



STM-2

Rate and Thickness Monitor

PN 074-613-P1D

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

**INFICON Inc.
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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: STM-2 Deposition Monitor (including its accessories and options)

Applicable Directives: 2014/30/EU (General EMC)

2011/65/EU (RoHS2)

2014/35/EU (Low Voltage Directive): This equipment is powered via USB. Input power is below the threshold for this Directive, therefore no safety testing is required.

Applicable Standards:

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)
(EMC – Measurement, Control & Laboratory Equipment)

RoHS: Fully Compliant

CE Implementation Date: Sept 10, 2014 (Revised 5/29/15)

Authorized Representative: Steven Schill

Thin Film Business Line Manager
INFICON, Inc.

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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

STM-2™ is a USB-powered thin film thickness and rate deposition monitor (see [Figure 1-1](#)). STM-2 provides precise control of thickness or mass deposition experiments using a USB connection, Windows® or LabVIEW™ software (provided), and a Windows computer (user supplied).

The STM-2 internal oscillator allows the sensor to be located within 76.2 cm (30 in.) of STM-2. An external oscillator, PN 783-500-013, can be used when the sensor is located farther than 101.6 cm (40 in.) from STM-2.

STM-2 makes ten measurements per second. The measurements are shown on a 0.01Å/s rate display. STM-2 LabVIEW software has an option for multi-layer mode. This mode enables a **Layer Stackup** pane, displaying a list of process layers. It also enables cumulative substrate thickness to be displayed on the software (see [section 4.3.1 on page 4-6](#)).

Figure 1-1 STM-2



1.1.1 Related Manuals

Sensors are covered in separate manuals. These manuals are contained in the Thin Film Manuals CD (PN 074-5000-G1), which is part of the ship kit.

- ◆ PN 074-154—Bakeable Sensor
- ◆ PN 074-156—Front Load Sensor, Single/Dual
- ◆ PN 074-157—Sputtering Sensor
- ◆ PN 074-609—Cool Drawer Sensor, Single/Dual

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 STM-2 efficiency when followed.



CAUTION

Failure to heed these messages could result in damage to STM-2 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



CAUTION

STM-2 contains delicate circuitry, susceptible to transient power line voltages. Disconnect the USB cord whenever making any sensor connections or when the case is open.

Refer all maintenance to qualified personnel.



CAUTION

STM-2 may not be suitable for use with RF sputtering systems or other electrically noisy environments.



WARNING

Failure to operate STM-2 in the manner intended by INFICON can circumvent the safety protection provided by the instrument and may result in personal injury.

1.3 How To Contact INFICON

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

- ◆ Sales and Customer Service
- ◆ Technical Support
- ◆ Repair Service

When communicating with INFICON about STM-2, please have the following information readily available:

- ◆ the Sales Order or Purchase Order number of the STM-2 purchase.
- ◆ the version of STM-2 software (see [section 3.3.3.1 on page 3-18](#) or [section 4.3.7 on page 4-18](#)).
- ◆ the version of Windows operating system.
- ◆ a description of the problem.
- ◆ an explanation of any corrective action that may have already been attempted.
- ◆ the exact wording of any error messages that may have been received.

1.3.1 Returning STM-2

Do not return any component of STM-2 to INFICON before speaking with a Customer Support Representative and obtaining a Return Material Authorization (RMA) number. STM-2 will not be serviced without a RMA number.

Packages delivered to INFICON without a RMA number will be held until the customer is contacted. This will result in delays in servicing STM-2.

If returning STM-2 with a crystal sensor or another component potentially exposed to process materials, prior to being given a RMA number, a completed Declaration Of Contamination (DOC) form will be required. DOC forms must be approved by INFICON before a RMA number is issued. INFICON may require that the component be sent to a designated decontamination facility, not to the factory.

1.4 Specifications

Compatible Sensor	Non-shuttered single QCM sensor
Sensor Inputs	1
Sensor Input	Female BNC
Measurement Frequency Range . . .	6.0 to 5.0 MHz (fixed)
Frequency Resolution	± 0.03 Hz @ 6 MHz
Measurement Interval	0.10 s
Reference Frequency Stability	± 2 ppm
Thickness and Rate	
Resolution/Measurement	± 0.037 Å @ tooling/density = 100/1 Fundamental frequency = 6 MHz
Thickness Display Resolution	1 Å
Interface	USB, 5 m (16.4 ft.) maximum length

1.4.1 Power

Rated Supply Voltage	400 mA, 5 V (dc)
USB Isolation Voltage	1000 V
USB Isolation Capacitance	300 pF typically

1.4.2 Operating Environment

Usage	Indoor use only
Operating Temperature	0 to 50°C (32 to 122°F)
Storage Temperature	-10 to 60°C (14 to 140°F)
Humidity	Up to 85% RH, non-condensing
Altitude	Up to 2000 meters
Pollution Degree	2

1.4.3 Size and Weight

Size	11.4 x 7.6 x 2.5 cm (4.5 x 3 x 1 in.)
Weight	57 g (2 oz.)

1.4.4 Computer Requirements

Operating system	Windows 8, Windows 7, Windows Vista, Windows XP, or Windows 2000
USB Port(s)	One USB 1.1 (or later) port for each STM-2

1.5 Unpacking and Inspection

- 1 Remove STM-2 from its packaging.
- 2 Carefully examine STM-2 for damage that may have occurred during shipping. It is especially important to note obvious rough handling on the outside of the container. *Immediately report any damage to the carrier and to INFICON.*

NOTE: Do not discard the packaging material until inventory has been taken and installation is successful.

- 3 Refer to the invoice and take inventory.
- 4 To install STM-2, see [Chapter 2, Installation](#).

For additional information or technical assistance, contact INFICON (refer to [section 1.3 on page 1-4](#)).

1.6 Parts and Options Overview

1.6.1 Base Configuration

STM-2 with software and cables . . . PN STM-2
 (Included cables shown in [section 1.6.2](#))

1.6.2 Accessories

5 m (16.4 ft.) USB cable PN 068-0506
 15.2 cm (6 in.) BNC PN 755-257-G6

1.6.2.1 Oscillator Kit

Although the STM2 has an internal oscillator, an option exists to use an external oscillator kit to interface the sensor to the controller (see [section 2.3 on page 2-4](#)).

3 m (10 ft.) Oscillator Kit PN 783-500-109-10
 7.6 m (25 ft.) Oscillator Kit PN 783-500-109-25
 15.2 m (50 ft.) Oscillator Kit PN 783-500-109-50
 22.9 m (75 ft.) Oscillator Kit PN 783-500-109-75

Oscillator kits include:

Oscillator PN 783-500-013

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

One of the following:

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

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

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

22.9 m (75 ft.) BNC Cable PN 782-902-012-75

These kits are designed for use with the standard in-vacuum cables ranging in length from 15.2 cm (6 in.) to 78.1 cm (30.75 in.).

1.6.2.2 Sensors

Front Load Single Sensor PN SL-XXXXX

Cool Drawer Single Sensor PN CDS-XXFXX

Sputtering Sensor PN 750-618-G1

UHV Bakeable Sensor PN BK-A0F

NOTE: "X" in part number indicates customer-selectable option, see www.inficon.com for Sensor Datasheets.

NOTE: Multi-crystal (rotary) sensors and dual sensors should not be used with STM-2.

Chapter 2

Installation

2.1 Installation Requirements

2.1.1 Parts Requirements

- ◆ STM-2 Monitor
 - ◆ One crystal sensor with feedthrough
 - ◆ One oscillator kit for the crystal sensor
- NOTE:** The oscillator kit is not required when using the internal oscillator.
- ◆ Quartz crystals appropriate for the application
 - ◆ One Windows computer meeting minimum specifications (refer to [section 1.4](#) on page 1-5).



CAUTION

To maintain proper STM-2 performance, use only the provided 15.2 cm (6 in.) BNC cable to connect STM-2 or the oscillator to the crystal sensor.

The length of the in-vacuum cable (Front Load and Sputtering sensors) or electrical conduit tube (Cool Drawer and Bakeable sensors) must not exceed 78.1 cm (30.75 in.).

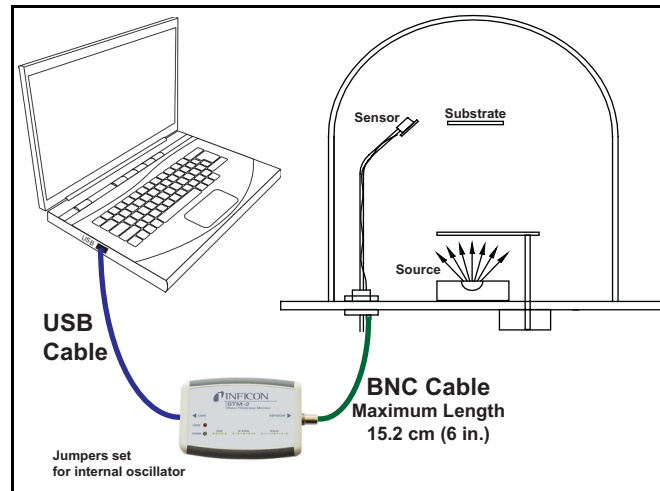
2.2 System Connections

STM-2 can be configured to use either an internal or external oscillator depending on the internal jumpers. The default jumper setting is to use the internal oscillator.

2.2.1 Internal Oscillator

- 1 Connect the (provided) USB cable to a computer USB port and to STM-2.
- 2 Use the (provided) 15.2 cm (6 in.) BNC cable to connect STM-2 to the sensor feedthrough (see [Figure 2-1](#)).

Figure 2-1 Internal oscillator



- 3 Install and run STM-2 Software or STM-2 LabVIEW Application (see [Chapter 3](#) or [Chapter 4](#)).

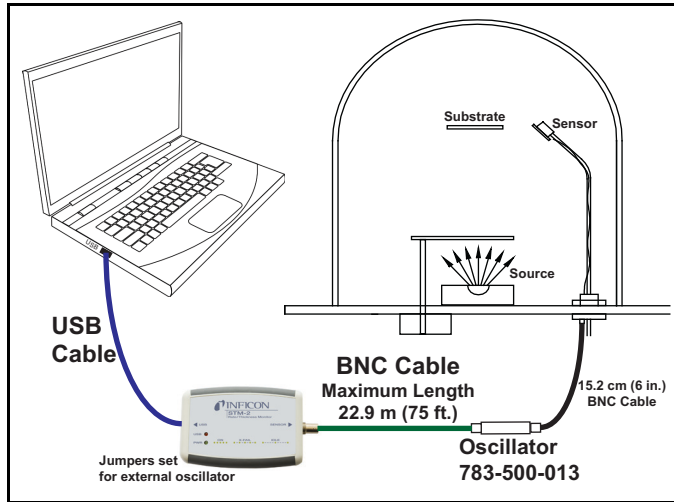
NOTE: STM-2 Software and STM-2 LabVIEW can be installed and run on the same computer without interference, but not simultaneously. Only one application should be active at any given time.

- 4 The PWR indicator on STM-2 illuminates (see [section 2.4.1 on page 2-5](#)).
- 5 The USB indicator on STM-2 illuminates (see [section 2.4.2 on page 2-5](#)).

2.2.2 External Oscillator

To use an optional external oscillator, the jumpers inside STM-2 must be repositioned (see [section 2.3](#)). The maximum BNC cable length connecting the external oscillator and STM-2 is 22.9 m (75 ft.) (see [Figure 2-2](#)).

Figure 2-2 External oscillator



2.3 Switching Between Internal and External Oscillator

Three jumpers must be repositioned inside the STM-2 case to switch between the internal oscillator and an external oscillator.



CAUTION

STM-2 contains delicate circuitry, susceptible to transient power line voltages. Disconnect the USB cord whenever making any sensor connections or when the case is open.



CAUTION - Static Sensitive Device

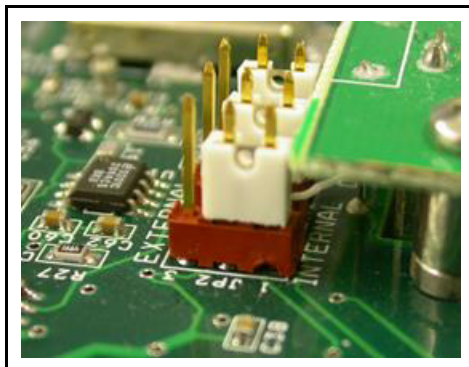
Observe proper ESD procedures when the STM-2 case is open.

Remove the two phillips screws which secure the back of the case, and remove the back of the case.

Near the BNC connector are three jumpers on the circuit board, labeled **Internal** and **External**. Move all three jumpers:

- ◆ To **Internal** for internal oscillator operation (see [Figure 2-3](#)).
- ◆ To **External** for external oscillator operation.

Figure 2-3 Jumpers set for internal oscillator operation



2.4 STM-2 Indicators

2.4.1 Power

- Illuminated STM-2 is powered up and is connected to a good crystal.

In addition, the host computer has initialized STM-2 by sending a reset command when the software begins communication.
- Flashing fast. STM-2 is powered up but cannot detect a good crystal.
- Blinking slow
(approximately once per second). STM-2 is powered up and the crystal is good, but the computer application has not initialized STM-2. Once the computer initializes STM-2 the indicator will illuminate continuously (see [section 6.1.1 on page 6-1](#)).
- Extinguished. STM-2 does not have power. Check the USB connection, and make sure the computer is turned on.

2.4.2 USB

The USB indicator detects communications signal traffic.

- Illuminated STM-2 is connected and communicating to a host computer. Communications sent/received every 100 ms will cause the indicator to be steadily illuminated.
- Flashing STM-2 is connected and communicating to a host computer. A flashing indicator will correspond to the time elapsed between sent and received communications. A query sent once per second will correspond to the indicator flashing approximately once per second.
- Extinguished. STM-2 is not communicating to the computer.

STM-x_win32 LabVIEW application software and INFICON STM-2 software will steadily illuminate the indicator due to communications queries sent every 100 ms. User-created software may not steadily illuminate the indicator due a longer time period elapsing between communications queries being sent.

Chapter 3

STM-2 Software Operation

3.1 Introduction

INFICON STM-2 Software is capable of interfacing up to eight STM-2 instruments to display Rate, Thickness, Frequency, and Crystal Life for the connected sensors. STM-2 Software has independent Density, Z-Ratio, and Tooling parameters for each STM-2 to allow for codeposition monitoring capabilities.

3.2 Installing INFICON STM-2 Software

3.2.1 Installing the Protocol Server

- 1 Insert the **Thin Film Manuals CD** into the CD drive on the computer that will be connected to STM-2.
- 2 Click **Windows Explorer** or **File Explorer >> Computer >> (CD drive letter:) >> Common Software**.
- 3 Double click **setup_smdp_svr_iv.exe**. The **Zip Self-Extractor** window will display.
- 4 Click **Unzip**. The **SMDP Serial Protocol Server** window will display.
- 5 On the **Destination Directory** pane, click **Browse** to select the location where all software will be installed.
- 6 Click **Next**.
- 7 Read the license agreement.
- 8 Click **I accept License Agreement(s)**.
- 9 Click **Next**.
- 10 Review the summary of information.
- 11 Click **Next**. **Installation Complete** will display.
- 12 Click **Next**. The **Setup Wizard** pane will display.
- 13 Click **Next**. The **Confirm Installation** pane will display.
- 14 Click **Next**.
- 15 Read the license agreement.
- 16 Click **I Agree**.
- 17 Click **Next**. **Installation Complete** will display.
- 18 Click **Close**.
- 19 Click **Close** on the **Zip Self-Extractor**.

3.2.2 Installing the INFICON STM-2 Software and Device Drivers

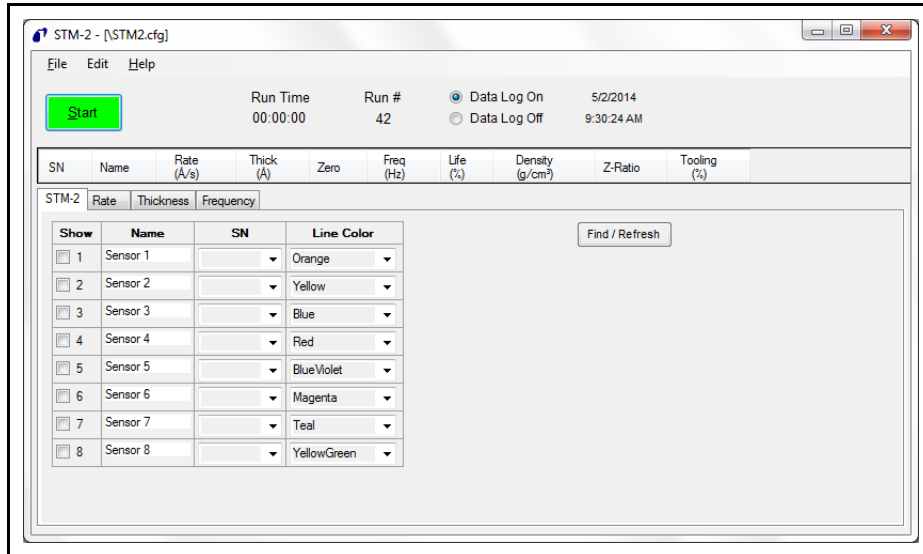
- 1 Insert the **Thin Film Manuals CD** into the CD drive of the computer that will be connected to STM-2.
- 2 Click **Windows Explorer** or **File Explorer >> Computer >> (CD drive letter:) >> STM-2**.
- 3 Double click **STM-2 v1.0.0 Setup.exe**. The **STM-2 - InstallShield Wizard** will display.
- 4 Click **Next**.
- 5 Review the summary of information.
- 6 Select **I accept the terms in the license agreement**.
- 7 Click **Next**.
- 8 Click **Change** to select the location of the software files to be installed.
- 9 Click **Next**.
- 10 Click **Install**.
- 11 Click **Finish**. The **USB Installer - InstallShield Wizard** window will display.
- 12 Click **Next**.
- 13 Review the summary of information.
- 14 Select **I accept the terms in the license agreement**.
- 15 Click **Next**.
- 16 Enter **User Name** and **Organization** information.
- 17 Click **Next**.
- 18 Click **Install**.
- 19 Click **Finish**. The **CP210x USB to UART Bridge Driver Installer** window will display.
- 20 Click **Next**.
- 21 Review the summary of information.
- 22 Select **I accept this agreement**.
- 23 Click **Next**.
- 24 Click **Finish**.

3.2.3 Starting INFICON STM-2 Software

3.2.3.1 Starting the Software in Windows XP or Windows 7

- 1 Click **Start >> All Programs >> INFICON >> STM-2**.
- 2 The **STM-2** window will display (see [Figure 3-1](#)).

Figure 3-1 STM-2 window



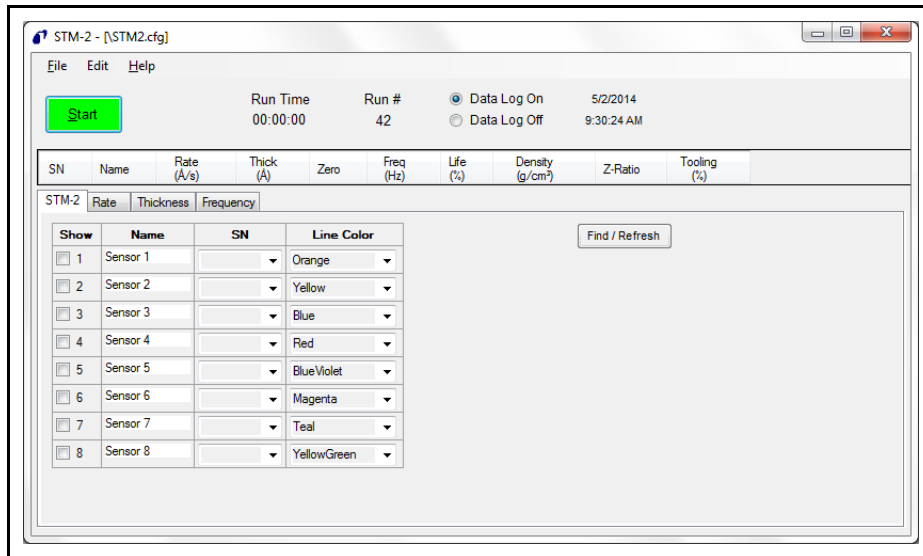
3.2.3.2 Starting the Software in Windows 8

- 1 In the **Start** window, click the **STM-2** icon.
- 2 If the icon cannot be found:
 - 2a Click **Search >> Apps**.
 - 2b Type **STM** in the **Search** text box.
 - 2c Click the **STM-2** icon.

3.3 STM-2 Window

The **STM-2** window displays Serial Number (SN), (Sensor) Name, Rate, Thick(ness) of the film, Zero thickness button, Freq(uecy), crystal Life, Density of the film, Z-Ratio, and Tooling for the connected sensor and process material. This window also provides a button to Start, Stop, or Pause/Resume monitoring. Also, the Run Time of the Process, the Run #, a selection for Data Log(ging) to be turned on and off, and the current date and time are displayed. From this window, there is also access to STM-2, Rate, Thickness, and Frequency tabs as well as the File, Edit, and Help menus for customization and configuration (see [Figure 3-2](#)).

Figure 3-2 STM-2 window



- ◆ **File** menu (see [section 3.3.1 on page 3-6](#))
- ◆ **Edit** menu (see [section 3.3.2 on page 3-8](#))
- ◆ **Help** menu (see [section 3.3.3 on page 3-18](#))
- ◆ **STM-2** tab (see [section 3.3.4 on page 3-19](#))
- ◆ **Rate** tab (see [section 3.3.5 on page 3-20](#))
- ◆ **Thickness** tab (see [section 3.3.6 on page 3-21](#))
- ◆ **Frequency** tab (see [section 3.3.7 on page 3-22](#))

STM-2 window

Start/Stop	Click to Start monitoring. Start changes to Stop. Stop will halt the process and data log until Start is clicked.
Pause/Resume	Pause is displayed while monitoring to pause the monitoring. Pause stops the monitoring at its current time and changes to Resume when clicked. Resume will continue monitoring and increment the Run Time.
Run Time	Time that the current run number has been monitored; resets when Start is clicked, stops and continues when Pause/Resume are clicked.
Run #	Incremented when Start is clicked.
Data Log On/Data Log Off	Select Data Log On to enable data logging. Select Data Log Off to disable data logging.
Date	Current date in month/day/year format.
Time	Current time in hh:mm:ss format.
SN	Serial Number of STM-2(s) selected to view (see section 3.3.4 on page 3-19).
Name	Name of STM-2(s) selected to view (see section 3.3.4 on page 3-19).
Rate	Rate, displayed in Å/s or Mass Rate displayed in ng/cm ² /s, of STM-2(s) selected to view (see section 3.3.4 on page 3-19).
Thick	Thickness displayed in Å or kÅ, or Mass in µg/cm ² , of STM-2(s) selected to view (see section 3.3.2.2 on page 3-16).
Zero	Click to zero thickness.
Freq	Frequency of the crystal connected to STM-2(s) selected to view (see section 3.3.4 on page 3-19). This changes to !XTAL FAIL! upon a crystal failure.
Life	Percentage of crystal life remaining, decremented from 100%.

NOTE: This is based on a 6 MHz crystal.

- Density** 0.5 to 99.99

Value in grams per cubic centimeter of material being deposited. Click in the text box to edit the density value. For a list of common material densities, see [Appendix A](#).
- Z-Ratio** 0.1 to 9.999

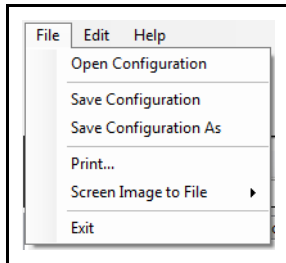
Z-Ratio of material being deposited. Click in the text box to edit the Z-Ratio value. For a list of Z-Ratios for common materials, see [Appendix A](#).
- Tooling** 10 to 399

Tooling of the sensor connected to STM-2. Click in the text box to edit the Tooling value. To determine tooling, see [section 7.3 on page 7-2](#).

3.3.1 File Menu

Click **File** to open or save a configuration file, to print or capture screen images, or to exit INFICON STM-2 Software (see [Figure 3-3](#)).

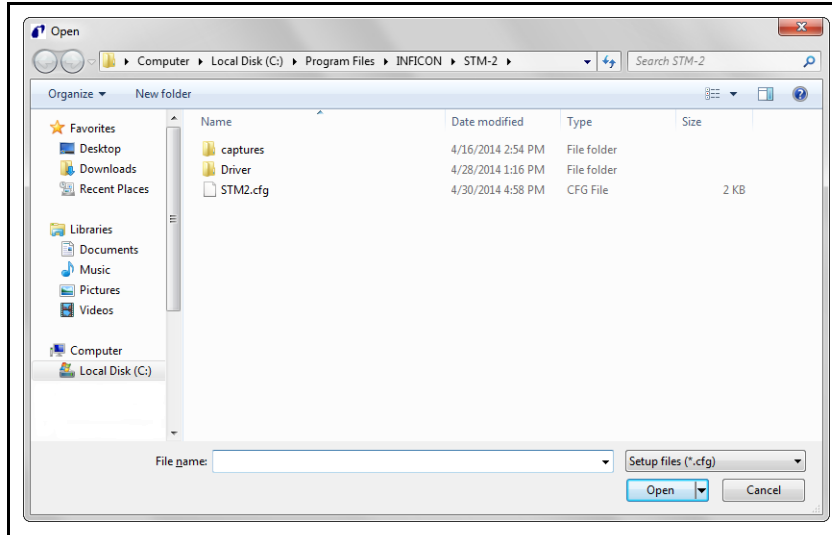
Figure 3-3 File menu



3.3.1.1 Open Configuration

Click to select a file location of a configuration file and load that configuration file into INFICON STM-2 Software (see [Figure 3-4](#)).

Figure 3-4 Open Configuration window



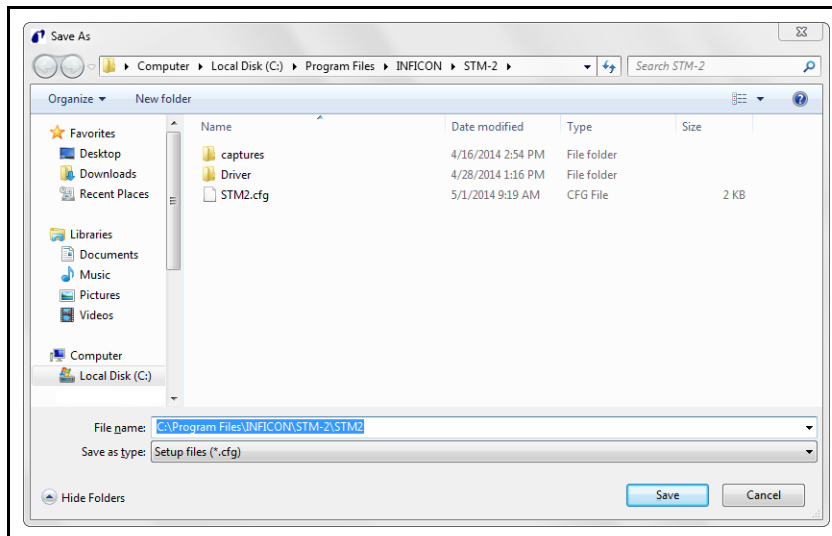
3.3.1.2 Save Configuration

Click to save the current configuration. The default configuration file is STM2.cfg.

3.3.1.3 Save Configuration As

Click to select a name and location to save the configuration file (see [Figure 3-5](#)).

Figure 3-5 Save As window



3.3.1.4 Print

Click to print all of the current views of the STM-2 window (refer to [Figure 3-2 on page 3-4](#)) or, print only the current window displayed.

NOTE: If the print setup window has been configured once during a session, the parameters selected will not be able to be changed until the software is exited and reloaded.

3.3.1.5 Screen Image to File

This list item will display a list of options regarding screen images.

Current View to JPG Places a JPEG image of the current window into the default Captures folder located in **Local Disk (C:) >> Program Files >> INFICON >> STM-2 >> captures**.

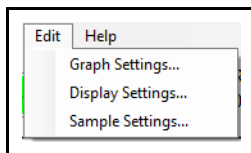
All Views to JPGs Places JPEG images of the current views of the **STM-2** window into the default Captures folder located in **Local Disk (C:) >> Program Files >> INFICON >> STM-2 >> captures**.

Select JPG Folder Displays a window to select the location and name of the folder where the JPEG screen images will be saved.

3.3.2 Edit Menu

Provides options to customize graph, display, and sample settings (see [Figure 3-6](#)).

Figure 3-6 Edit menu



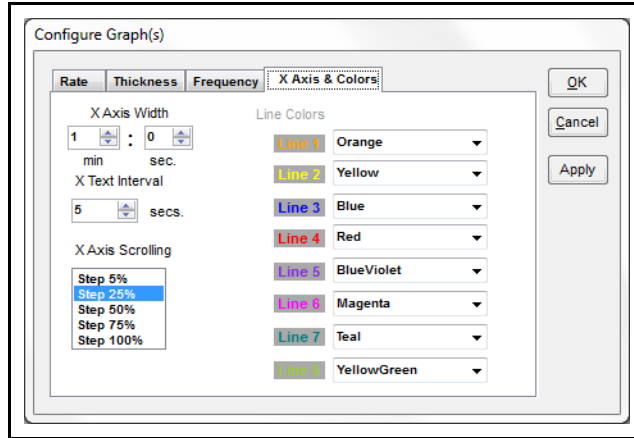
3.3.2.1 Graph Settings

Click to display a window to configure the settings for Rate, Thickness, and Frequency graphs. Also provides customization of line colors, axis formatting, and scrolling.

NOTE: Graph Settings is disabled while monitoring.

3.3.2.1.1 X Axis & Colors

Figure 3-7 X Axis & Colors tab



X Axis Width 1 minute to 120 minutes, 59 seconds

Use the spin box to enter the minutes and seconds displayed as a maximum x-axis value on all of the graphs.

X Text Interval 1 to 480 seconds

Displays the time on the x-axis of all graphs for the selected interval.

X Axis Scrolling Select Step 5%, 25%, 50%, 75%, or 100%, to determine the percentage of the graph that is available for new data once the plot reaches the maximum x-axis value.

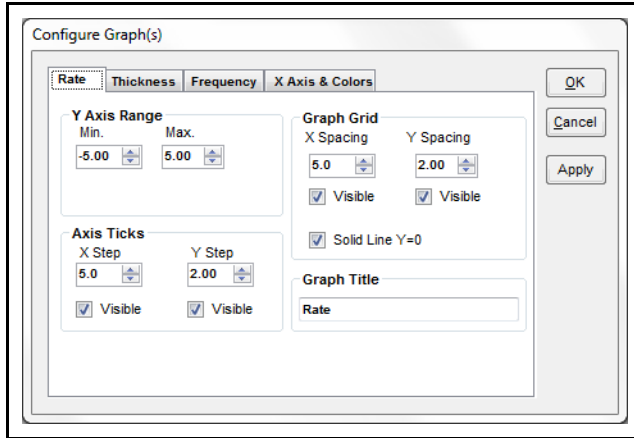
Line Colors Use the drop-down list box to select a color to correspond with each STM-2 connected.

NOTE: This will also change the Line Color on the **STM-2** tab (see [Figure 3-15 on page 3-19](#)).

Click **Apply** to update the display with any changes made, thereby making the changes active. Click **OK** to save changes and exit the **Configure Graph(s)** window. Click **Cancel** to cancel any changes not yet applied and exit the **Configure Graph(s)** window.

3.3.2.1.2 Rate Tab

Figure 3-8 Rate tab



Y Axis Range pane

Min. -100.00 to 100.00

Minimum y-axis value displayed on the Rate graph.

NOTE: Minimum value must be less than the value entered for the maximum.

Max. -100.00 to 100.00

Maximum y-axis value displayed on the Rate graph.

NOTE: Maximum value must be greater than the value entered for the minimum.

Axis Ticks pane

X Step 0 to 100.0

Displays unlabeled x-axis ticks at the interval selected.

NOTE: Ticks are only visible if **Visible** has been selected. Clear to disable ticks.

Y Step 0 to 100.0

Displays unlabeled y-axis ticks at the interval selected.

NOTE: Ticks are only visible if **Visible** has been selected. Clear to disable ticks.

Graph Grid pane

X Spacing 0 to 100.0

Displays x-axis grid at the interval selected.

NOTE: Grid is only visible at the selected interval when **Visible** has been selected. Clear to disable grid lines.

Y Spacing 0 to 100.0

Displays y-axis grid at the interval selected.

NOTE: Grid is only visible at the selected interval when **Visible** has been selected. Clear to disable grid lines.

Solid Line Y=0 Select to display a solid line on the Rate graph at Y=0. Clear to remove the solid line at Y=0.

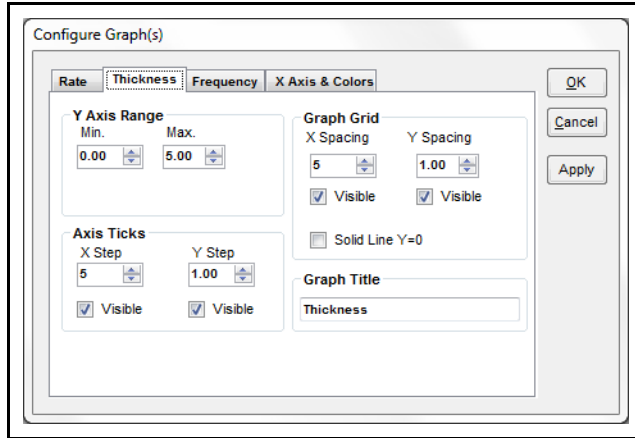
Graph Title pane

Edit text box to rename the Rate graph.

NOTE: Click **Apply** to update the display with any changes made. Click **OK** to save changes and exit the **Configure Graph(s)** window. Click **Cancel** to cancel any changes and exit the **Configure Graph(s)** window.

3.3.2.1.3 Thickness Tab

Figure 3-9 Thickness tab



Y Axis Range pane

Min. -100.00 to 100.00

Minimum y-axis value displayed on the Thickness graph.

NOTE: Minimum value must be less than the value entered for the maximum.

Max. -100.00 to 100.00

Maximum y-axis value displayed on the Thickness graph.

NOTE: Maximum value must be greater than the value entered for the minimum.

Axis Ticks pane

X Step 0 to 100.0

Displays unlabeled x-axis ticks at the interval selected.

NOTE: Ticks are only visible if **Visible** has been selected. Clear to disable ticks.

Y Step 0 to 100.0

Displays unlabeled y-axis ticks at the interval selected.

NOTE: Ticks are only visible if **Visible** has been selected. Clear to disable ticks.

Graph Grid pane

X Spacing 0 to 100.0

Displays x-axis grid at the interval selected.

NOTE: Grid is only visible at the selected interval when **Visible** has been selected. Clear to disable grid lines.

Y Spacing 0 to 100.0

Displays y-axis grid at the interval selected.

NOTE: Grid is only visible at the selected interval when **Visible** has been selected. Clear to disable grid lines.

Solid Line Y=0 Select to display a solid line on the Thickness graph at Y=0. Clear to remove the solid line at Y=0.

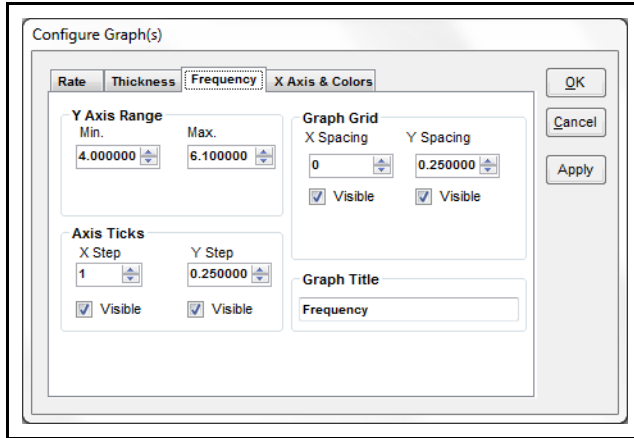
Graph Title pane

Edit text box to rename the Thickness graph.

NOTE: Click **Apply** to update the display with any changes made. Click **OK** to save changes and exit the **Configure Graph(s)** window. Click **Cancel** to cancel any changes and exit the **Configure Graph(s)** window.

3.3.2.1.4 Frequency Tab

Figure 3-10 Frequency tab



Y Axis Range pane

Min. 4.000000 to 6.100000 MHz

Minimum y-axis value displayed on the Frequency graph.

NOTE: Minimum value must be less than the value entered for the maximum.

Max. 4.000000 to 6.100000 MHz

Maximum y-axis value displayed on the Frequency graph.

NOTE: Maximum value must be greater than the value entered for the minimum.

Axis Ticks pane

X Step 0 to 100

Displays unlabeled x-axis ticks at the interval selected.

NOTE: Ticks are only visible if **Visible** has been selected. Clear to disable ticks.

Y Step 0.000000 to 100.000000 MHz

Displays unlabeled y-axis ticks at the interval selected.

NOTE: Ticks are only visible if **Visible** has been selected. Clear to disable ticks.

Graph Grid pane

X Spacing 0 to 100

Displays x-axis grid at the interval selected.

NOTE: Grid is only visible at the selected interval when **Visible** has been selected. Clear to disable grid lines.

Y Spacing 0.000000 to 100.000000

Displays y-axis grid at the interval selected.

NOTE: Grid is only visible at the selected interval when **Visible** has been selected. Clear to disable grid lines.

Graph Title pane

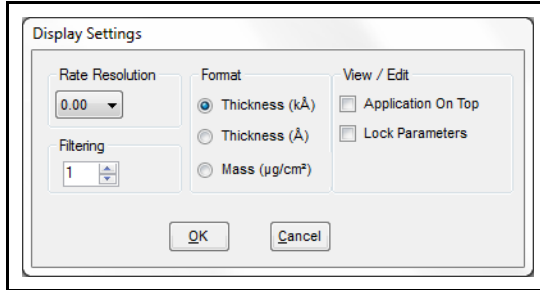
Edit text box to rename the Frequency graph.

NOTE: Click **Apply** to update the display with any changes made. Click **OK** to save changes and exit the **Configure Graph(s)** window. Click **Cancel** to cancel any changes and exit the **Configure Graph(s)** window.

3.3.2.2 Display Settings

Click to display a window to configure the settings for Rate Resolution, Filtering, Format, and View of the **STM-2** window (see [Figure 3-11](#)).

Figure 3-11 Display Settings window



- Rate Resolution** Use the drop-down list box to select 0.0 or 0.00 as the rate resolution to be displayed on the **STM-2** window.

- Filtering** 1 to 99
 Use the spin box to enter the number of samples to be averaged together for the **STM-2** window Rate display.
NOTE: This value will not affect graphs or data logs. Use the Samples Averaged parameter (see [section 3.3.2.3](#)) for averaging to affect all displays and data logs.

- Format** Select Thickness in kÅ, Thickness in Å, or Mass in µg/cm² to be displayed on the **STM-2** window and on the Thickness graph.
NOTE: Mass in µg/cm² will display Rate as a Mass Rate in ng/cm²/s.

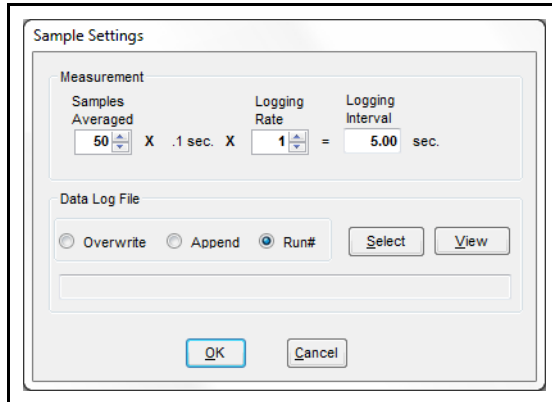
- View/Edit** Select **Application On Top** to display the **STM-2** window in front of all other open windows. Select **Lock Parameters** to disable editing of **Density**, **Z-Ratio**, and **Tooling** on the **STM-2** window.

3.3.2.3 Sample Settings

Click to display a window to configure the settings for data logging, display, and graphs (see Figure 3-12).

NOTE: Sample Settings is disabled while monitoring.

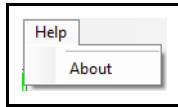
Figure 3-12 Sample Settings window



- Samples averaged** 1 to 50
Use the spin box to enter the number of samples averaged for the display, graphs, and data logging.
- Logging Rate** 1 to 120
Use the spin box to select the logging rate. A Logging Rate of 1 will log every averaged measurement.
- Logging Interval** Displays the data logging period in seconds.
- Overwrite** Select to overwrite the current data log with new data.
- Append** Select to add new data log information to current data log.
- Run#** Select to create a new data log named with the run number being logged.
- Select** Click to select the name and location of data log files.
- View** Click to view the current data log.

3.3.3 Help Menu

Figure 3-13 Help menu



About Click to view the **About** window (see [section 3.3.3.1](#)).

3.3.3.1 About Window

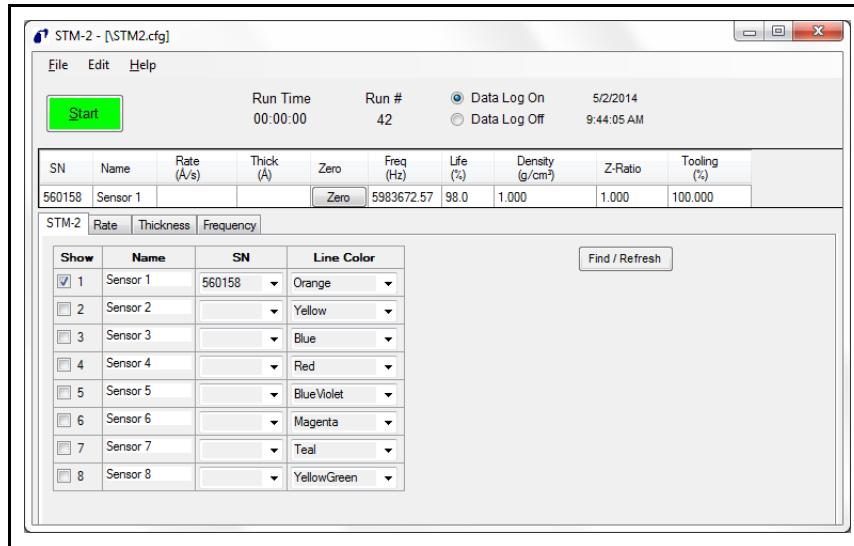
Displays the version number of INFICON STM-2 Software, copyright information, and the location of the software files (see [Figure 3-14](#)).

Figure 3-14 About window



3.3.4 STM-2 Tab

Figure 3-15 STM-2 tab

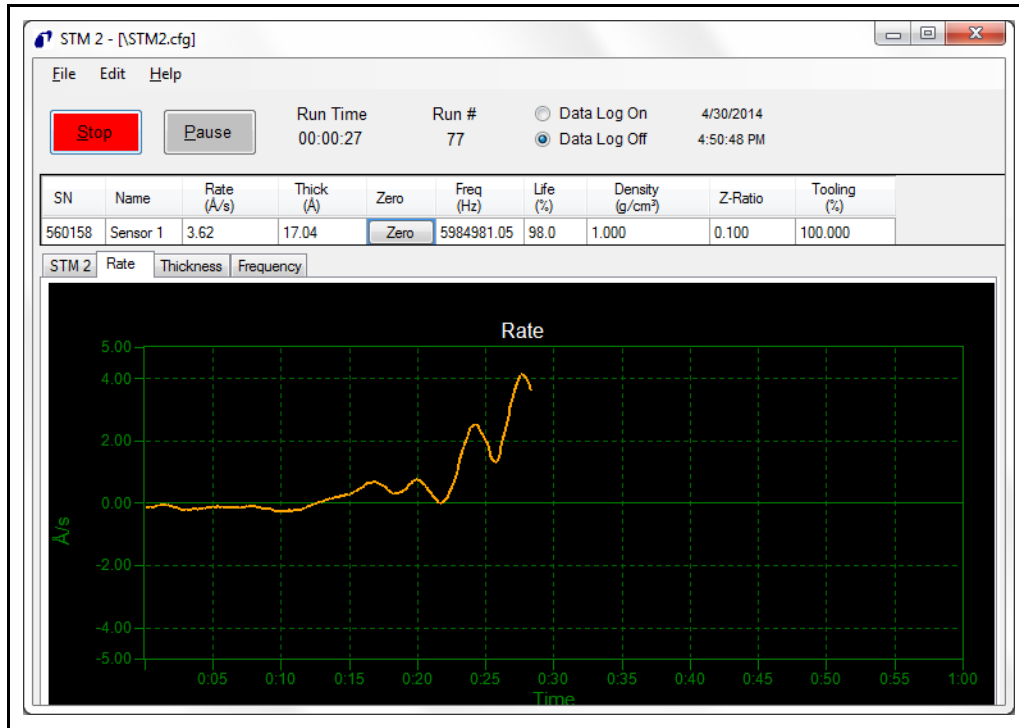


- Show** Select the sensors to be displayed on the **STM-2** window.
- Name** Edit the name of the sensor. This name will be displayed on the **STM-2** window if selected. This ensures a fixed assignment between the sensor and the STM-2 module, as each module has a unique serial number.
- SN** Use the drop-down list box to select the serial number of the connected STM-2 associated with the named sensor.
- Line Color** Use the drop-down list box to select a color to correspond with each STM-2 connected.
NOTE: This will also change the Line Color on the **X Axis & Colors** tab of the **Graph Settings** window (refer to [Figure 3-7 on page 3-9](#)).
- Find/Refresh** Click to Find or Refresh connected STM-2(s).

3.3.5 Rate Tab

Displays a graph of Rate and Time for the selected STM-2(s) (see Figure 3-16).

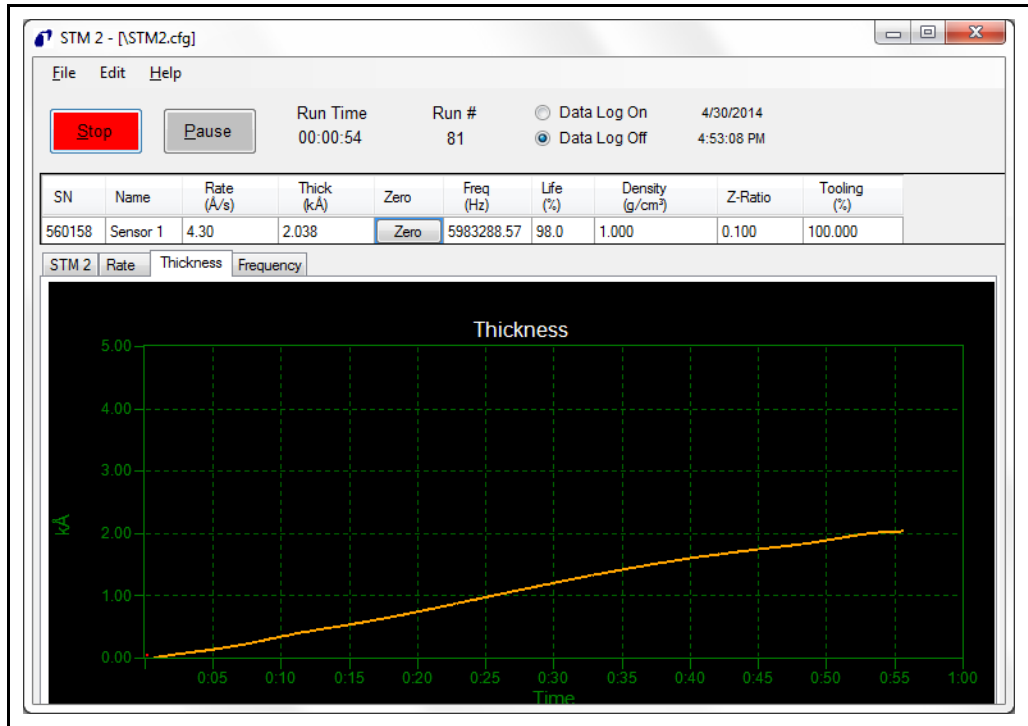
Figure 3-16 Rate tab



3.3.6 Thickness Tab

Displays a graph of Thickness or Mass and Time for the selected STM-2(s) (see Figure 3-17).

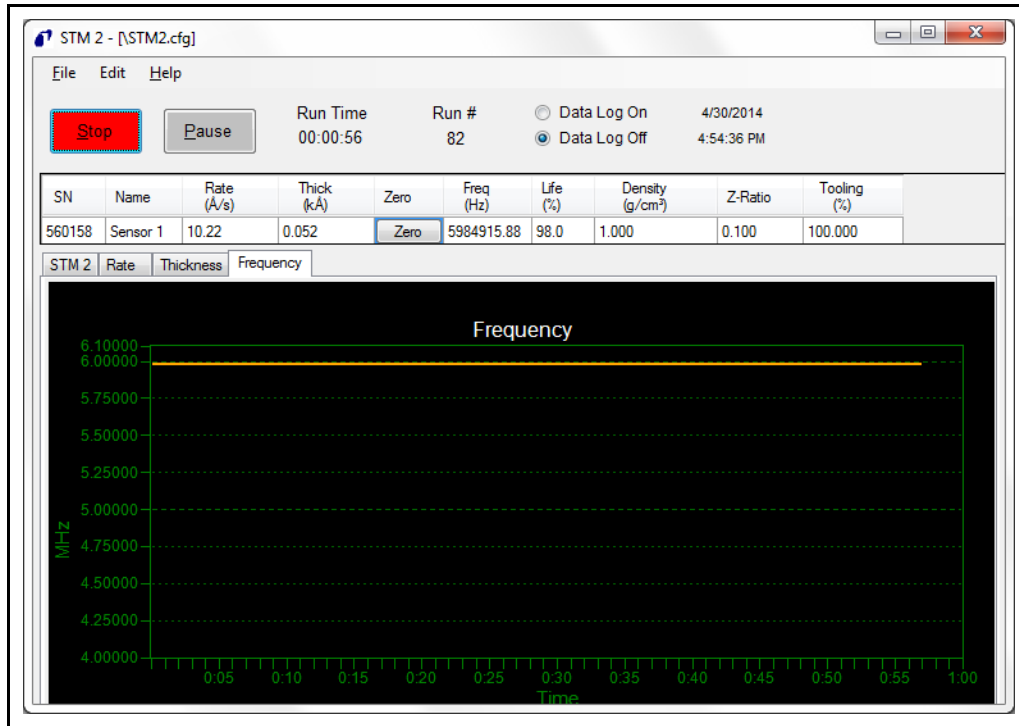
Figure 3-17 Thickness tab



3.3.7 Frequency Tab

Displays a graph of Frequency and Time for the selected STM-2(s) (see [Figure 3-18](#)).

Figure 3-18 Frequency tab



Chapter 4

STM-2 LabVIEW Operation

4.1 Introduction

STM-2 LabVIEW Application is capable of displaying Rate, Thickness, and Crystal Life for one STM-2 and the connected sensor. STM-2 LabVIEW Application has the option to use Multi-layer mode to enable a cumulative Substrate Thickness and independent Density, Z-Ratio, Tooling, and Sample parameters for each film to allow for multi-layer monitoring capabilities. STM-2 LabVIEW Application can also operate in Simulate mode without a connected STM-2.

4.2 Installing the STM-2 LabVIEW Application

4.2.1 Installing the Protocol Server

- 1** Insert the **Thin Film Manuals CD** into the CD drive on the computer that will be connected to STM-2.
- 2** Click **Windows Explorer** or **File Explorer >> Computer >> (CD drive letter:) >> Common Software**.
- 3** Double click **setup_smdp_svr_iv.exe**. The **Zip Self-Extractor** window will display.
- 4** Click **Unzip**. The **SMDP Serial Protocol Server** window will display.
- 5** On the **Destination Directory** pane, click **Browse** to select the location where all software will be installed.
- 6** Click **Next**.
- 7** Read the license agreement.
- 8** Click **I accept License Agreement(s)**.
- 9** Click **Next**.
- 10** Review the summary of information.
- 11** Click **Next**. **Installation Complete** will display.
- 12** Click **Next**. The **Setup Wizard** pane will display.
- 13** Click **Next**. The **Confirm Installation** pane will display.
- 14** Click **Next**.
- 15** Read the license agreement.
- 16** Click **I Agree**.
- 17** Click **Next**. **Installation Complete** will display.
- 18** Click **Close**.
- 19** Click **Close** on the **Zip Self-Extractor**.

4.2.2 Installing the LabVIEW Application and Device Drivers

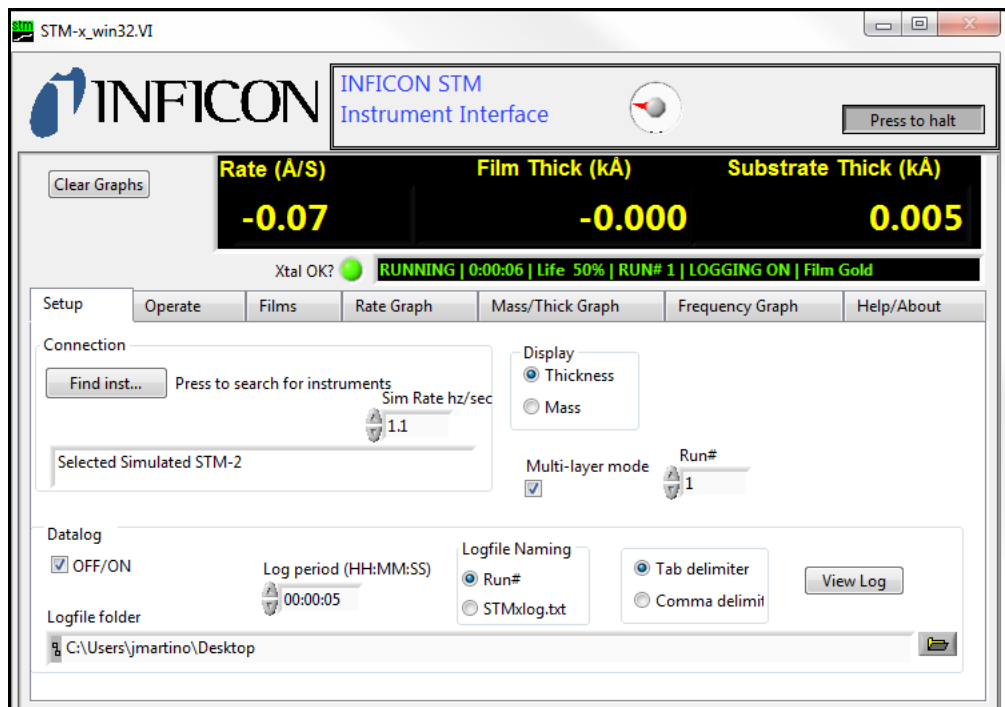
- 1 Insert the **Thin Film Manuals CD** into the CD drive on the computer that will be connected to STM-2.
- 2 Click **Windows Explorer** or **File Explorer >> Computer >> (CD drive letter:) >> STM-2 >> TOOLS >> main app.**
- 3 Double click **setup_stm-x_win32.exe**. The **Zip Self-Extractor** window will display.
- 4 Click **Unzip**. The **Sycon STM-x_win32** window will display.
- 5 On the **Destination Directory** pane, click **Browse** to select the location where all software will be installed.
- 6 Click **Next**.
- 7 Review the summary of information.
- 8 Click **Next**. **Installation Complete** will display.
- 9 Click **Next**. The **Silicon Laboratories CP210x VCP Drivers for Windows 2000/XP/2003 Server/Vista window** will display.
- 10 Click **Next**.
- 11 Read the license agreement.
- 12 Click **I accept the terms of the license agreement**.
- 13 Click **Next**.
- 14 On the **Choose Destination Location** pane, click **Browse** to select the location where all drivers will be installed.
- 15 Click **Next**.
- 16 Click **Install**. The **InstallShield Wizard Complete** pane will display.
- 17 Select **Launch the CP210x VCP Driver Installer**.
- 18 Click **Finish**. The **Silicon Laboratories CP210x USB to UART Bridge Driver Installer** window will display.
- 19 Click **Change Install Location** to select the location where all drivers will be installed.
- 20 Click **Install**. The **Success** window will display.
- 21 Click **OK**.
- 22 Click **Close** on the **Zip Self-Extractor**.

4.2.3 Starting the STM-2 LabVIEW Application

4.2.3.1 Starting the Software in Windows XP or Windows 7

- 1 Click **Start >> All Programs >> Inficon >> STM-xINF_win32 >> STM-xINFwin32**.
- 2 The **STM-x_win32.VI** window will display (see [Figure 4-1](#)).

Figure 4-1 STM-x_win32.VI initial display



4.2.3.2 Starting the Software in Windows 8

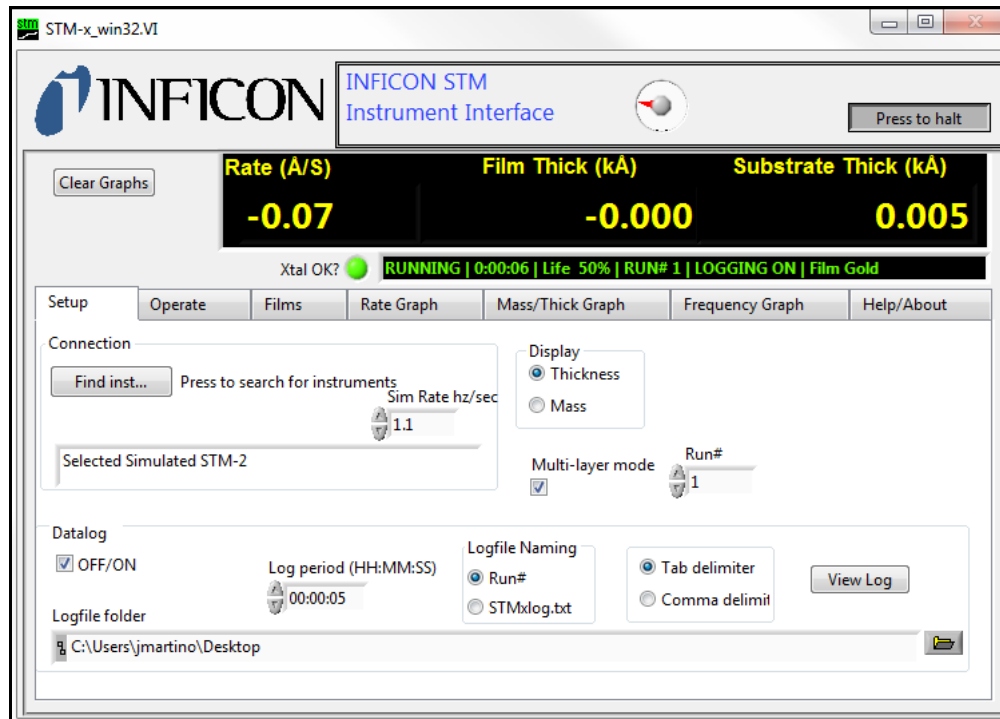
- 1 In the **Start** window, click the **STM-x_win32** icon.
- 2 If the icon cannot be found:
 - 2a Click **Search >> Apps**.
 - 2b Type **STM** in the **Search** text box.
 - 2c Click the **STM-x_win32** icon.

4.3 STM-x_win32.VI Window

The **STM-x_win32.VI** window displays Rate, Film Thick(ness), and Substrate Thick(ness) for the connected sensor. This window also provides an indicator for a crystal fail (Xtal OK?), Running time, Life percentage, Run number, Logging status, and Film name as well as customizable display parameters, graphical information, and access to Setup, Operate, Films, Rate Graph, Mass/Thick Graph, Frequency Graph, and Help/About tabs (see [Figure 4-2](#)).

NOTE: Right-click and select **Description and Tip** for additional information.

Figure 4-2 STM-x_win32.VI live display

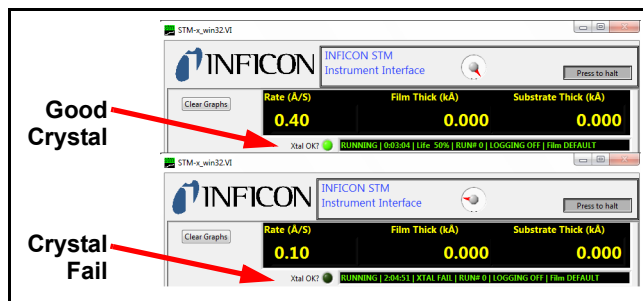


- ◆ **Setup** tab (see [section 4.3.1](#) on page 4-6)
- ◆ **Operate** tab (see [section 4.3.2](#) on page 4-10)
- ◆ **Films** tab (see [section 4.3.3](#) on page 4-12)
- ◆ **Rate Graph** tab (see [section 4.3.4](#) on page 4-14)
- ◆ **Mass/Thick Graph** tab (see [section 4.3.5](#) on page 4-15)
- ◆ **Frequency Graph** tab (see [section 4.3.6](#) on page 4-16)
- ◆ **Help/About** tab (see [section 4.3.7](#) on page 4-18)

Inficon STM Instrument Interface pane

- Press to Halt** Click to exit STM-x_win32.VI application.
Notice the upper right X exit button is greyed out. Press to Halt is the only way to exit the program.
- Rate** Deposition rate based on the frequency of the crystal.
- Film Thick/Film Mass** Thickness or Mass of Film being monitored.
- Substrate Thick/Substrate Mass** . . Accumulated Thickness or Mass of all layers.
- Clear Graphs** Clears Rate, Mass/Thick, and Frequency graphs.
- Xtal OK?** Illuminated light green when a good crystal is connected; dark green when a crystal fail has occurred (see Figure 4-3).

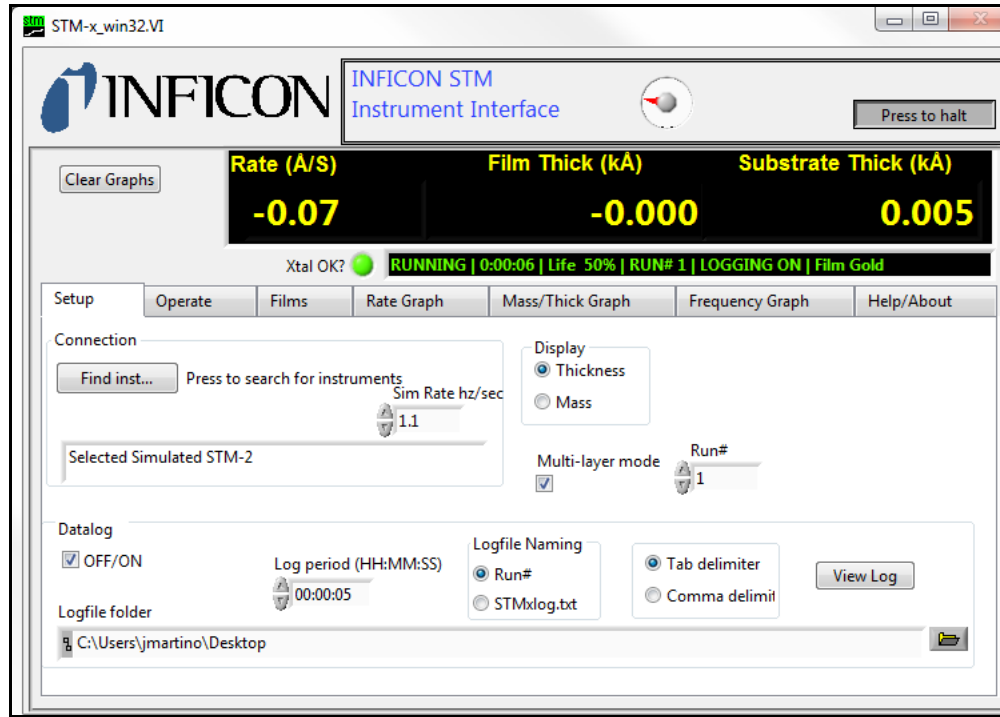
Figure 4-3 Xtal OK



- RUNNING/PAUSED** Running changes to Paused if the process is paused on the **Operate** tab (see section 4.3.2 on page 4-10).
- h:mm:ss** Time that the current run number has been running; resets with each new run.
- Life/XTAL FAIL** Percentage of crystal life remaining, decremented from 100%; changes to XTAL FAIL upon a crystal failure.
- RUN #.** Incremented when New run is clicked on the **Operate** tab (see section 4.3.2 on page 4-10).
- LOGGING OFF/LOGGING ON** Logging off changes to logging on when data logging is enabled by selecting **OFF/ON** in the **Datalog** pane of the **Setup** tab (see section 4.3.1).
- Film** Name of film being monitored is displayed.

4.3.1 Setup

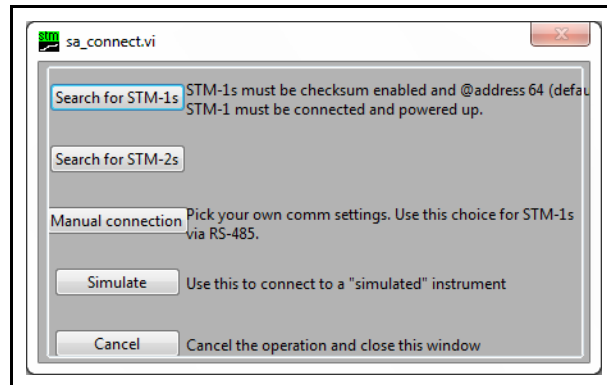
Figure 4-4 Setup tab



Connection pane

Find Instrument Click to search for instruments (see Figure 4-5).

Figure 4-5 Find instrument window



Search for STM-1s Automatically detects connected STM-1s.

Search for STM-2s Automatically detects connected STM-2s.

Manual Connection See section 4.3.1.1 on page 4-8.

Simulate See section 4.3.1.2 on page 4-9.

Cancel Closes Find Instrument window.


Text Box Displays the connection information for the connected STM-2.

Display pane

- Thickness** Displays Rate units of Å/s, Film Thick units of kÅ, and Substrate Thick units of kÅ on the **STM-x_win32.VI** window.
- Mass** Displays Rate units of $\mu\text{g}^*\text{s}/\text{cm}^2$, Film Mass units of $\mu\text{g}/\text{cm}^2$, and Substrate Mass units of $\mu\text{g}/\text{cm}^2$ on the **STM-x_win32.VI** window.
- Multi-layer mode** When enabled, displays Substrate Thick/Substrate Mass on the **STM-x_win32.VI** window and displays the New Layer button and **Layer Stackup** pane on the **Operate** tab.
- Run#** Manually increment/decrement the Run number on the **INFICON STM Instrument Interface** pane.

Datalog pane

- OFF/ON** Enables data logging.
- Log Period** hh:mm:ss
 Assigns a data log period to record monitored values. Records:
 - ◆ Date
 - ◆ Time
 - ◆ Running
 - ◆ Life
 - ◆ Run#
 - ◆ Logging on
 - ◆ Film
 - ◆ Rate
 - ◆ Film Thickness/Film Mass
 - ◆ Substrate Thickness/Substrate Mass
 - ◆ Frequency
- Run#** Names the file with the Run number.
- STMxlog.txt** Names the file with STMxlog.
- Tab delimiter** Records values in data logs delimited with tabs to separate each field.
- Comma delimiter** Records values in data logs with commas to separate each field.
- View Log** Click to view current data log.

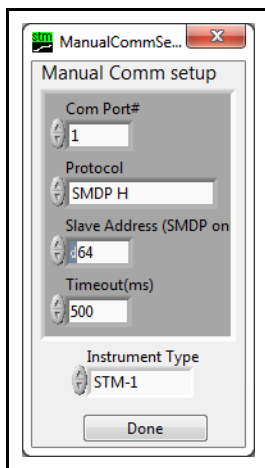
Logfile folder Click the folder icon () to select the location to save data log files.

4.3.1.1 Manual Connection

STM-x_win32.VI software allows the creation of a manual connection to STM-1, STM-2, or Simulate. To enable a manual connection, click **Find Instruments** on the **Setup** tab and click **Manual connection**. The **Manual Comm Setup** window will display. Select the correct **Com Port#**, **Protocol**, **Slave Address**, **Timeout(ms)**, and **Instrument Type**. Click **Done** (see [Figure 4-6](#)).

NOTE: Do NOT close the **Manual Comm Setup** window by selecting **X**.

Figure 4-6 Manual connection



Comm Ports 1 to 255
Enter the communications port connected to STM-2.

Protocol Sycon, SMDP L, SMDP M, SMDP H
Enter the STM-2 communications protocol and baud rate. For STM-2 SMDP H is the only valid setting.

- ♦ Sycon: Sycon protocol (9.6 kbps)
- ♦ SMDP L: SMDP protocol (9.6 kbps)
- ♦ SMDP M: SMDP protocol (38.4 kbps)
- ♦ SMDP H: SMDP protocol (115.2 kbps)

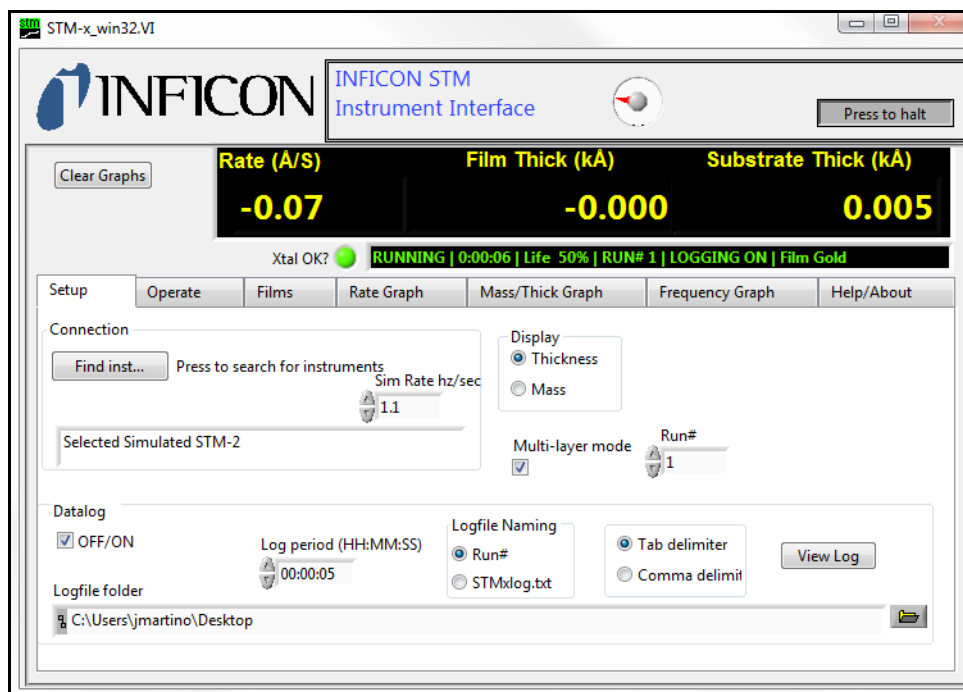
Slave Address 16-254
The STM-2 communication slave address is ignored for STM-2. Because this is a USB connection, no multidrop addressing is used. Any valid value will work.

- Timeout** 0 to 1068576 milliseconds (1068 seconds, approx 17 minutes)
Communications will timeout when the value entered in milliseconds has elapsed.
- Instrument Type** STM-1, STM-2, Simulate
- Done** Close window.

4.3.1.2 Simulate Mode

STM-x_win32.VI software allows a simulated deposition without connection to STM-2. To enable simulate mode, click **Find Instruments** on the **Setup** tab and click **Simulate**. The **Sim Rate hz/sec** box will display on the **Setup** tab. Enter the rate simulation in hertz per second (see Figure 4-7).

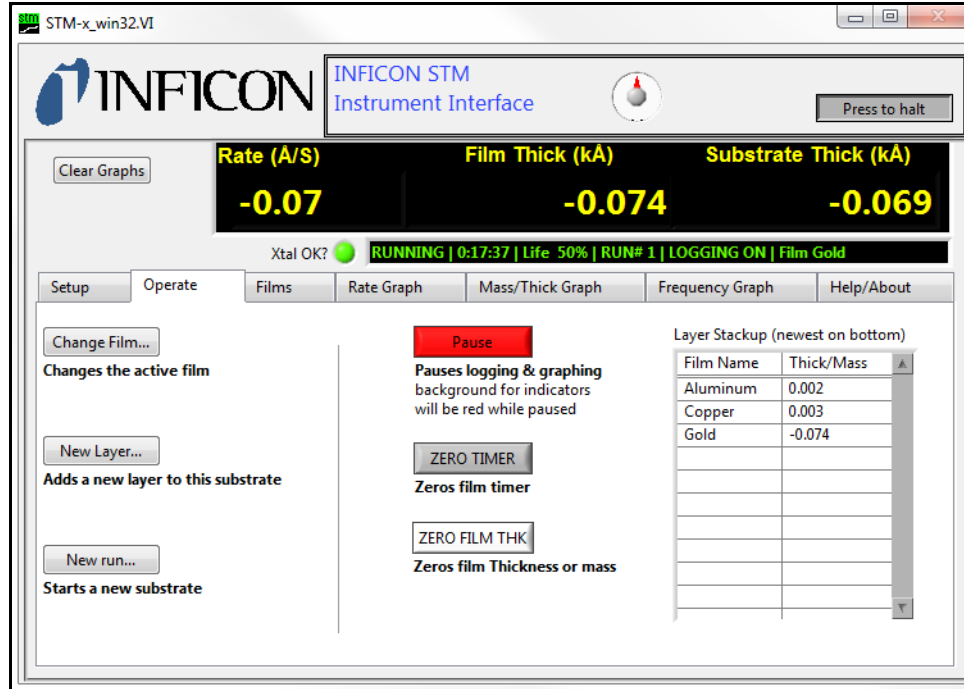
Figure 4-7 Simulate mode



With a rate of hertz per second defined, the software will convert the change in frequency to Rate in angstroms per second or microgram second per centimeter squared based on the selection of **Thickness** or **Mass** on the **Display** pane.

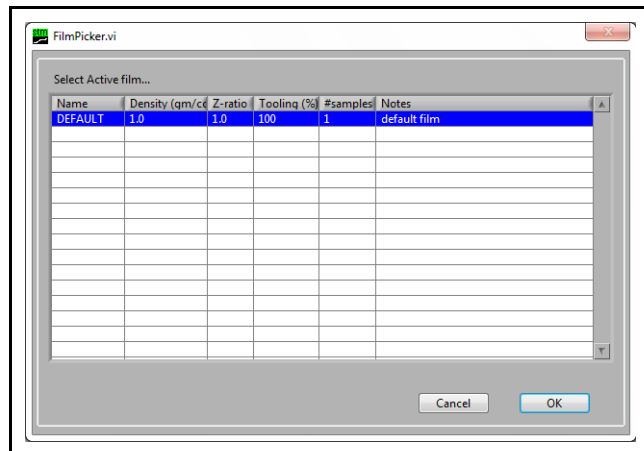
4.3.2 Operate

Figure 4-8 Operate tab



Change Film Changes the active film. Clicking this opens the **FilmPicker.vi** window that displays films to run (see Figure 4-9). Existing thickness is not zeroed, the thickness is recalculated with the new Z-Ratio and tooling.

Figure 4-9 FilmPicker.vi window



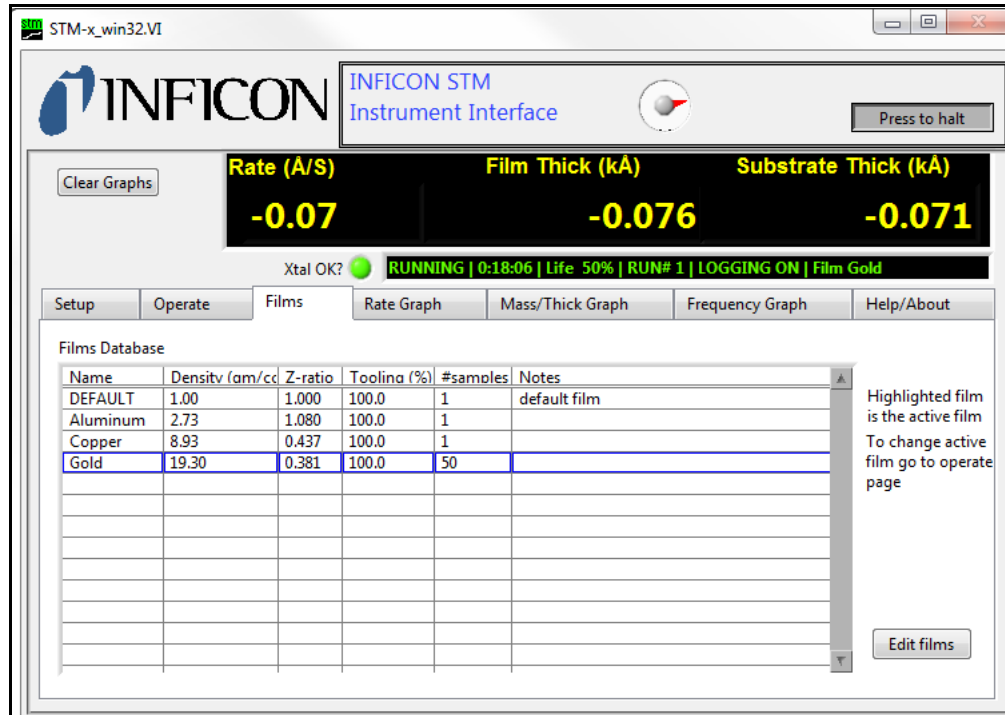
NOTE: If a film is not displayed in this window, the film will need to be added by clicking **Edit Films** on the **Films** tab (see section 4.3.3).

- New Layer** Opens the **FilmPicker.vi** window and adds the selection as a new layer to the Layer Stackup.
- New run** Clears the Layer Stackup, opens the **FilmPicker.vi** window, adds the selection as a new layer to the Layer Stackup, and increments the Run number.
- Pause/Resume** Changes the **Pause** button to **Resume** and changes the background of the Sycon STM Instrument Interface pane to red. Pauses data logging and graphing until **Resume** is clicked.
- ZERO TIMER** Resets the timer on the Sycon STM Instrument Interface pane.
- ZERO FILM THK** Resets Film Thickness or Film Mass.
- Layer Stackup** Lists Film Name and current Thickness or Mass for each layer in the process.

4.3.3 Films

Displays a list of films set up for the process in the Films Database. The film outlined in blue is the active film.

Figure 4-10 Films tab

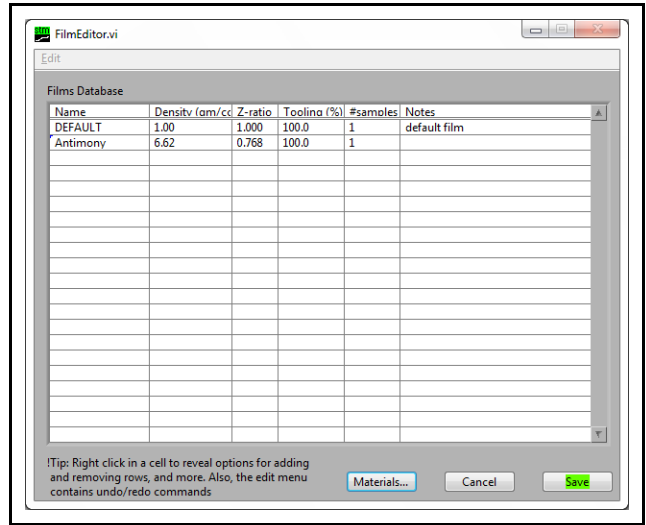


Edit films Displays **FilmEditor.vi** window to add or remove films to the Films Database (see Figure 4-11). Each of the following parameters can be manually edited or input using the **Materials** button:

- ◆ Name
- ◆ Density
- ◆ Z-Ratio
- ◆ Tooling
- ◆ # samples
- ◆ Notes

NOTE: User defined films can be input by typing over existing values or by entering data into empty cells.

Figure 4-11 FilmEditor.vi window



- Materials** List of materials to be added to the Films Database on the **FilmEditor.vi** window.
- Cancel** Exits the **FilmEditor.vi** window without saving changes.
- Save** Saves changes to Films Database on **Films** tab.

NOTE: Right-click on the **FilmEditor.vi** window to Cut, Copy, Insert, or Delete rows.

4.3.4 Rate Graph

Displays a graph of the monitored Rate (see Figure 4-12).

Figure 4-12 Rate Graph tab

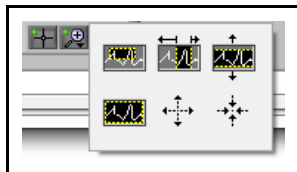


Right-click anywhere on the graph to Copy Data, Export Simplified Image, Clear Chart, Auto Scale X, Auto Scale Y, or Update Mode.

Click the magnifying glass icon to zoom in or out of the graph (see Figure 4-13).


NOTE: Zoom in and out are not available if Auto Scale X or Auto Scale Y are selected.

Figure 4-13 Zoom in and out



- ◆ Click the upper-left icon, then press and drag in the graph pane to select and zoom in on a defined area
- ◆ Click the upper-middle icon, then press and drag in the graph pane to select and zoom in on a defined x-range
- ◆ Click the upper-right icon, then press and drag in the graph pane to select and zoom in on a defined y-range

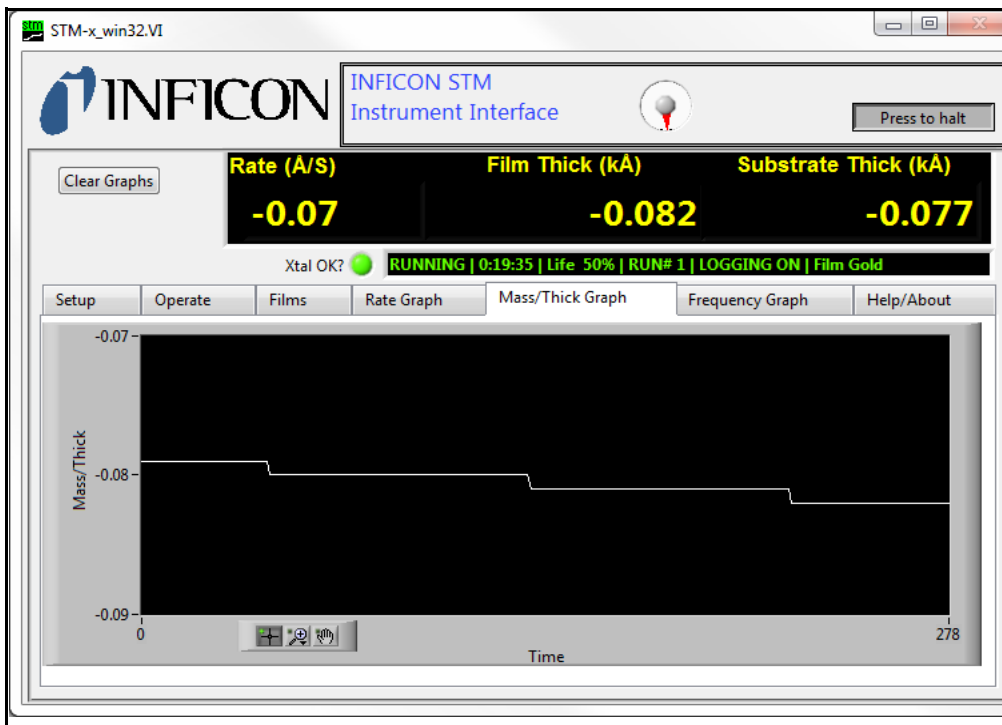
- Click the lower-left icon to return to the previous graph
- Click the lower-middle icon, then click anywhere in the graph pane to zoom in on a defined location on the graph

Click the hand icon () and then press and drag in the graph pane to move the graph.

4.3.5 Mass/Thick Graph

Displays a graph of Film Thickness or Film Mass being monitored (see Figure 4-14).

Figure 4-14 Mass/Thick Graph tab

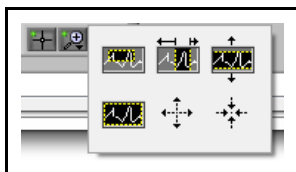


Right-click anywhere on the graph to Copy Data, Export Simplified Image, Clear Chart, Auto Scale X, Auto Scale Y, or Update Mode.


Click the magnifying glass icon to zoom in or out of the graph (see Figure 4-15).

NOTE: Zoom in and out are not available if Auto Scale X or Auto Scale Y are selected.

Figure 4-15 Zoom in and out



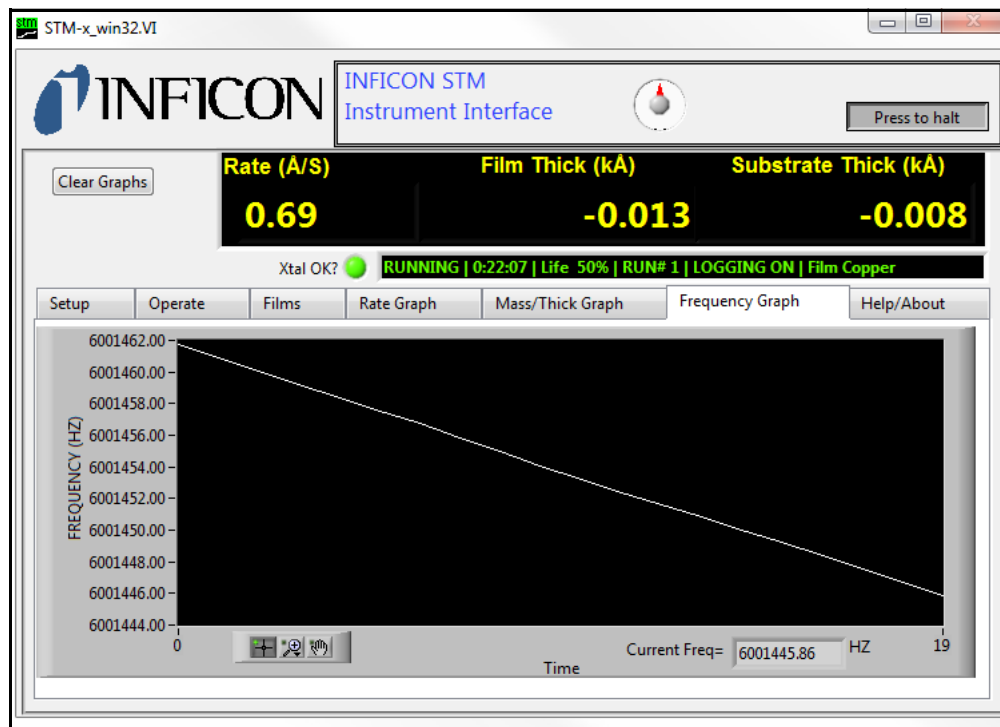
- ◆ Click the upper-left icon, then press and drag in the graph pane to select and zoom in on a defined area
- ◆ Click the upper-middle icon, then press and drag in the graph pane to select and zoom in on a defined x-range
- ◆ Click the upper-right icon, then press and drag in the graph pane to select and zoom in on a defined y-range
- ◆ Click the lower-left icon to return to the previous graph
- ◆ Click the lower-middle icon, then click anywhere in the graph pane to zoom in on a defined location on the graph

Click the hand icon () and then press and drag in the graph pane to move the graph.

4.3.6 Frequency Graph

Displays a graph of Frequency of the crystal used to monitor. Also displays a live value in the **Current Freq** pane (see [Figure 4-16](#)).

Figure 4-16 Frequency Graph tab

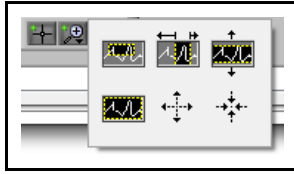


Right-click anywhere on the graph to Copy Data, Export Simplified Image, Clear Chart, Auto Scale X, Auto Scale Y, or Update Mode.


Click the magnifying glass icon to zoom in or out of the graph (see [Figure 4-17](#)).

NOTE: Zoom in and out are not available if Auto Scale X or Auto Scale Y are selected.

Figure 4-17 Zoom in and out



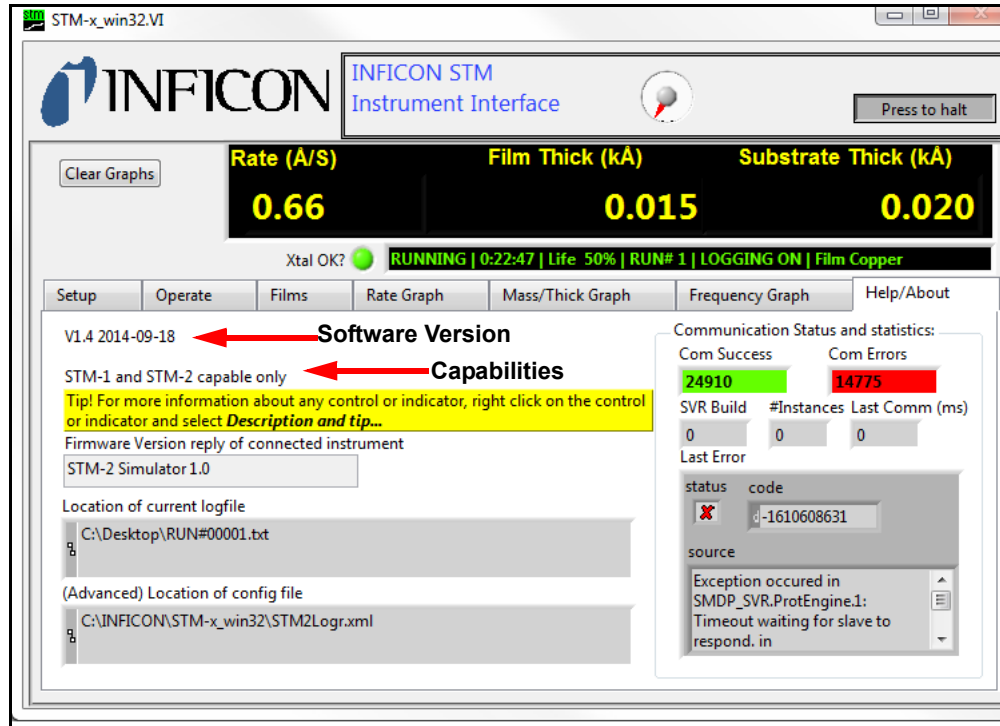
- ◆ Click the upper-left icon, then press and drag in the graph pane to select and zoom in on a defined area
- ◆ Click the upper-middle icon, then press and drag in the graph pane to select and zoom in on a defined x-range
- ◆ Click the upper-right icon, then press and drag in the graph pane to select and zoom in on a defined y-range
- ◆ Click the lower-left icon to return to the previous graph
- ◆ Click the lower-middle icon, then click anywhere in the graph pane to zoom in on a defined location on the graph

Click the hand icon () and then press and drag in the graph pane to move the graph.

4.3.7 Help/About

Displays information for troubleshooting and help (see Figure 4-18).



Figure 4-18 Help/About tab



- Software Version** Displays the software version.
- Capabilities** Displays the instruments compatible with STM-x_win32.VI Application software.
- Tip** Displays directions on how to access Descriptions and Tips throughout the STM-x_win32.VI Application.
- Firmware Version** Queries STM-2 and displays the firmware version of the connected STM-2.
- Location of current logfile** Displays the location of the log file that was set up on the **Setup** tab.
- (Advanced) Location of config file** Displays the location of the configuration file.

Communication Status and Statistics pane

- Com Success** Counter which displays the number of successful communication attempts to STM-2.
- Com Error** Counter which displays the number of failed communications (communication errors).
- SVR Build** Build or version of the communication server.
- #Instances** Displays the number of instruments using the communication server. It is possible to have multiple instances of **STM-x_win32.VI** running.

NOTE: It is possible to have other programs running that access the same instrument without conflict.
- Last Comm (ms)** The last communication time in milliseconds.
- Last Error** Report of errors in communication.
 - Status**  indicates successful communication
 indicates failed communication.
 - Code** Displays the Error Code for the Failed Communication.
 - Source** Describes the Error Code.

Chapter 5

Communication

5.1 Communication Protocol

Although STM-2 connects via USB, it integrates as a virtual serial port. Therefore, STM-2 may be opened, read from, and written to just like any serial port. STM-2 follows the SMDP (Sycon Multi Drop Protocol), which makes it possible to communicate with STM-2 without following USB protocol (see [section 5.2](#)).

If custom software will be developed on Windows, INFICON provides an ActiveX control that implements the SMDP protocol and manages the serial ports, allowing multiple programs to access the same STM-2. For more information concerning ActiveX and SMDP, contact INFICON (refer to [section 1.3 on page 1-4](#)).

Since each STM-2 connects to the host computer via its own USB-to-serial bridged COM port, there is no need to consider the multidrop addressing function of the SMDP protocol. Each STM-2 is on a private serial connection, so any valid address for SMDP can be used for any or all units. The Windows COM port assignment keeps the communications to each STM-2 unit separate.

5.2 Sycon Multi-Drop Protocol (SMDP)

SMDP is a byte-packet, binary protocol. All eight bits of the data of a byte/character are used. Standard asynchronous serial conventions apply. A packet begins with STX (ASCII 0x02) and ends with CR (carriage return, 0x0D).

The SMDP specification provides several common, mandated command codes. STM-2 responds to these common messages. For example, the reset command will cause STM-2 to reboot, as though power was cycled. This will set STM-2 into a known state. Another common command queries the product type or ID. This command (0x30) will return an ASCII integer code that identifies the product type (see [section 5.2.1.2 on page 5-4](#)). This allows a master computer to poll a network and locate devices by their types and ensure that the proper connection and commands are used for the appropriate product.

NOTE: Each field in angle brackets (< >) is a byte, and is not optional. Fields in regular brackets ([]) are optional. Ellipses (...) mean one or more of the previous.

5.2.1 Command Format

<STX><ADDR><CMD_RSP> [<DATA> . . .] <CKSUM1><CKSUM2><CR>

- STX** Start of text character (hexadecimal 02)

Multiple STX characters in a row are allowed. Data between STX characters is ignored. A single STX character initializes the receiver to receive a new message, purging any data collected since the last STX character or carriage return received.
- ADDR** One byte address field

The address (ADDR) byte identifies the SMDP address in order to select which device the command/query is sent to, in cases where multiple slave devices share a common link. In the case of the USB STM2, the address is not used.

The range of values are 10 hexadecimal to FE hexadecimal (16 to 254 decimal).

Address FF hexadecimal is reserved. It is used as an extension to indicate another byte of address information follows for products that have an address range higher than an address of FE hexadecimal.
- CMD_RSP** Command/Response field

When a command is sent from master to slave, the RSPF bit is zero and the RSP field (3 bits) is zero.

When a command is received from a slave to a master, CMD bits are the same as in the message that was sent (see [section 5.2.1.2](#)), but the RSP2 through RSP0 field will be non-zero (indicating actual unit response status) (see [section 5.2.1.3](#)). The slave will set or clear the RSPF flag bit in the reply CMD_RSP frame to indicate an unacknowledged slave reset. This bit only has meaning when a command is going from slave to master. If this bit is 1, the slave has

been reset since the last AckPF, acknowledge power fail flag command was received (see [Table 5-1](#)).

Table 5-1 Command/Response

D7	D6	D5	D4	D3	D2	D1	D0
CMD3	CMD2	CMD1	CMD0	RSPF	RSP2	RSP1	RSP0

DATA Optional data

STX and carriage return characters are not allowed in the data field.

To send a data byte valued as hexadecimal 02, send the protocol escape character (hexadecimal 07) followed by zero (hexadecimal 30).

To send a data byte valued at hexadecimal 0D, send the protocol escape character (hexadecimal 07) followed by one (hexadecimal 31).

To send a data value of hexadecimal 07, send the protocol escape character followed by two (hexadecimal 32).

The protocol escape character cannot be sent as a single byte, but can only be sent as the first byte of a pair, followed by an ASCII 0, 1, or 2.

If the protocol escape character is seen but is not followed by an ASCII 0, 1, or 2, the command is invalid and is ignored.

CKSUM1,2 Checksum characters for the message

This is the mod-256 checksum of the command binary message data. The checksum does not include STX and carriage return, and it is calculated before escape character byte stuffing (see [section 5.2.1.1](#)).

5.2.1.1 Checksum

- ◆ Compute the mod 256 checksum of ADDR, CMD_RSP and DATA fields, before byte stuffing with escape characters. This is the logical content (payload) of the command.
- ◆ CKSUM1 is the upper (most significant) four bits of the checksum (read as a nibble, 0 through 15, or right justified) plus hexadecimal 30 (ASCII zero). This yields an ASCII character from zero (hexadecimal 30) to ? (hexadecimal 3f).
- ◆ CKSUM2 is the lower (least significant) four bits of the checksum plus hexadecimal 30 (ASCII zero). This yields an ASCII character from zero (hexadecimal 30) to ? (hexadecimal 3f).

NOTE: If the checksum of the command is invalid (in form or value), the packet is deemed invalid and will be ignored.



CAUTION

Invalid commands (bad checksum, too short, corrupt data, bad escape sequences) will be ignored by slaves (and masters). No response will be sent by the slave.

5.2.1.2 Command Packet Format

```
<STX><ADDR><CMD_RSP> [<DATA> . . . ] <CKSUM1><CKSUM2><CR>
```

Where <CMD> is:

1,2	Reserved	Reserved for future use in protocol stack.
3	Prod_id	Product identifier, returned as decimal string. NOTE: The value for STM-2 is 19 decimal.
4	Version	Request slave to return software version string.
5	Reset	Request slave to reset/reboot.
6	AckPF	Request slave to acknowledge power failure flag and clear RSPF bit.
7	PROTV	Request slave to return protocol stack version as decimal string.
8	Product_Specific	Application API prefix to precede STM-2 commands (see section 5.3 on page 5-7).

NOTE: SMDP will respond to commands in the range of 1 through 7. Commands 3 through 7 are handled in the protocol, at the protocol layer. Applications are not to use commands 3 through 7 except to implement the protocol specification.

5.2.1.3 Response Packet Format

<STX><ADDR><CMD_RSP> [<DATA> . . .] <CKSUM1><CKSUM2><CR>

NOTE: In the CMD_RSP byte, the CMD bits are unchanged from the master, but the RSP bits are filled in according to the status of the slave.

Where <RSP> is:

1	OK	Command understood and executed.
2	Err_Inv_cmd	Illegal command (CMD code not valid).
3	Err_syntax	Syntax error (too many bytes in data field, not enough bytes).
4	Err_range	Data range error.
5	Err_inh	Inhibited.
6	Err_obso	Obsolete command. No action taken.

5.2.2 Optional Serialization Command Mode

SMDP (version 3 and greater) allows for a serial number in the command to associate a command from the master with the correct response. This detects errors in serial communications ports where commands are queued and sent out of order. The protocol structure is nearly identical to [section 5.2, Sycon Multi-Drop Protocol \(SMDP\), on page 5-1](#), except:

- ◆ A serial number byte must be placed before the checksum bytes. This must be a value greater than or equal to 0x10 (16), otherwise it could be mistaken as a framing or escape character byte (see [section 5.2.2.1](#)). This byte is summed as a part of the packet payload in computing the packet checksum value.
- ◆ The checksum character base must be hexadecimal 40 (@), instead of hexadecimal 30 (0) to inform the slave that it is receiving a packet with the extra SRLNO field postamble. This makes the last two characters of the command (the checksums) range from @ (0x40) through the letter, O (0x4f).
- ◆ For a response, the slave places the corresponding SRLNO byte into its response packet just before the two reply packet checksum characters, also 0x40 based.

In order for this serial command mode to be effective, the master should generate a new SRLNO value for each command that it sends (modulo 255, and greater than 0x10). This allows for 240 unique serial number values before repeating. The value could be an incrementing tag that rolls over from 255 to 16 with the understanding that there would never be 240 outstanding messages. Alternatively, the tag could have a unique value or range of values for each line of communication to the product at a specific address. This will allow the responses to be received by the proper line of communication.

NOTE: When an SMDP response packet is received by the master, verify the SRLNO value and use it to associate it with the source of the command/query. This will prevent out-of-sequence replies from being misinterpreted and invalid results being generated.

5.2.2.1 Optional Serial Command Format

<STX><ADDR><CMD_RSP> [<DATA> . . .] <SRLNO><ACKSM1><ACKSM2><CR>

SRLNO Serial Number

Associates a command from the master with the correct response. The value must be greater than or equal to 0x10 (16) in order to not be mistaken as a framing or escape character byte.

ACKSM1, 2 Alternate 0x40 based checksum characters

This has a range of values from @ (0x40) through the letter, O (0x4f).

NOTE: Refer to [section 5.2.1 on page 5-2](#) for additional information identifying the bytes in this command string.

5.3 Communications Commands

Some processes may require the development of specialized software. The STM-2 command set is listed in [Table 5-2](#).

STM-2 uses command prefix 0x80 to introduce command sequences. The data payload that follows 0x80 are standard ASCII character sequences. This vocabulary is documented in [section 5.2.1.2 on page 5-4](#).

Common commands have the same initial character sequences, and are distinguished by variable numeric arguments which further specify the intended action or target of the command/query.

Therefore, only the data payload content which distinguishes these commands are found in this section.

All responses conform to the SMDP specification (refer to [section 5.2 on page 5-1](#)) with the lower four bits of the returned <CMD_RSP> byte being a non-zero value in the range of 1 to 15. The upper 4 bits are the same as the host command group (CmdOpcode_<xxx>), 3 to 8. The lower three bits have the value 1 to 7 as defined in [section 5.2.1.3 on page 5-5](#). This value indicates whether the receiver could process the query or found fault with it. If the address is not matched with a slave, the checksum of the frame fails, or the command is otherwise improper, no response is returned by the slave.

The fourth bit (D3, 8 weight) is a power fail flag bit, and the slave replies with this bit set when the platform has been reset, until such a time as the master sends one of the following:

- ◆ Acknowledge-power-fail command (CmdOpcode_ACKPF 0x60), low level SMDP message
- ◆ ACKALL ('L') command, application specific command (0x80). This message from the master clears the power fail flag such that the status bit, D3, of all subsequent replies is now zero. This allows the master to detect at the earliest transaction (first valid communications after reboot/reset) that the slave device has been reset and needs to be re-synchronized. This might be considered a fatal error (power supply was reset and system state harmed), a soft error which can be recovered from, or a non-issue requiring no intervention.

Table 5-2 STM-2 command set

STM-2 command	Parameter	Send	Returned	Description
@	None	@	STM-2 A0.3	Instrument model and firmware version. User references this when reporting product behavior issues.
@A	None	@A	600022	Instrument serial number (600022 is an example, each unit is unique). This reply allows multiple units connected to a computer to be identified to associate with correct sensor.
@B	None	@B	1	Instrument build type

Table 5-2 STM-2 command set (continued)

STM-2 command	Parameter	Send	Returned	Description
L	None	L		Acknowledge "a" response, reset flags so response to 'a' poll is "@" next time.
b	None	b		Set parameters to default values. Clears memory, reboots module, sets power loss and memloss flags so response to 'a' command is 'E'.
d	None	d		Cause reset
p	None	p		Queries firmware version CRC as a decimal value. Associates with @ command, but returns a decimal value that is unique for each version. i.e. version A0.3 is 4645.
Zeroing commands				
B	None	B		Zeroes timer and thickness
C	None	C		Zeroes thickness
D	None	D		Zeroes timer
Film commands = nnn to update parameter ? to query parameter				
q	=[8 char string],[?]	q=COPPER		Sets the current film name to COPPER. This allows the customer to name each module for simple reference. Additionally, the unique serial number reply to the query @A will allow a unique module specific identification.
E	=[0.40 - 99.99],[?]	E=1.23		Set current film density to 1.23
F	=[0.100 - 9.999],[?]	F?	1.230	Returns current film Z-ratio
J	=[10.0 - 999.9],[?]	J = 80.1		Set current film tooling to 80.1%. Spaces before or after = sign are legal. Can be used for readability.
r	=[1 - 50],[?]	r=10		Sets number of samples to 10 for temporal averaging
Runtime data commands				
M	None	M	!	Return crystal fail status @ = crystal good ! = crystal failed
S	None	S	-1.595	Return thickness value -1.595 Å
s	None	s	1.234	Return film mass 1.234 µg/cm ²
T	None	T	12.46	Return rate, 12.46 Å/s
t	None	t	1.307	Return mass accumulation rate in µg/ (*s/cm ²), 1.307 µg/ (*s/cm ²)

Table 5-2 STM-2 command set (continued)

STM-2 command	Parameter	Send	Returned	Description
U	None	U	5319234.34	Return sensor frequency 5,319,234.34Hz
V	None	V	15	Return crystal life, the example shows 15% remaining. Display is integer only, no decimal points. 100 is new crystal, 6 MHz, 0 is 5 MHz, values between 100 and 0 are proportional.
W	None	W	0:12:45	Return timer in H:MM:SS format, 12 min 45 s
a	None	a	A	Return RESET Status @ = OK A = lost power D = lost NONV memory E = lost power and NONV memory NOTE: NONV refers to non-volatile memory, i.e. memory that is persistent even when power is lost. This status is indicating that there was a loss of data, either due to an internal database problem, or a database purge.

Chapter 6

Troubleshooting and Maintenance

6.1 Troubleshooting Guide

If STM-2 fails to function, or appears to have diminished performance, the following troubleshooting charts may be helpful.



CAUTION

There are no user serviceable components within the STM-2 case.

Refer all maintenance to qualified personnel.

6.1.1 Indicator

If there is a problem with STM-2, the indicator will display a signal as to the likely cause, (see [Table 6-1](#)).

Table 6-1 Indicator troubleshooting guide

SYMPTOM	CAUSE	REMEDY
Power indicator flashing	STM-2 and/or sensor not connected.	Verify proper STM-2/sensor connections.
	Failed crystal/no crystal.	Replace crystal with new INFICON crystal.
	Two crystals placed into the crystal holder.	Remove one of the crystals.
	Computer did not initialize STM-2.	Click Find Instruments >> Search for STM-2s on LabVIEW Application.
Power indicator extinguished	STM-2 does not have power.	Verify computer is turned on and USB cable is plugged in.
	Device drivers not properly installed.	Uninstall and reinstall device drivers.
USB indicator is flashing	Communication traffic.	Program software to query STM-2 every 100 ms for indicator to be illuminated.
USB indicator is extinguished	Software not running.	Open STM-x_win32 application.
	Software not installed.	Install STM-x_win32 application.

6.1.2 General STM-2 Troubleshooting

Table 6-2 General troubleshooting

SYMPTOM	CAUSE	REMEDY
Rate, Thickness, and Frequency readings are unstable or incorrect.	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. Refer to the sensor operating manual. Clean or replace the crystal holder. Refer to the sensor operating manual. Use SPC-1157-G10 crystals designed to minimize frequency shifts due to thermal shock.
	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. Flow water above the dew point of the room through the sensor when the chamber is open.
	Defective in-vacuum cable or coax cables.	Use an ohmmeter to check electrical continuity and isolation.
	Crystal seating on the crystal holder surface is scratched or contaminated.	Clean or replace crystal holder. Refer to the sensor operating manual.
	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 STM-2 or oscillator and feedthrough.

Table 6-2 General troubleshooting (continued)

SYMPTOM	CAUSE	REMEDY
Crystal 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.
	Build-up of material at crystal holder aperture is touching the crystal.	Clean or replace the crystal holder. Refer to the sensor operating manual.
	Crystal frequency is not within the Min and Max frequency settings.	Install a new crystal. Use a 6 MHz crystal.
	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 STM-2 or oscillator and feedthrough.
	Sensor not connected, or bad electrical connection in sensor head or feedthrough, or bad cables.	Check sensor connections. Refer to the sensor operating manual. 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 operating manual. Substitute a 5.5 MHz test crystal or a known good sensor for the suspect sensor.
Crystal fail	Bad coax cable between feedthrough and STM-2 or oscillator, or bad coax cable between oscillator and STM-2.	Use an ohmmeter to check electrical continuity / isolation. Substitute a known good coax cable.
	STM-2 or oscillator is malfunctioning.	Substitute a known good STM-2 (or other QCM). Substitute a known good oscillator.

Table 6-2 General troubleshooting (continued)

SYMPTOM	CAUSE	REMEDY
Crystal fail during deposition before “normal” life of crystal is exceeded.	Crystal is being hit by small droplets of molten material from the evaporation source (spatter or spitting).	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 buildup on crystal holder is partially masking the crystal surface.	Clean or replace the crystal holder. Refer to the sensor operating manual.
	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.
Crystal 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 dew point of the room through the sensor when the chamber is open.

Table 6-2 General troubleshooting (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 STM-2.	Locating STM-2 and 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. Ground wires or straps should be short with large surface area to minimize impedance to ground.

Table 6-2 General troubleshooting (continued)

SYMPTOM	CAUSE	REMEDY
Thickness reading has large excursions during deposition.	Mode hopping due to damaged or heavily dampened 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. Refer to the sensor operating manual.
	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, and BNC cables. Refer to the sensor operating manual.
	Inadequate cooling of crystal.	Check water flow rate and temperature for sensor cooling. Refer to the sensor operating manual.

Table 6-2 General troubleshooting (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).	Crystal not properly seated or dirty crystal holder.	Check crystal installation. Clean the crystal seating surface inside the crystal holder or replace crystal holder. Refer to the sensor operating manual.
	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 crystals designed to minimize frequency shifts due to thermal shock.
	Inadequate cooling of crystal.	Check water flow rate and temperature for sensor cooling. Refer to the sensor operating manual.
	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 (spatter or spitting).	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 operating manual.

Table 6-2 General troubleshooting (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.
	Material does not adhere well to the crystal.	Check for contamination on the surface of the crystal. Evaporate an intermediate layer of appropriate material onto the crystal to improve adhesion. Use gold, silver, or alloy crystals as appropriate.

6.1.3 Troubleshooting Computer Communications

Table 6-3 Troubleshooting computer communications

SYMPTOM	CAUSE	REMEDY
Communications cannot be established between the host computer and STM-2.	Improper cable connection.	Verify for cable connections are seated properly.
	Driver not installed properly.	Reinstall drivers.
	Computer did not initialize STM-2.	Click Find Instruments >> Search for STM-2s on LabVIEW Application.

Chapter 7

Calibration Procedures

7.1 Importance of Density, Tooling and Z-Ratio

The quartz crystal microbalance is capable of precisely measuring the mass added to the face of the oscillating quartz crystal sensor. STM-2 recognizes the density of this added material to allow 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 7.2](#).

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 7.3 on page 7-2](#).

If the Z-Ratio is not known, it could be estimated from the procedures, as outlined in [section 7.4 on page 7-3](#).

7.2 Determining Density

NOTE: The bulk density values retrieved from [Appendix A](#) are sufficiently accurate for most applications.

To determine density value:

- 1 Place a substrate (with proper masking for film thickness measurement) adjacent to the sensor, to ensure 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%.
- 4 Place a new crystal in the sensor and make a short deposition (1000 to 5000 Å).
- 5 After deposition, remove the test substrate and measure the Film thickness with either a multiple beam interferometer or a stylus-type profilometer.

- 6 Determine the new Density value with [equation \[1\]](#):

$$\text{Density}(\text{g}/\text{cm}^3) = D_1 \left(\frac{T_x}{T_m} \right) \quad [1]$$

where:

D_1 = Initial Density setting

T_x = Thickness reading on STM-2

T_m = Measured thickness

- 7 A quick check of the calculated Density may be made. If the STM-2 thickness has not been zeroed between the test deposition, enter the calculated Density. Program STM-2 with the new Density value and observe whether the displayed thickness is equal to the measured thickness.

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 $T_x = T_m$.

7.3 Determining Tooling

- 1 Place a test substrate in the substrate holder of the system.
- 2 Make a short deposition and determine actual thickness.
- 3 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 STM-2 software

TF_i = Initial tooling factor

- 4 Round percent tooling to the nearest 0.1%.
- 5 When entering this new value for Tooling into the program, if calculations are done properly, T_m will equal T_x .

NOTE: To account for variations in source distribution and other system factors, obtain an average value for Tooling, using a minimum of three separate evaporations.

7.4 Laboratory Determination of Z-Ratio

A list of Z-Ratio values for materials commonly used are available in [Appendix A](#). For other materials, Z-Ratio can be calculated from the following formulas:

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

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

where:

d_f = Density (g/cm³) of deposited film

μ_f = Shear modulus (dynes/cm²) of deposited film

d_q = Density of quartz (crystal) (2.649 g/cm³)

μ_q = Shear modulus of quartz (crystal) (3.32 x 10¹¹ dynes/cm²)

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

Laboratory results indicate that Z-Ratio 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 7.2 on page 7-1](#).
- 2 Install a new crystal and record its starting Frequency, F_{co} .
The starting Frequency will be displayed on the **Frequency Graph** tab.
- 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.
- 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.

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

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/(m²*s))

p = Density of deposited film (g/cm³)

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 material 1 Z-Ratio for both layers.
- ◆ If the thickness of layer 1 is thin compared to layer 2, use material 2 Z-Ratio 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-Ratio values for deposition of layer 2 and subsequent layers.

Chapter 8

Measurement and Theory

8.1 Basics

The Quartz Crystal deposition Monitor (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 sharp electro-mechanical resonance is encountered.

When mass is added to the face of a resonating quartz crystal, the frequency of these resonances are 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 1950's it was noted by Sauerbrey^{1,2} and Lostis³ that the change in frequency, $DF = F_q - F_c$, 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:

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

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

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

where the film thickness, T_f , is proportional (through K) to the frequency change, DF , and inversely proportional to the density of the film, d_f . The constant, $K = N_{at}d_q/F_q^2$; where $d_q (= 2.649 \text{ g/cm}^3)$ is the density of single crystal quartz and $N_{at} (= 166100 \text{ Hz cm})$ is the frequency constant of AT cut quartz.

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)

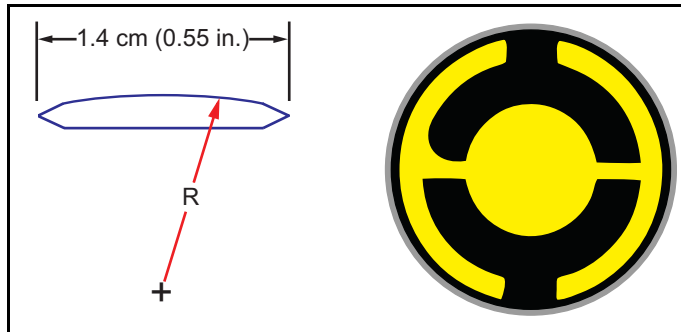
A crystal with a starting frequency of 6.0 MHz will display a reduction of its frequency by 2.27 Hz when 1 angstrom of Aluminum (density of 2.77 g/cm³) is added to its surface. In this manner, the thickness of a rigid adlayer is inferred from the precise measurement of the frequency shift of the crystal.

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.

8.1.1 Monitor Crystals

No matter how sophisticated the electronics surrounding it, the essential device of the deposition monitor is the quartz crystal. The quartz crystal shown in Figure 8-1 has a frequency response spectrum that is schematically shown in Figure 8-2. The ordinate represents the magnitude of response, or current flow of the crystal, at the specified frequency.

Figure 8-1 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 8-3 on page 8-4.

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 are also a series of anharmonics slightly higher in frequency associated with the quasiharmonic.

The monitor crystal design depicted in Figure 8-1 is the result of several significant improvements from the square crystals, with fully electroded plane parallel faces, that were first used.

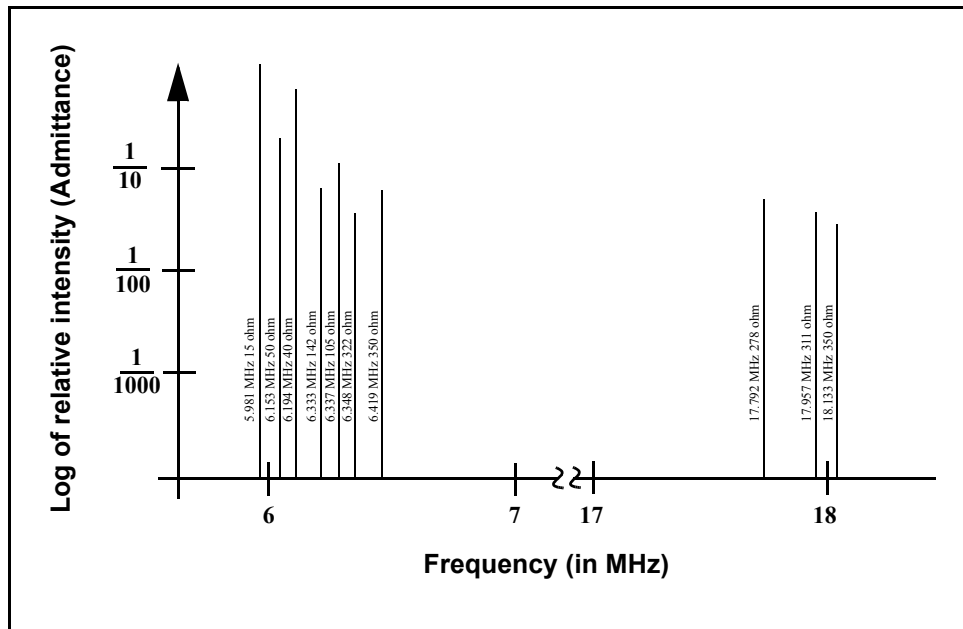
The first improvement implemented the use of circular crystals. The resulting increase in symmetry greatly reduced the number of allowed vibrational modes.

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. 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 vibrations of the crystal 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 8-2 Frequency response spectrum

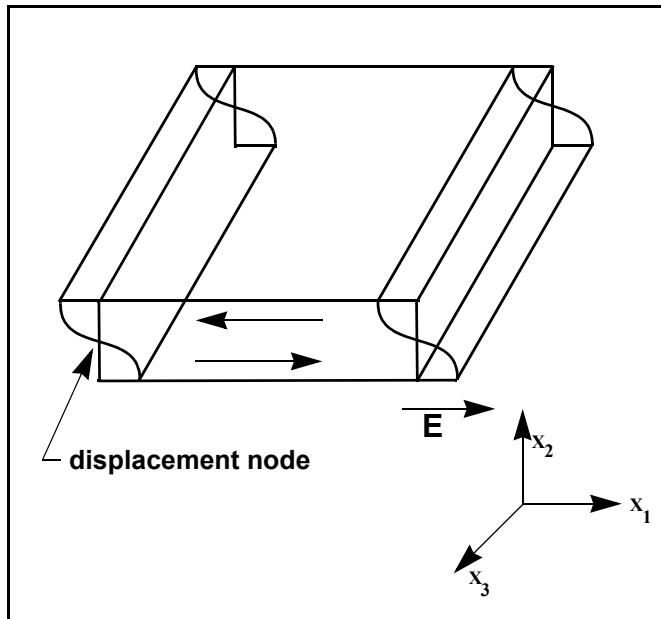


The use of an adhesion layer has improved the electrode-to-quartz bonding, reducing “rate spikes” caused by micro-tears between the electrode and the quartz, as film stress rises. These micro-tears leave portions of the deposited film unattached, and therefore unable to participate in the oscillation.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

Figure 8-3 Thickness shear displacement



8.1.2 Period Measurement Technique

Although instruments using equation [2] were very useful, it was soon noted that they had a limited range of accuracy, typically holding accuracy for ΔF less than $0.02 F_q$. In 1961, it was recognized by Behrndt⁴ that:

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

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:

- ◆ the digital implementation of time measurement, and
- ◆ the recognition of the mathematically rigorous formulation of the proportionality between the thickness of the crystal, l_q , and the period of oscillation, $T_q = 1/F_q$.

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

Electronically, the period measurement technique uses a second crystal oscillator, or reference oscillator, not affected by the deposition, which is 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.

Since the frequency of the reference is stable and known, the time to accumulate the m counts is known to an accuracy equal to $\pm 2/F_r$ where F_r is the reference frequency of the oscillator.

The period of the monitor crystal 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 (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. All of these require high time precision to resolve the small, mass-induced frequency shifts between measurements.

When the change in frequency between measurements of a monitor crystal is small, that is, on the same order of size as the measurement precision, it is not possible to establish quality rate control. The uncertainty of the measurement injects more noise into the control loop, which can be counteracted only by longer time constants. Long time constants cause the correction of rate errors to be very slow, resulting in relatively long term deviations from the desired rate.

These deviations may not be important for some simple films, but can cause unacceptable errors in the production of critical films such as optical filters or very thin-layered superlattices grown at low rates.

In many cases, the desired properties of these films can be lost if the layer-to-layer reproducibility exceeds one, or two, percent. Ultimately, the practical stability and frequency of the reference oscillator limits the precision of measurement for conventional instrumentation.

8.1.3 Z-match Technique

After learning of fundamental work by Miller and Bolef⁵, which rigorously treated the resonating quartz and deposited film system as a one-dimensional, continuous acoustic resonator, Lu and Lewis⁶ 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/monitors sold today use this sophisticated equation that takes into account the acoustic properties of the resonating quartz and film system as shown in [equation \[4\]](#).

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

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)

Appendix A

Material Table

A.1 Introduction

The following [Table A-1](#) represents the density and Z-Ratio for various materials. The list is alphabetical by chemical formula.



CAUTION

Some of these materials are toxic. Please consult the material safety data sheet and safety instructions before use.

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.

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 ₂ O ₃	3.970	0.336	aluminum oxide
Al ₄ C 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 ₂ Se ₃	4.750	*1.000	arsenic selenide
Au	19.300	0.381	gold
B	2.370	0.389	boron
B ₂ O ₃	1.820	*1.000	boron oxide
B ₄ C	2.370	*1.000	boron carbide
BN	1.860	*1.000	boron nitride
Ba	3.500	2.100	barium
BaF ₂	4.886	0.793	barium fluoride

Table A-1 Material Table (continued)

Formula	Density	Z-Ratio	Material Name
BaN ₂ O 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 ₂ O ₃	8.900	*1.000	bismuth oxide
Bi ₂ S ₃	7.390	*1.000	bismuth trisulfide
Bi ₂ Se ₃	6.820	*1.000	bismuth selenide
Bi ₂ Te 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 ₈ H 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-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
CeO ₂	7.130	*1.000	cerium (IV) dioxide
Co	8.900	0.343	cobalt

Table A-1 Material Table (continued)

Formula	Density	Z-Ratio	Material Name
CoO	6.440	0.412	cobalt oxide
Cr	7.200	0.305	chromium
Cr ₂ O ₃	5.210	*1.000	chromium (III) oxide
Cr ₃ C ₂	6.680	*1.000	chromium carbide
CrB	6.170	*1.000	chromium boride
Cs	1.870	*1.000	cesium
Cs ₂ SO 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 ₂ O	6.000	*1.000	copper oxide
Cu ₂ S	5.600	0.690	copper (I) sulfide (alpha)
Cu ₂ S	5.800	0.670	copper (I) sulfide (beta)
CuS	4.600	0.820	copper (II) sulfide
Dy	8.550	0.600	dysprosium
DY ₂ O ₃	7.810	*1.000	dysprosium oxide
Er	9.050	0.740	erbium
Er ₂ O 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 ₂ O ₃	5.240	*1.000	iron oxide
FeO	5.700	*1.000	iron oxide
FeS	4.840	*1.000	iron sulfide
Ga	5.930	0.593	gallium
Ga ₂ O 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
Gd	7.890	0.670	gadolinium
Gd ₂ O ₃	7.410	*1.000	gadolinium oxide

Table A-1 Material Table (continued)

Formula	Density	Z-Ratio	Material Name
Ge	5.350	0.516	germanium
Ge ₃ N 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	holmium
Ho ₂ O ₃	8.410	*1.000	holmium oxide
In	7.300	0.841	indium
In ₂ O ₃	7.180	*1.000	indium sesquioxide
In ₂ Se ₃	5.700	*1.000	indium selenide
In ₂ Te 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 ₂ O 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
LiBr	3.470	1.230	lithium bromide
LiF	2.638	0.778	lithium fluoride

Table A-1 Material Table (continued)

Formula	Density	Z-Ratio	Material Name
LiNbO ₃	4.700	0.463	lithium niobate
Lu	9.840	*1.000	lutetium
Mg	1.740	1.610	magnesium
MgAl ₂ O ₄	3.600	*1.000	magnesium aluminate
MgAl ₂ O 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 ₂ C	9.180	*1.000	molybdenum carbide
MoB ₂	7.120	*1.000	molybdenum boride
MoO ₃	4.700	*1.000	molybdenum trioxide
MoS ₂	4.800	*1.000	molybdenum disulfide
Na	0.970	4.800	sodium
Na ₃ AlF ₆	2.900	*1.000	cryolite
Na ₅ Al ₃ F 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 ₂ O ₃	7.500	*1.000	niobium trioxide
Nb ₂ O 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	neodymium
Nd ₂ O ₃	7.240	*1.000	neodymium oxide
NdF ₃	6.506	*1.000	neodymium fluoride
Ni	8.910	0.331	nickel

Table A-1 Material Table (continued)

Formula	Density	Z-Ratio	Material Name
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 ₃ N 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 ₂ O 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	sulfur
Sb	6.620	0.768	antimony
Sb ₂ O ₃	5.200	*1.000	antimony trioxide
Sb ₂ S ₃	4.640	*1.000	antimony trisulfide
Sc	3.000	0.910	scandium
Sc ₂ O ₃	3.860	*1.000	scandium oxide

Table A-1 Material Table (continued)

Formula	Density	Z-Ratio	Material Name
Se	4.810	0.864	selenium
Si	2.320	0.712	silicon
Si ₃ N 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 ₂ O 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 ₂ O 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 ₂ O ₃	4.600	*1.000	titanium sesquioxide
TiB ₂	4.500	*1.000	titanium boride
TiC	4.930	*1.000	titanium carbide

Table A-1 Material Table (continued)

Formula	Density	Z-Ratio	Material Name
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 ₃ O ₈	8.300	*1.000	tri uranium octoxide
U ₄ O ₉	10.969	0.348	uranium oxide
UO ₂	10.970	0.286	uranium dioxide
V	5.960	0.530	vanadium
V ₂ O 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 disulfide
WSi ₂	9.400	*1.000	tungsten silicide
Y	4.340	0.835	yttrium
Y ₂ O ₃	5.010	*1.000	yttrium oxide
Yb	6.980	1.130	ytterbium
Yb ₂ O ₃	9.170	*1.000	ytterbium oxide
Zn	7.040	0.514	zinc
Zn ₃ Sb ₂	6.300	*1.000	zinc antimonide
ZnF ₂	4.950	*1.000	zinc fluoride
ZnO	5.610	0.556	zinc oxide
ZnS	4.090	0.775	zinc sulfide
ZnSe	5.260	0.722	zinc selenide

Table A-1 Material Table (continued)

Formula	Density	Z-Ratio	Material Name
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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