or oscillator is malfunctioning.	Substitute a known good IQM-233 card (or other QCM). Substitute a known good oscillator. Substitute a 5.5 MHz test crystal or a known good sensor for the sensor. Refer to section 2.1.2.2.1, Sensor Connection Troubleshooting, on page 2-12.

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Table 5-1 Symptom/Cause/Remedy Chart (continued)

SYMPTOM	CAUSE	REMEDY
Freq (Hz) displays Fail during deposition before "normal" life of crystal is exceeded.	Crystal is being hit by small droplets of molten material from the evaporation source.	Use a shutter to shield the sensor during source conditioning. Move the crystal farther away (at least 25.4 cm (10 in.)) from the source.
	Damaged crystal or deposited material is causing stress to crystal.	Replace the crystal. Use an Alloy crystal if appropriate for deposited material.
	Material build-up on crystal holder is partially masking the crystal surface.	Clean or replace the crystal holder.
Freq (Hz) displays Fail during deposition before "normal" life of crystal is exceeded.	Shutter is partially obstructing deposition flux or sensor is poorly positioned, causing uneven distribution of material on crystal.	Visually check crystal for an uneven coating, and if present, correct shutter or sensor positioning problem.
Freq (Hz) displays Fail when vacuum chamber is opened to air.	Crystal was near the end of its life; opening to air causes film oxidation, which increases film stress.	Replace the crystal.
	Excessive moisture accumulation on the crystal.	Avoid condensation by turning off cooling water to sensor before opening the vacuum chamber to air, and then flow heated water above the room's dew point through the sensor when the chamber is open.

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Table 5-1 Symptom/Cause/Remedy Chart (continued)

SYMPTOM	CAUSE	REMEDY
Rate, Thickness, and Frequency readings are noisy.	Excessive cable length between oscillator and crystal.	Use 78.1 cm (30.75 in.) in-vacuum cable (or shorter). Use 15.2 cm (6 in.) cable between oscillator and feedthrough.
	Electrical noise is being picked up by the coax cable between the oscillator and IQM-233 card.	Locating the IQM-233 card sensor / oscillator cables and source output cables at least 30.5 cm (1 ft.) away from high voltage / high power cables and other sources of electrical noise significantly reduces noise pickup.
	Inadequate system grounding.	Ground wires or straps should connect to an appropriate earth ground. Refer to section 2.1.1.5, Ground Requirements, on page 2-4. Ground wires or straps should be short with large surface area to minimize impedance to ground.

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Table 5-1 Symptom/Cause/Remedy Chart (continued)

SYMPTOM	CAUSE	REMEDY
Thickness reading has large excursions during deposition.	Mode hopping due to damaged crystal.	Replace the crystal.
	Crystal is near the end of its life.	Replace the crystal.
	Scratches or foreign particles on the crystal holder seating surface.	Clean the crystal seating surface inside the crystal holder or replace crystal holder.
	Uneven coating onto crystal.	A straight line from center of source to center of crystal should be perpendicular to face of crystal.
	Particles on crystal.	Replace crystal. Remove source of particles.
	Intermittent cables or connections.	Use an ohmmeter to check electrical continuity / isolation of sensor head, feedthrough, in-vacuum cable, SMA/BNC adapter cable, and BNC cables. Refer to the sensor's operating manual for detailed troubleshooting information.
	Inadequate cooling of crystal.	Check water flow rate and temperature for sensor cooling.
Thickness reading has large excursions during source warm-up or when source shutter is opened (usually causes Thickness reading to decrease) and after the termination of deposition (usually causes Thickness reading to increase).	Crystal not properly seated or dirty crystal holder.	Check crystal installation. Clean the crystal seating surface inside the crystal holder or replace crystal holder.

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Table 5-1 Symptom/Cause/Remedy Chart (continued)

SYMPTOM	CAUSE	REMEDY
Thickness reading has large excursions during source warm-up or when source shutter is opened (usually causes Thickness reading to decrease) and after the termination of deposition (usually causes Thickness reading to increase).	Excessive heat input to the crystal.	If heat is due to radiation from the evaporation source, move sensor farther away (at least 25.4 cm (10 in.)) from source. Use SPC-1157-G10 thermal shock crystals designed to minimize frequency shifts due to heat load.
	Inadequate cooling of crystal.	Check water flow rate and temperature for sensor cooling.
	Crystal is being heated by electron flux.	Use a sputtering sensor for non-magnetron sputtering.
	Crystal is being hit by small droplets of molten material from the evaporation source.	Use a shutter to shield the sensor during source conditioning. Move the crystal farther away (at least 25.4 cm (10 in.)) from the source.
	Intermittent connection occurring in sensor or feedthrough with thermal variation.	Use an ohmmeter to check electrical continuity / isolation of sensor head, feedthrough, and in-vacuum cable. Refer to the sensor's operating manual for detailed troubleshooting information.

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Table 5-1 Symptom/Cause/Remedy Chart (continued)

SYMPTOM	CAUSE	REMEDY
Thickness reproducibility is poor.	Erratic evaporation flux characteristics.	Move sensor to a different location. Check the evaporation source for proper operating conditions. Ensure relatively constant pool height and avoid tunneling into the melt. Assign multiple sensors to the source.
	Material does not adhere well to the crystal.	Check for contamination on the crystal's surface. Evaporate an intermediate layer of appropriate material onto the crystal to improve adhesion. Use gold, silver, or alloy crystals, as appropriate.
Rate control is poor.	PID control loop parameters are incorrect.	Test in Manual mode to ensure a stable rate is possible. Change PID control loop parameters. Refer to section 6.5.2, Loop Tuning Procedure, on page 6-7.
	Electron beam sweep frequency "beating" with the IQM-233 card's measurement frequency.	Adjust the sweep frequency so it is not in phase with the IQM-233 card's measurement frequency.
	Resolution is too low.	Increase the measurement period. Use measurement averaging.

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Table 5-1 Symptom/Cause/Remedy Chart (continued)

SYMPTOM	CAUSE	REMEDY
Source output of IQM-233 card is not functioning properly.	A voltage is being applied to the source output cable by the source power supply or other equipment.	Remove the cause of the applied voltage.
	Polarity of source output voltage is reversed or Full Scale voltage setting in software is not appropriate for source power supply.	Check the required input polarity and input voltage of the source power supply. Check the source output wiring of the IQM-233. Set the appropriate polarity and voltage range in IQM-233 or IQS-233 software.
	Source output cable wiring is incorrect.	Check source output cable wiring.
	IQM-233 card is malfunctioning.	Substitute a known good IQM-233 card (or other QCM).
Software is not recognizing the IQM-233 card.	IQM-233 card is not fully inserted into the PCI Express slot.	Reinstall IQM-233 card.
	IQM-233 device driver is not installed correctly.	Verify the operating system is Windows XP SP3, 7, or 8. Remove existing IQM233 DLL, device driver, and WinDriver. Remove IQM-233 Standard/IQS-233 Codeposition software. Determine if Windows operating system is 32-bit or 64-bit, and then install appropriate (32-bit or 64-bit) IQM233 DLL and install software. Refer to section 2.1.2.1.1, IQM-233 Card Installation Troubleshooting, on page 2-8.

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5.2 Maintenance

Routine maintenance is not required for the IQM-233 card. However, the computer the IQM-233 card is installed in should be operated in a clean environment. If cleaning of the inside of the computer (and therefore the IQM-233 card) becomes necessary due to dust accumulation, follow the computer manufacturer's cleaning recommendation.

5.3 Spare Parts

Oscillator . . . . . PN 782-900-010

SMA/BNC Adapter Cable . . . . . PN 600-1441-P1

BNC Cable (15.2 cm (6 in.)) . . . . . PN 782-902-011

BNC Cable (3.0 m (10 ft.)) . . . . . PN 782-902-012-10

BNC Cable (7.6 m (25 ft.)) . . . . . PN 782-902-012-25

BNC Cable (15.2 m (50 ft.)) . . . . . PN 782-902-012-50

BNC Cable (30.5 m (100 ft.)) . . . . . PN 782-902-012-99

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Chapter 6
Calibration Procedures

6.1 Importance of Density, Tooling and Z-Ratio

The quartz crystal microbalance precisely measures the mass added to the face of the oscillating quartz crystal sensor. The IQM-233's knowledge of the density of this added material allows conversion of the mass information into thickness. In some instances, where highest accuracy is required, it is necessary to make a density calibration as outlined in section 6.2.

Because the flow of material from a deposition is not uniform, it is necessary to account for the different amount of material flow onto the sensor compared to the substrates. This is accounted for by the Tooling parameter. Tooling can be experimentally established by following the guidelines in section 6.3 on page 6-2.

The Z-Ratio compensates for the elasticity of the deposited material to the quartz crystal. If the Z-Ratio is not known, it can be estimated from the procedures outlined in section 6.4 on page 6-3.

6.2 Determining Density

NOTE: The bulk density values retrieved from Appendix A, Material Table are sufficiently accurate for most applications.

Follow the steps below to determine density value.

1. Place a substrate (with proper masking for film thickness measurement) adjacent to the sensor, so that the same thickness will be accumulated on the crystal and substrate.
2. Set Density to the bulk value of the film material or to an approximate value.
3. Set Z-Ratio to 1.000 and Tooling to 100.00%.
4. Place a new crystal in the sensor and make a short deposition (1000-5000 Å).
5. After deposition, remove the test substrate and measure the film thickness with a multiple beam interferometer or a stylus-type profilometer.

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6 Determine the new density value with equation [1]:

$$\text{Density}(g/cm^3) = D_i\left(\frac{T_x}{T_m}\right) \quad [1]$$

where:

D_i = Initial density setting

T_x = Thickness reading on IQM-233

T_m = Measured thickness

7 Round off density to the nearest 0.01 g/cm^3.

8 A quick check of the calculated density may be made by programming the IQM-233 with the new density value and observing that the displayed thickness is equal to the measured thickness, provided that the IQM-233's thickness has not been zeroed between the test deposition and entering the calculated density.

NOTE: Due to variations in source distribution and other system factors, it is recommended that a minimum of three separate evaporations be made to obtain an average value for density.

NOTE: Slight adjustment of density may be necessary in order to achieve $T_x = T_m$.

6.3 Determining Tooling

1 Place a test substrate in the system's substrate holder.

2 Make a short deposition.

3 Remove the test substrate and measure the film thickness with a multiple beam interferometer or a stylus-type profilometer.

4 Calculate Tooling from the relationship shown in equation [2]:

$$\text{Tooling (\%)} = TF_i\left(\frac{T_m}{T_x}\right) \quad [2]$$

where

T_m = Actual thickness at substrate holder

T_x = Thickness reading in the IQM-233 software

TF_i = Initial Tooling factor

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5 Enter this new value for Tooling, rounded to the nearest 0.01%, in the Tooling box of the IQM-233 Standard software; T_m will equal T_x if calculations are done properly.

NOTE: Due to variations in source distribution and other system factors, it is recommended that a minimum of three separate evaporations be made to obtain an average value for Tooling.

6.4 Determining Z-Ratio

A list of Z-Ratio values for materials commonly used are available in Appendix A, Material Table. For other materials, Z-Ratio can be calculated from the following formula:

$$Z = \left(\frac{d_q \mu_q}{d_f \mu_f}\right)^{\frac{1}{2}} \qquad [3]$$

$$Z = 9.378 \times 10^5 (d_f \mu_f)^{-\frac{1}{2}} \qquad [4]$$

where:

d_f = Density (g/cm^3) of deposited film

μ_f = Shear modulus (dynes/cm^2) of deposited film

d_q = Density of quartz (crystal) (2.649 g/cm^3)

μ_q = Shear modulus of quartz (crystal) (3.32 x 10^{11} dynes/cm^2)

The densities and shear moduli of many materials can be found in a number of handbooks.

Laboratory results indicate that Z-Ratio values of materials in thin-film form are very close to the bulk values. However, for high stress producing materials, Z-Ratio values of thin films are slightly smaller than those of the bulk materials. For applications that require more precise calibration, the following direct method is suggested:

1 Establish the correct density value as described in section 6.2 on page 6-1.

2 Install a new crystal and record its starting frequency, F_{co}. The starting frequency will be displayed in the Freq (Hz) field of the Sensor-Output window.

3 Make a deposition on a test substrate such that the percent crystal life display will read approximately 50%, or near the end of crystal life for the particular material, whichever is smaller (the accuracy of the Z-Ratio determination will improve with increased material thickness).

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4 Stop the deposition and record the ending crystal frequency F_c.

5 Remove the test substrate and measure the film thickness with either a multiple beam interferometer or a stylus-type profilometer.

6 Using the density value from step 1 and the recorded values for F_{co} and F_c, adjust the Z-Ratio value in thickness equation [5] to bring the calculated thickness value into agreement with the actual thickness. If the calculated value of thickness is greater than the actual thickness, increase the Z-Ratio value. If the calculated value of thickness is less than the actual thickness, decrease the Z-Ratio value.

$$T_f = \frac{Z_q \times 10^4}{2\pi zp}\left\{\left(\frac{1}{F_{co}}\right)\mathrm{ATan}\left(z\mathrm{Tan}\left(\frac{\pi F_{co}}{F_q}\right)\right) - \left(\frac{1}{F_c}\right)\mathrm{ATan}\left(z\mathrm{Tan}\left(\frac{\pi F_c}{F_q}\right)\right)\right\} \qquad [5]$$

where:

T_f = Thickness of deposited film (kÅ)

F_{co} = Starting frequency of the sensor crystal (Hz)

F_c = Final frequency of the sensor crystal (Hz)

F_q = Nominal blank frequency = 6045000 (Hz)

z = Z-Ratio of deposited film material

Z_q = Specific acoustic impedance of quartz = 8765000 (kg/(m^2 x s))

p = Density of deposited film (g/cm^3)

For multiple layer deposition (for example, two layers), the Z-Ratio used for the second layer is determined by the relative thickness of the two layers. For most applications the following three rules will provide reasonable accuracies:

- If the thickness of layer 1 is large compared to layer 2, use the Z-Ratio of material 1 for both layers.
- If the thickness of layer 1 is thin compared to layer 2, use the Z-Ratio of material 2 for both layers.
- If the thickness of both layers is similar, use a value for Z-Ratio which is the weighted average of the two Z-Ratios for deposition of layer 2 and subsequent layers.

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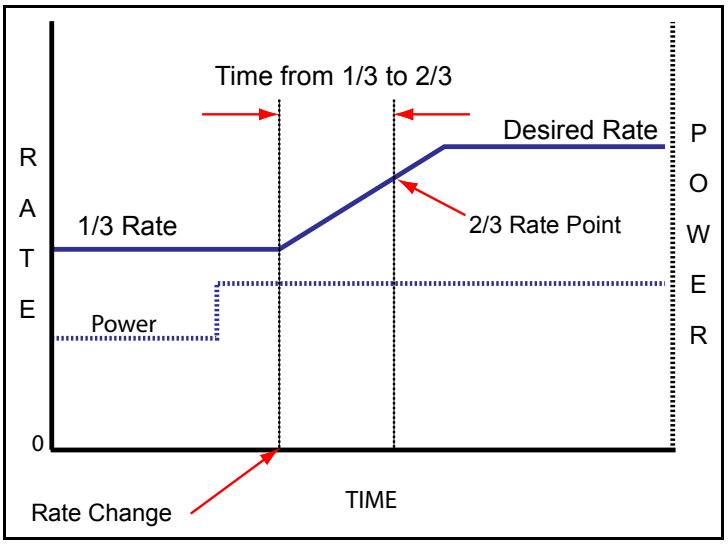
6.5 Tuning the Control Loop

The function of the control loop parameters is to match the instrument's reaction to an error (between the measured deposition rate and the desired rate) to the time related characteristics of the deposition source and its power supply. There are three adjustable parameters; **P** (proportional), **I** (integral) and **D** (derivative) used to accomplish this. It is convenient to think of sources as falling into two categories: "fast" or "slow." The tuning parameters are affected by source level, rate, sweep range or beam density, Tooling and source condition.

The P parameter is the proportional term that sets the gain of the control loop. Enter a higher value for a more responsive (but potentially unstable) control loop and a lower value for the less responsive control loop.

The I parameter is defined as the integral term that inversely sets the set point correction gain (a small number causes more error correction). It can be estimated as twice the time for the rate to go from 1/3 to 2/3 of the desired rate (see Figure 6-1). It instructs the controller on how much attention to pay to the schedule of the rate profile.

Figure 6-1 Determining the I value



The D parameter is equivalent to the system Dead Time and is used to compensate for slow responding sources such as boats and induction heated sources. This value can be estimated from the time difference between a change in % power and the start of an actual change in rate (see Figure 6-2.) The D parameter instructs the controller on how much attention to pay to the Rate Deviation error. A value of zero tells the controller to ignore the Rate Deviation error. A large value tells the controller that the source is slow and it is going to be harder to get it going and harder to stop it. Therefore, if the rate starts to fall off, power increases, or if the target rate is quickly approaching, power decreases. Measurement rate noise may

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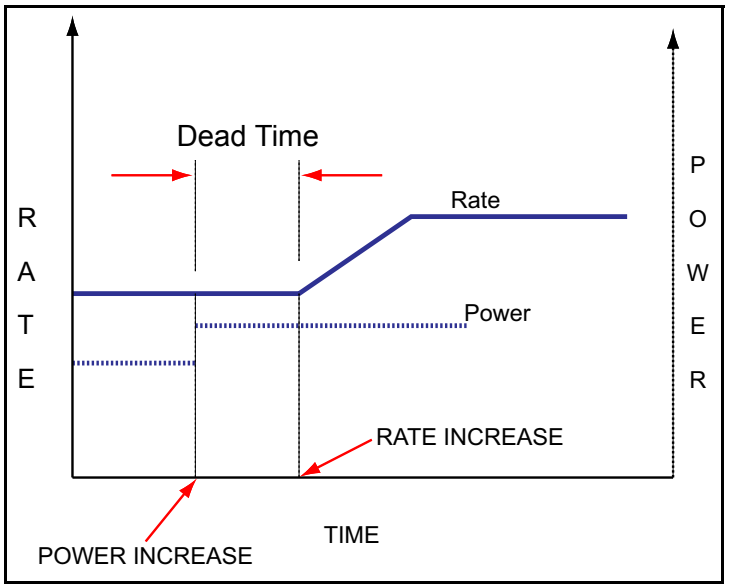
cause power output instability with larger D values. Use of the Filter Readings parameter can help reduce a power output instability (refer to section 3.3.3.1.2, General, on page 3-10).

Figure 6-2 Determining the D value



6.5.1 Identifying a Fast or Slow Source

Classifying a source as being fast or slow is based on the time it takes for the rate to change from a change in power (delay). It is straight forward to measure the delay. Using manual power, establish a rate and allow it to become steady. Increase the source power a few percent (~5% if possible). Allow the source to again stabilize. If the delay time is greater than 1 second, the source is characterized as slow. All other sources are considered fast. In general, electron beam (e-beam) sources (unless a hearth liner is used), some very small filament sources, and sputtering sources are considered fast sources. Thermal evaporation sources are typically considered slow.

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6.5.2 Loop Tuning Procedure

NOTE: Control loop tuning is a trial and error process and there is no "best" procedure to accomplish this task. It may take several adjustments to achieve the desired tune.

1 Set System Parameters

In the Setup window (**Setup >> General**):

- Set Measurement Period to 0.25.
- Set Filter Readings to 1 (no filter) to see the noise of the system.
- Clear the **Enable Simulate** check box (if selected).

2 Create a One-Layer Test Process

- In the Sensor Setup window (**Setup >> Sensor**), enter the Z-Ratio and density of the material being deposited.
- In the Source Setup window (**Setup >> Source**), set the desired rate and a non-zero Final Thickness (Final Thickness setting must be large enough so it will not be reached during this procedure).

3 Activate Data Logging

- Select the Data Log path by clicking **Setup >> Log** and choosing the desired save location.
- Click **Logging Off** (shown in red) on the IQM-233 Standard window. **Logging On** will now be displayed in green.

NOTE: Data logging does not collect data until **Start** is clicked.

4 Test the System Setup

- Set Source Control to Manual and click **Start.**
- Slowly increase Power to 10% and verify that the power supply output is 10% of Full Scale. If the readings do not agree, verify that the Full Scale voltage in the Source Setup window (**Setup >> Source**) agrees with the power supply input specifications.
- Continue to increase power until the desired rate is achieved.
- Log the data for a few minutes.
- Slowly decrease power to 0%, and then press **Stop**.
- Plot the data in a spreadsheet program. If the system has significant short term noise at a fixed power, the control loop will be difficult to adjust, especially at low rates. The source of the noise should be eliminated before attempting to set the PID values (see section 5.1, Troubleshooting Guide, on page 5-1).

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5 Set Filter Readings Parameter

In the Setup window (**Setup >> General**):

- Set the Measurement Period to the desired value.
- Test the setup following step 4 above.
- If rate noise is present with Filter Readings setting of 1, slowly increase the value from 1 to a higher value until the rate display noise is minimized.

NOTE: If Filter Readings is set too high, the display will lag the true system response and may hide significant problems.

6 Determine Max Power

- Verify Source Control is set to Manual and click **Start.**
- Slowly increase power until the desired rate is achieved.
- Record the Power reading at the desired rate as PWR_{DR}.
- Set **Max Power (%)** to a value 20% higher than PWR_{DR}.
- If finished, slowly decrease power to 0%, and then press **Stop**. Otherwise, continue to step 7.

7 Determine Open Loop Response Time (refer to Figure 6-1)

- Calculate 1/3 of the desired rate ($RATE_{1/3}$), and 2/3 of the desired rate ($RATE_{2/3}$).
- Slowly adjust the power until the rate matches $RATE_{1/3}$ and is steady.
- Quickly adjust Power (%) to PWR_{DR} and measure the time for the rate to equal $RATE_{2/3}$.
- Twice the measured time is the step response time, $TIME_{SR}$.
- If finished, slowly decrease power to 0%, and then press **Stop**. Otherwise, continue to step 8.

NOTE: $TIME_{SR}$ is typically 0.2 to 1 second for e-beam evaporation and at least 5 seconds for thermal evaporation.

NOTE: It is recommended to repeat this step several times to get an average response time.

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8 **Determine the Dead Time** (refer to Figure 6-2)

- Slowly increase power until the desired rate is achieved.
- Quickly adjust Power by 1 to 2% and measure the time between when the power is changed and when a change in rate is observed.
- The time between the change in power and when the rate starts to change is the Dead Time.
- If finished, slowly decrease power to 0%, and then press **Stop**. Otherwise, continue at step 9.

NOTE: It is common for the Dead Time of a fast source, such as an e-beam, to be very small and possibly immeasurable. In this case, the Dead Time can be considered zero.

9 **Set Initial PID Values**

- Set the power to zero.

9a **For a fast source** (refer to section 6.5.1)

- In the Source Setup window (**Setup >> Source**):
  - Set P to 25.
  - Set I to the TIMESR value (calculated in step 7) or zero.
  - Set D to zero.

9b **For a slow source** (refer to section 6.5.1)

- In the Source Setup window (**Setup >> Source**):
  - Set P to 25.
  - Set I to the TIMESR value (calculated in step 7).
  - Set D to the Dead Time value (calculated in step 8).

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10 Adjust PID Values according to control response

- Set Source Control to Auto to activate PID control and observe the power.
  - The power should rise from 0% and stabilize near PWR_{DR}.
  - If there is more than 10% overshoot in power or if the curve appears under damped, lower the P value. If the time to reach PWR_{DR} is very slow (over damped), increase the P value. See Figure 6-3.
  - A lower I value will increase response for over damped sources. A higher value may reduce ringing and rate deviations seen with under damped sources. See Figure 6-3.
  - The D value should not need much adjustment, but if under damped behavior is observed, increase the D value. If it appears over damped, decrease the D value. See Figure 6-4.
- Continue to adjust P and I values, alternating between 0% power in Manual mode and Auto mode until the steady-state response is smooth and the step response is controlled.
- If finished, slowly decrease power to 0%, and then press **Stop**.

NOTE: Preconditioning will minimize step changes.

NOTE: E-beam systems may require additional steps to limit the control loop response during arcing. First, be sure the Max Power parameter in the Source Setup window is set to limit the output to a reasonable value for the material and rate. The Slew setting can further limit aggressive power changes, see section 3.3.3.1.4 on page 3-14. At rates below 10 Å/s, a Slew of 1 - 2% is common. Increasing the Filter Readings parameter will limit the PID response to occasional large noise spikes, such as those from arcing.

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Figure 6-3 Examples of Control Loop Damping

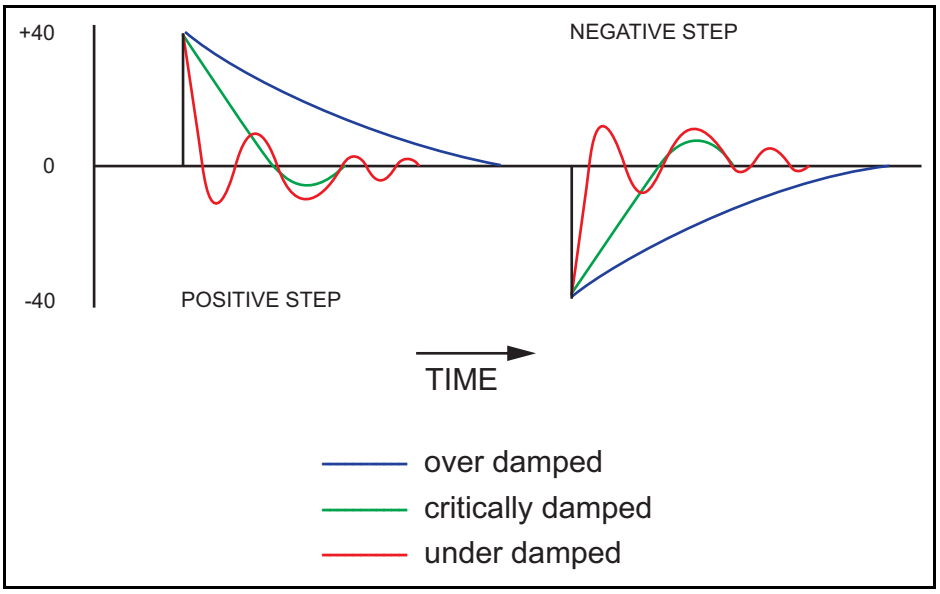
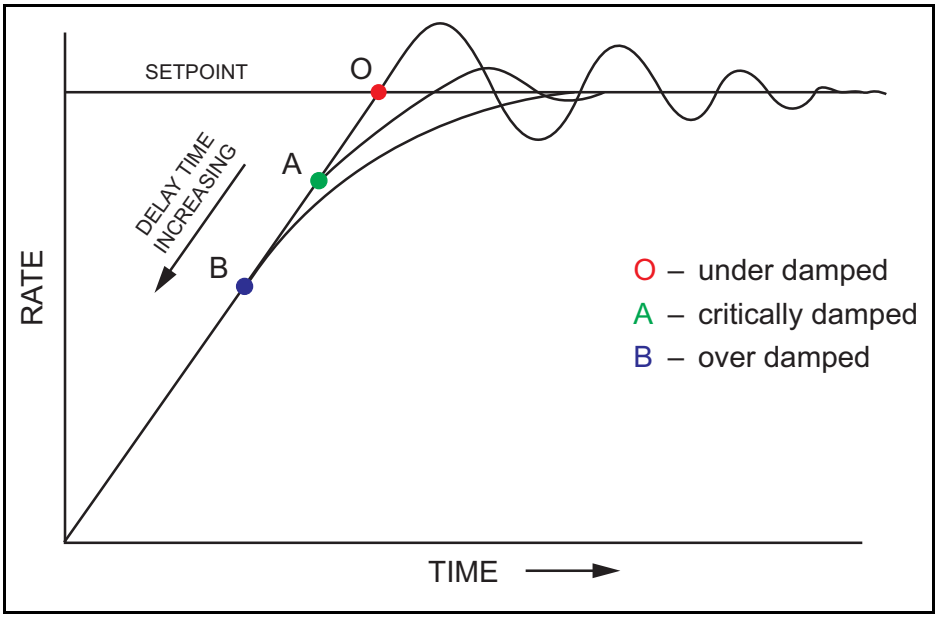


Figure 6-4 Examples of Dead Time Settings



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Chapter 7
Measurement Theory

7.1 Basics

The quartz crystal deposition monitor, or QCM, utilizes the piezoelectric sensitivity of a quartz monitor crystal to added mass. The QCM uses this mass sensitivity to control the deposition rate and final thickness of a vacuum deposition.

When a voltage is applied across the faces of a properly shaped piezoelectric crystal, the crystal is distorted and changes shape in proportion to the applied voltage. At certain discrete frequencies of applied voltage, a condition of very sharp electro-mechanical resonance is encountered.

When mass is added to the face of a resonating quartz crystal, the frequency of these resonances is reduced. This change in frequency is very repeatable and is precisely understood for specific oscillating modes of quartz. This heuristically easy-to-understand phenomenon is the basis of an indispensable measurement and process control tool that can easily detect the addition of less than an atomic layer of an adhered foreign material.

In the late 1950s it was noted by Sauerbrey[1,2] and Lostis[3] that the change in frequency, $\Delta F = F_q - F_c$, of a quartz crystal with coated (or composite) and uncoated frequencies, F_c and F_q respectively, is related to the change in mass from the added material, M_f , as follows:

$$\frac{M_f}{M_q} = \frac{(\Delta F)}{F_q} \qquad [1]$$

where M_q is the mass of the uncoated quartz crystal. Simple substitutions lead to the equation that was used with the first “frequency measurement” instruments:

$$T_f = \frac{K(\Delta F)}{d_f} \qquad [2]$$

where the film thickness, T_f, is proportional (through K) to the frequency change, ΔF, and inversely proportional to the density of the film, d_f. The constant, $K = N_{at} d_q / F_q^2$; where d_q (= 2.649 g/cm^3) is the density of single crystal quartz and N_{at} (=166100 Hz cm) is the frequency constant of AT cut quartz. A crystal with a starting frequency of 6.0 MHz will display a reduction of its frequency by 2.27 Hz

1.G. Z. Sauerbrey, Phys. Verhand .8, 193 (1957)
2.G. Z. Sauerbrey, Z. Phys. 155,206 (1959)
3.P. Lostis, Rev. Opt. 38,1 (1959)

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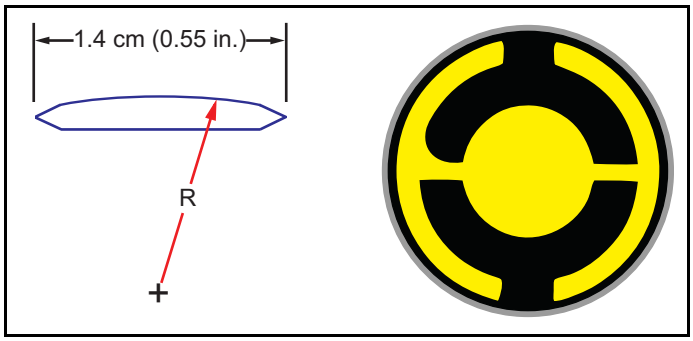
when 1 angstrom of Aluminum (density of 2.77 g/cm^3) is added to its surface. In this manner the thickness of a rigid adlayer is inferred from the precise measurement of the crystal's frequency shift. The quantitative knowledge of this effect provides a means of determining how much material is being deposited on a substrate in a vacuum system, a measurement that was not convenient or practical prior to this understanding.

7.1.1 Monitor Crystals

No matter how sophisticated the electronics surrounding it, the essential device of the deposition monitor is the quartz crystal. The quartz resonator shown in Figure 7-1 has a frequency response spectrum that is schematically shown in Figure 7-2. The ordinate represents the magnitude of response, or current flow of the crystal, at the specified frequency.

Figure 7-1 Quartz resonator



The lowest frequency response is primarily a "thickness shear" mode that is called the fundamental. The characteristic movement of the thickness shear mode is for displacement to take place parallel to the major monitor crystal faces. In other words, the faces are displacement antinodes as shown in Figure 7-3.

The responses located slightly higher in frequency are called anharmonics; they are a combination of the thickness shear and thickness twist modes. The response at about three times the frequency of the fundamental is called the third quasiharmonic. There is also a series of anharmonics slightly higher in frequency associated with the quasiharmonic.

The monitor crystal design depicted in Figure 7-1 is the result of several significant improvements from the square crystals with fully electroded plane parallel faces that were first used.

The first improvement was to use circular crystals. This increased symmetry greatly reduced the number of allowed vibrational modes. The second set of improvements was to contour one face of the crystal and to reduce the size of the exciting electrode. These improvements have the effect of trapping the acoustic energy. Reducing the electrode diameter limits the excitation to the central area.

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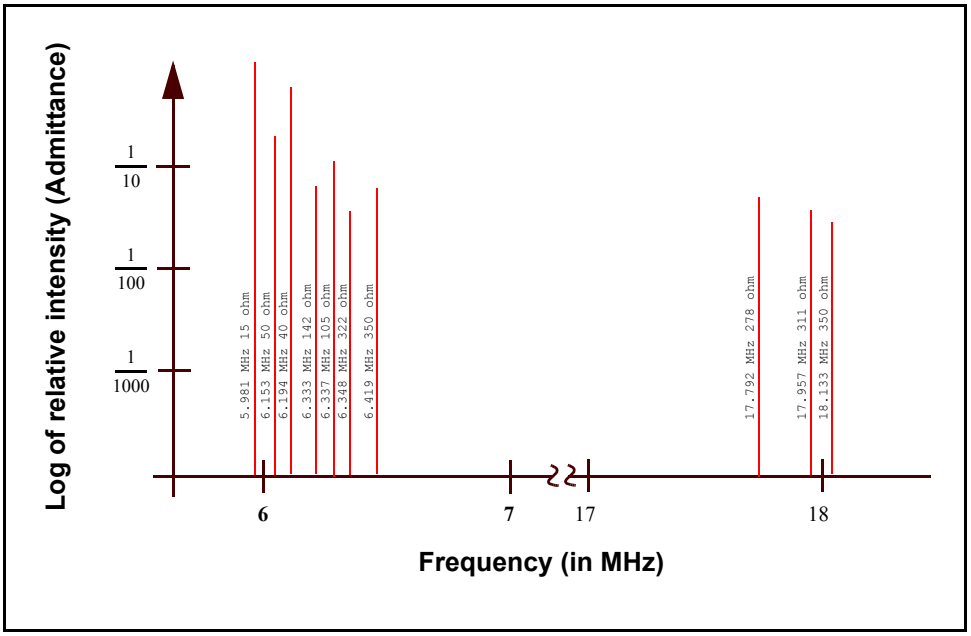
Contouring dissipates the energy of the traveling acoustic wave before it reaches the edge of the crystal. Energy is not reflected back to the center where it can interfere with other newly launched waves, essentially making a small crystal appear to behave as though it is infinite in extent. With the crystal's vibrations restricted to the center, it is practical to clamp the outer edges of the crystal to a holder and not produce any undesirable effects.

Contouring also reduces the intensity of response of the generally unwanted anharmonic modes; hence, the potential for an oscillator to sustain an unwanted oscillation is substantially reduced.

Figure 7-2 Frequency response spectrum



The use of an adhesion layer has improved the electrode-to-quartz bonding, reducing *rate spikes* caused by micro-tears between the electrode and the quartz as film stress rises. These micro-tears leave portions of the deposited film unattached and therefore unable to participate in the oscillation. These free portions are no longer detected and the wrong thickness consequently inferred.

The AT resonator is usually chosen for deposition monitoring because at room temperature it can be made to exhibit a very small frequency change due to temperature changes. Since there is presently no way to separate the frequency change caused by added mass (which is negative) or even the frequency changes caused by temperature gradients across the crystal or film induced stresses, it is essential to minimize these temperature-induced changes. It is only in this way that small changes in mass can be measured accurately.

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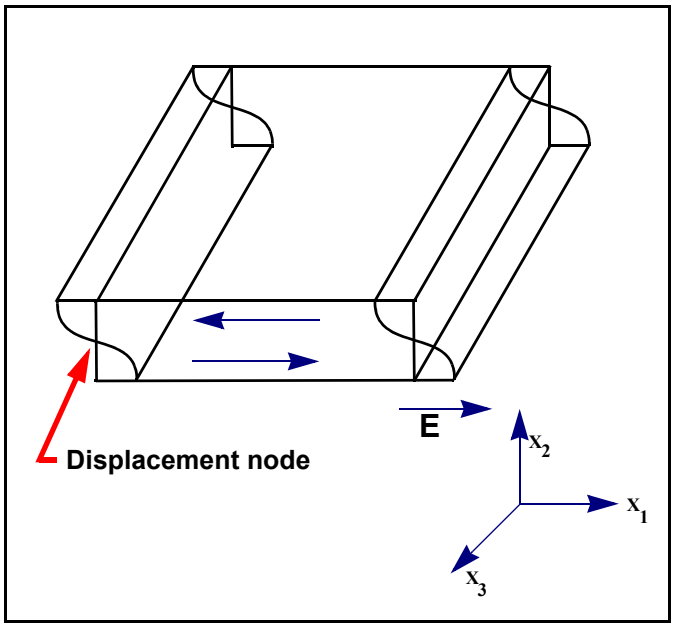
Figure 7-3 Thickness shear displacement



7.1.2 Period Measurement Technique

Although instruments using equation [2] were very useful, it was soon noted they had a very limited range of accuracy, typically holding accuracy for ΔF less than 0.02 F_q. In 1961, it was recognized by Behrndt[4] that:

$$\frac{M_f}{M_q} = \frac{(T_c - T_q)}{T_q} = \frac{(\Delta F)}{F_c} \qquad [3]$$

where T_c and T_q are the periods of oscillation of the crystal with film (composite) and the bare crystal respectively.

The period measurement technique was the outgrowth of two factors; first, the digital implementation of time measurement, and second, the recognition of the mathematically rigorous formulation of the proportionality between the crystal's thickness, I_q, and the period of oscillation, $T_q = 1/F_q$.

Electronically, the period measurement technique uses a second crystal oscillator, or reference oscillator, not affected by the deposition and usually much higher in frequency than the monitor crystal. This reference oscillator is used to generate small precision time intervals which are used to determine the oscillation period of the monitor crystal. This is done by using two pulse accumulators. The first is used to accumulate a fixed number of cycles, m, of the monitor crystal. The second is turned on at the same time and accumulates cycles from the reference oscillator until m counts are accumulated in the first.

4.K. H. Behrndt, J. Vac. Sci. Technol. 8, 622 (1961)

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Since the frequency of the reference is stable and known, the time to accumulate the m counts is known to an accuracy equal to ± $2/F_r$ where F_r is the reference oscillator's frequency. The monitor crystal's period is $(n/F_r)/m$ where n is the number of counts in the second accumulator. The precision of the measurement is determined by the speed of the reference clock and the length of the gate time (which is set by the size of m). Increasing one or both of these leads to improved measurement precision. Having a high frequency reference oscillator is important for rapid measurements (which require short gating times), low deposition rates and low density materials.

7.1.3 Z-Match Technique

After learning of fundamental work by Miller and Bolef [5], which rigorously treated the resonating quartz and deposited film system as a one-dimensional continuous acoustic resonator, Lu and Lewis[6] developed the simplifying Z-Match® equation in 1972. Advances in electronics taking place at the same time, namely the micro-processor, made it practical to solve the Z-Match equation in "real-time". Most deposition process controllers sold today use this sophisticated equation that takes into account the acoustic properties of the resonating quartz and film system as shown in equation [4].

$$T_f = \left(\frac{N_{at} d_q}{\pi d_f F_c Z}\right) \arctan\left(Z \tan\left[\frac{\pi(F_q - F_c)}{F_q}\right]\right) \qquad [4]$$

where $Z=(d_q u_q/d_f u_f)^{1/2}$ is the acoustic impedance ratio and u_q and u_f are the shear moduli of the quartz and film, respectively. Finally, there was a fundamental understanding of the frequency-to-thickness conversion that could yield theoretically correct results in a time frame that was practical for process control. To achieve this new level of accuracy requires only that the user enter an additional material parameter, Z, for the film being deposited. This equation has been tested for a number of materials, and has been found to be valid for frequency shifts equivalent to $F_f = 0.4F_q$. Keep in mind that equation [2] was valid to only $0.02F_q$ and equation [3] was valid only to $\sim 0.05F_q$.

5.J. G. Miller and D. I. Bolef, J. Appl. Phys. 39, 5815, 4589 (1968)
6.C. Lu and O. Lewis, J Appl. Phys. 43, 4385 (1972)

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Appendix A
Material Table

A.1 Introduction

Table A-1 represents the density and Z-Ratio for various materials. The list is alphabetical by chemical formula.

An * is used to indicate that a Z-Ratio has not been established for a certain material. A value of 1.000 is defaulted in these situations. To determine the Z-Ratio where the Z-Ratio for a material has not been established, refer to section 6.4, Determining Z-Ratio, on page 6-3.

WARNING

Some of these materials are toxic. Consult their material safety data sheet and safety instructions before use.

Table A-1 Material table

Formula	Density	Z-Ratio	Material Name
Ag	10.500	0.529	silver
AgBr	6.470	1.180	silver bromide
AgCl	5.560	1.320	silver chloride
Al	2.700	1.080	aluminum
Al_2O_3	3.970	0.336	aluminum oxide
Al_4C_3	2.360	*1.000	aluminum carbide
AlF_3	3.070	*1.000	aluminum fluoride
AlN	3.260	*1.000	aluminum nitride
AlSb	4.360	0.743	aluminum antimonide
As	5.730	0.966	arsenic
As_2Se_3	4.750	*1.000	arsenic selenide
Au	19.300	0.381	gold
B	2.370	0.389	boron
B_20_3	1.820	*1.000	boron oxide
B_4C	2.370	*1.000	boron carbide
BN	1.860	*1.000	boron nitride

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Table A-1 Material table (continued)

Formula	Density	Z-Ratio	Material Name
Ba	3.500	2.100	barium
BaF_2	4.886	0.793	barium fluoride
BaN_2O_6	3.244	1.261	barium nitrate
BaO	5.720	*1.000	barium oxide
$BaTiO_3$	5.999	0.464	barium titanate (tetr)
$BaTiO_3$	6.035	0.412	barium titanate (cubic)
Be	1.850	0.543	beryllium
BeF_2	1.990	*1.000	beryllium fluoride
BeO	3.010	*1.000	beryllium oxide
Bi	9.800	0.790	bismuth
Bi_2O_3	8.900	*1.000	bismuth oxide
Bi_2S_3	7.390	*1.000	bismuth trisulphide
Bi_2Se_3	6.820	*1.000	bismuth selenide
Bi_2Te_3	7.700	*1.000	bismuth telluride
BiF_3	5.320	*1.000	bismuth fluoride
C	2.250	3.260	carbon (graphite)
C	3.520	0.220	carbon (diamond)
C_8H_8	1.100	*1.000	parlyene (union carbide)
Ca	1.550	2.620	calcium
CaF_2	3.180	0.775	calcium fluoride
CaO	3.350	*1.000	calcium oxide
$CaO\text{-}SiO_2$	2.900	*1.000	calcium silicate (3)
$CaSO_4$	2.962	0.955	calcium sulfate
$CaTiO_3$	4.100	*1.000	calcium titanate
$CaWO_4$	6.060	*1.000	calcium tungstate
Cd	8.640	0.682	cadmium
CdF_2	6.640	*1.000	cadmium fluoride
CdO	8.150	*1.000	cadmium oxide
CdS	4.830	1.020	cadmium sulfide
CdSe	5.810	*1.000	cadmium selenide
CdTe	6.200	0.980	cadmium telluride
Ce	6.780	*1.000	cerium
CeF_3	6.160	*1.000	cerium (iii) fluoride

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Table A-1 Material table (continued)

Formula	Density	Z-Ratio	Material Name
CeO_2	7.130	*1.000	cerium (iv) dioxide
Co	8.900	0.343	cobalt
CoO	6.440	0.412	cobalt oxide
Cr	7.200	0.305	chromium
Cr_2O_3	5.210	*1.000	chromium (iii) oxide
Cr_3C_2	6.680	*1.000	chromium carbide
CrB	6.170	*1.000	chromium boride
Cs	1.870	*1.000	cesium
Cs_2SO_4	4.243	1.212	cesium sulfate
CsBr	4.456	1.410	cesium bromide
CsCl	3.988	1.399	cesium chloride
CsI	4.516	1.542	cesium iodide
Cu	8.930	0.437	copper
Cu_2O	6.000	*1.000	copper oxide
Cu_2S	5.600	0.690	copper (i) sulfide (alpha)
Cu_2S	5.800	0.670	copper (i) sulfide (beta)
CuS	4.600	0.820	copper (ii) sulfide
Dy	8.550	0.600	dysprosium
Dy_2O_3	7.810	*1.000	dysprosium oxide
Er	9.050	0.740	erbium
Er_2O_3	8.640	*1.000	erbium oxide
Eu	5.260	*1.000	europium
EuF_2	6.500	*1.000	europium fluoride
Fe	7.860	0.349	iron
Fe_2O_3	5.240	*1.000	iron oxide
FeO	5.700	*1.000	iron oxide
FeS	4.840	*1.000	iron sulphide
Ga	5.930	0.593	gallium
Ga_2O_3	5.880	*1.000	gallium oxide (b)
GaAs	5.310	1.590	gallium arsenide
GaN	6.100	*1.000	gallium nitride
GaP	4.100	*1.000	gallium phosphide
GaSb	5.600	*1.000	gallium antimonide

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Table A-1 Material table (continued)

Formula	Density	Z-Ratio	Material Name
Gd	7.890	0.670	gadolinium
Gd_2O_3	7.410	*1.000	gadolinium oxide
Ge	5.350	0.516	germanium
Ge_3N_2	5.200	*1.000	germanium nitride
GeO_2	6.240	*1.000	germanium oxide
GeTe	6.200	*1.000	germanium telluride
Hf	13.090	0.360	hafnium
HfB_2	10.500	*1.000	hafnium boride
HfC	12.200	*1.000	hafnium carbide
HfN	13.800	*1.000	hafnium nitride
HfO_2	9.680	*1.000	hafnium oxide
$HfSi_2$	7.200	*1.000	hafnium silicide
Hg	13.460	0.740	mercury
Ho	8.800	0.580	holminum
Ho_2O_3	8.410	*1.000	holminum oxide
In	7.300	0.841	indium
In_2O_3	7.180	*1.000	indium sesquioxide
In_2Se_3	5.700	*1.000	indium selenide
In_2Te_3	5.800	*1.000	indium telluride
InAs	5.700	*1.000	indium arsenide
InP	4.800	*1.000	indium phosphide
InSb	5.760	0.769	indium antimonide
Ir	22.400	0.129	iridium
K	0.860	10.189	potassium
KBr	2.750	1.893	potassium bromide
KCl	1.980	2.050	potassium chloride
KF	2.480	*1.000	potassium fluoride
KI	3.128	2.077	potassium iodide
La	6.170	0.920	lanthanum
La_2O_3	6.510	*1.000	lanthanum oxide
LaB_6	2.610	*1.000	lanthanum boride
LaF_3	5.940	*1.000	lanthanum fluoride
Li	0.530	5.900	lithium

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Table A-1 Material table (continued)

Formula	Density	Z-Ratio	Material Name
LiBr	3.470	1.230	lithium bromide
LiF	2.638	0.778	lithium fluoride
$LiNbO_3$	4.700	0.463	lithium niobate
Lu	9.840	*1.000	lutetium
Mg	1.740	1.610	magnesium
$MgAl_2O_4$	3.600	*1.000	magnesium aluminate
$MgAl_2O_6$	8.000	*1.000	spinel
MgF_2	3.180	0.637	magnesium fluoride
MgO	3.580	0.411	magnesium oxide
Mn	7.200	0.377	manganese
MnO	5.390	0.467	manganese oxide
MnS	3.990	0.940	manganese (ii) sulfide
Mo	10.200	0.257	molybdenum
Mo_2C	9.180	*1.000	molybdenum carbide
MoB_2	7.120	*1.000	molybdenum boride
MoO_3	4.700	*1.000	molybdenum trioxdide
MoS_2	4.800	*1.000	molybdenum disulfide
Na	0.970	4.800	sodium
Na_3AlF_6	2.900	*1.000	cryolite
$Na_5Al_3F_{14}$	2.900	*1.000	chiolite
NaBr	3.200	*1.000	sodium bromide
NaCl	2.170	1.570	sodium chloride
$NaClO_3$	2.164	1.565	sodium chlorate
NaF	2.558	1.645	sodium fluoride
$NaNO_3$	2.270	1.194	sodium nitrate
Nb	8.578	0.492	niobium (columbium)
Nb_2O_3	7.500	*1.000	niobium trioxide
Nb_2O_5	4.470	*1.000	niobium (v) oxide
NbB_2	6.970	*1.000	niobium boride
NbC	7.820	*1.000	niobium carbide
NbN	8.400	*1.000	niobium nitride
Nd	7.000	*1.000	neodynium
Nd_2O_3	7.240	*1.000	neodynium oxide

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Table A-1 Material table (continued)

Formula	Density	Z-Ratio	Material Name
NdF_3	6.506	*1.000	neodynium fluoride
Ni	8.910	0.331	nickel
NiCr	8.500	*1.000	nichrome
NiCrFe	8.500	*1.000	inconel
NiFe	8.700	*1.000	permalloy
NiFeMo	8.900	*1.000	supermalloy
NiO	7.450	*1.000	nickel oxide
P_3N_5	2.510	*1.000	phosphorus nitride
Pb	11.300	1.130	lead
$PbCl_2$	5.850	*1.000	lead chloride
PbF_2	8.240	0.661	lead fluoride
PbO	9.530	*1.000	lead oxide
PbS	7.500	0.566	lead sulfide
PbSe	8.100	*1.000	lead selenide
$PbSnO_3$	8.100	*1.000	lead stannate
PbTe	8.160	0.651	lead telluride
Pd	12.038	0.357	palladium
PdO	8.310	*1.000	palladium oxide
Po	9.400	*1.000	polonium
Pr	6.780	*1.000	praseodymium
Pr_2O_3	6.880	*1.000	praseodymium oxide
Pt	21.400	0.245	platinum
PtO_2	10.200	*1.000	platinum oxide
Ra	5.000	*1.000	radium
Rb	1.530	2.540	rubidium
RbI	3.550	*1.000	rubidium iodide
Re	21.040	0.150	rhenium
Rh	12.410	0.210	rhodium
Ru	12.362	0.182	ruthenium
S_8	2.070	2.290	sulphur
Sb	6.620	0.768	antimony
Sb_2O_3	5.200	*1.000	antimony trioxide
Sb_2S_3	4.640	*1.000	antimony trisulfide

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Table A-1 Material table (continued)

Formula	Density	Z-Ratio	Material Name
Sc	3.000	0.910	scandium
Sc_2O_3	3.860	*1.000	scandium oxide
Se	4.810	0.864	selenium
Si	2.320	0.712	silicon
Si_3N_4	3.440	*1.000	silicon nitride
SiC	3.220	*1.000	silicon carbide
SiO	2.130	0.870	silicon (ii) oxide
SiO_2	2.648	1.000	silicon dioxide
Sm	7.540	0.890	samarium
Sm_2O_3	7.430	*1.000	samarium oxide
Sn	7.300	0.724	tin
SnO_2	6.950	*1.000	tin oxide
SnS	5.080	*1.000	tin sulfide
SnSe	6.180	*1.000	tin selenide
SnTe	6.440	*1.000	tin telluride
Sr	2.600	*1.000	strontium
SrF_2	4.277	0.727	strontium fluoride
SrO	4.990	0.517	strontium oxide
Ta	16.600	0.262	tantalum
Ta_2O_5	8.200	0.300	tantalum (v) oxide
TaB_2	11.150	*1.000	tantalum boride
TaC	13.900	*1.000	tantalum carbide
TaN	16.300	*1.000	tantalum nitride
Tb	8.270	0.660	terbium
Tc	11.500	*1.000	technetium
Te	6.250	0.900	tellurium
TeO_2	5.990	0.862	tellurium oxide
Th	11.694	0.484	thorium
ThF_4	6.320	*1.000	thorium (iv) fluoride
ThO_2	9.860	0.284	thorium dioxide
$ThOF_2$	9.100	*1.000	thorium oxyfluoride
Ti	4.500	0.628	titanium
Ti_20_3	4.600	*1.000	titanium sesquioxide

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Table A-1 Material table (continued)

Formula	Density	Z-Ratio	Material Name
TiB_2	4.500	*1.000	titanium boride
TiC	4.930	*1.000	titanium carbide
TiN	5.430	*1.000	titanium nitride
TiO	4.900	*1.000	titanium oxide
TiO_2	4.260	0.400	titanium (iv) oxide
Tl	11.850	1.550	thallium
TlBr	7.560	*1.000	thallium bromide
TlCl	7.000	*1.000	thallium chloride
TlI	7.090	*1.000	thallium iodide (b)
U	19.050	0.238	uranium
U_3O_8	8.300	*1.000	tri uranium octoxide
U_4O_9	10.969	0.348	uranium oxide
UO_2	10.970	0.286	uranium dioxide
V	5.960	0.530	vanadium
V_2O_5	3.360	*1.000	vanadium pentoxide
VB_2	5.100	*1.000	vanadium boride
VC	5.770	*1.000	vanadium carbide
VN	6.130	*1.000	vanadium nitride
VO_2	4.340	*1.000	vanadium dioxide
W	19.300	0.163	tungsten
WB_2	10.770	*1.000	tungsten boride
WC	15.600	0.151	tungsten carbide
WO_3	7.160	*1.000	tungsten trioxide
WS_2	7.500	*1.000	tungsten disulphide
WSi_2	9.400	*1.000	tungsten silicide
Y	4.340	0.835	yttrium
Y_20_3	5.010	*1.000	yttrium oxide
Yb	6.980	1.130	ytterbium
Yb_2O_3	9.170	*1.000	ytterbium oxide
Zn	7.040	0.514	zinc
Zn_3Sb_2	6.300	*1.000	zinc antimonide
ZnF_2	4.950	*1.000	zinc fluoride
ZnO	5.610	0.556	zinc oxide

Table A-1 Material table (continued)

Formula	Density	Z-Ratio	Material Name
ZnS	4.090	0.775	zinc sulfide
ZnSe	5.260	0.722	zinc selenide
ZnTe	6.340	0.770	zinc telluride
Zr	6.490	0.600	zirconium
ZrB_2	6.080	*1.000	zirconium boride
ZrC	6.730	0.264	zirconium carbide
ZrN	7.090	*1.000	zirconium nitride
ZrO_2	5.600	*1.000	zirconium oxide

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