Operating Manual

STM-2™

Rate/Thickness Monitor

074-613-P1E

INFICON

Two Technology Place

East Syracuse, NY 13057-9714

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Trademarks

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2 Declaration of Conformity

INFICON

DECLARATION OF CONFORMITY

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

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

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

Equipment Description: 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.

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

3 Warranty

WARRANTY AND LIABILITY - LIMITATION: Seller warrants the products manufactured by it, or by an affiliated company and sold by it, to be, for the period of warranty coverage specified below, free from defects of materials or workmanship under normal proper use and service. The period of warranty coverage is specified for the respective products in the respective Seller instruction manuals for those products but shall not be less than one (1) year from the date of shipment thereof by Seller. Seller's liability under this warranty is limited to such of the above products or parts thereof as are returned, transportation prepaid, to Seller's plant, not later than thirty (30) days after the expiration of the period of warranty coverage in respect thereof and are found by Seller's examination to have failed to function properly because of defective workmanship or materials and not because of improper installation or misuse and is limited to, at Seller's election, either (a) repairing and returning the product or part thereof, or (b) furnishing a replacement product or part thereof, transportation prepaid by Seller in either case. In the event Buyer discovers or learns that a product does not conform to warranty, Buyer shall immediately notify Seller in writing of such non-conformity, specifying in reasonable detail the nature of such non-conformity. If Seller is not provided with such written notification, Seller shall not be liable for any further damages which could have been avoided if Seller had been provided with immediate written notification.

THIS WARRANTY IS MADE AND ACCEPTED IN LIEU OF ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, WHETHER OF MERCHANTABILITY OR OF FITNESS FOR A PARTICULAR PURPOSE OR OTHERWISE, AS BUYER'S EXCLUSIVE REMEDY FOR ANY DEFECTS IN THE PRODUCTS TO BE SOLD HEREUNDER. All other obligations and liabilities of Seller, whether in contract or tort (including negligence) or otherwise, are expressly EXCLUDED. In no event shall Seller be liable for any costs, expenses or damages, whether direct or indirect, special, incidental, consequential, or other, on any claim of any defective product, in excess of the price paid by Buyer for the product plus return transportation charges prepaid.

No warranty is made by Seller of any Seller product which has been installed, used or operated contrary to Seller's written instruction manual or which has been subjected to misuse, negligence or accident or has been repaired or altered by anyone other than Seller or which has been used in a manner or for a purpose for which the Seller product was not designed nor against any defects due to plans or instructions supplied to Seller by or for Buyer.

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

4 Introduction and Specifications

4.1 Introduction

STM-2™ is a USB-powered thin film thickness and rate deposition monitor. 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-G1, can be used when the sensor is located farther than 101.6 cm (40 in.) from STM-2.

STM-2 makes 10 measurements per second. The measurements are shown on a 0.01 Å/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.

4.1.1 Related Manuals

Sensors are covered in separate manuals. PDF files of these manuals can be found on www.inficon.com.

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

4.2 Safety

4.2.1 General Safety Information

⚠ DANGER

Risk of Electric Shock

There are no user-serviceable components within the instrument case. Potentially lethal voltages are present. Refer all maintenance to qualified personnel.

⚠ CAUTION

Do not use the product in a manner not specified by the manufacturer.

If used in a manner not specified by the manufacturer, protection provided by the equipment may be impaired.

⚠ CAUTION

The instrument contains delicate circuitry that is susceptible to transient power line voltages. Disconnect power whenever making any interface connections. Refer all maintenance to qualified personnel.

4.2.2 Earth Ground

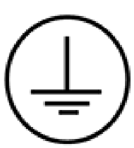
A sealed three-core (three-conductor) power cable connects the instrument to earth ground. It must be plugged into a socket outlet with a protective earth terminal. If an extension cable is used, it must always have three conductors, including a protective earth terminal. If a user-supplied power supply is used, the power supply connector must have a shield that is grounded to the AC line ground.

⚠ DANGER

Warning of Electrical Shock

Never interrupt the protective earth circuit. Any interruption of the protective earth circuit inside or outside the instrument or disconnection of the protective earth terminal may cause dangerous voltages to be present on or inside the instrument.

This symbol indicates where the protective earth ground is connected inside the instrument. Never unscrew or loosen this connection.



4.3 How to Contact Us

Worldwide customer support information is available at www.inficon.com, where you can contact:

- a Product Engineer with questions regarding applications and programming INFICON equipment
- a Service Engineer with questions regarding troubleshooting, diagnosing or repairing INFICON equipment
- Sales and Customer Service, to find the INFICON Sales office nearest you
- Repair Service, to find the INFICON Service Center nearest you

If you are experiencing a problem with the instrument, please have the following information readily available:

- the serial number and software version numbers
- a description of the problem
- an explanation of any corrective action you may have already attempted
- the exact wording of any error messages you have received

4.3.1 Returning the Product

Do not return any component of the instrument to INFICON without first speaking with a Customer Support Representative to obtain a Return Material Authorization (RMA) number. If a package is sent to INFICON without an RMA number, the package will be held and the sender will be contacted. This will result in delays in servicing. Prior to being given an RMA number, a Declaration Of Contamination (DOC) form must be completed to document if the product has been exposed to process materials. DOC forms must be approved by INFICON before an RMA number is issued. INFICON may require the product be sent to a designated decontamination facility prior to being accepted by the factory.

4.4 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 at 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

4.4.1 Power

Rated supply voltage	400 mA, 5 V (dc)
USB isolation voltage	1000 V
USB isolation capacitance	300 pF typically

4.4.2 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

4.4.3 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.)

4.4.4 Computer Requirements

Operating system	Windows 11, Windows 10, 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

4.5 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 exterior of the container. Immediately report any damage to the carrier as well as to INFICON.
3. Turn **ON** STM-2.
4. Refer to the invoice and take inventory (see Configurations and Accessories). Do not discard the packing materials before verifying inventory and power.
5. To install and set up, see Installation.
6. For additional information or technical assistance, contact INFICON (refer to How to Contact INFICON).

4.6 Parts and Options Overview

Base Configurations

STM-2 with software and cables	PN STM-2

Accessories

5 m (16.4 ft.) USB cable	PN 962-023-G1
15.2 cm (6 in.) BNC	PN 755-257-G6

Oscillator Kit

Although STM-2 has an internal oscillator, an option exists to use an external oscillator kit to interface the sensor to the controller.

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-G1
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.).

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

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

Multi-crystal (rotary) sensors should not be used with STM-2.

5 Instrument Safety

5.1 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.

6 Installation

6.1 Installation Requirements

Parts Requirements

- STM-2 monitor
- One crystal sensor with feedthrough
- One oscillator kit for each crystal sensor
  - The oscillator kit is not required when using the internal oscillator.
- Quartz crystals appropriate for the application
- One Windows computer meeting the minimum specifications. Refer to Specifications [▸ 12].

To maintain proper STM-2 performance, use only the BNC cable that is included to connect STM-2 or the oscillator to the crystal sensor.

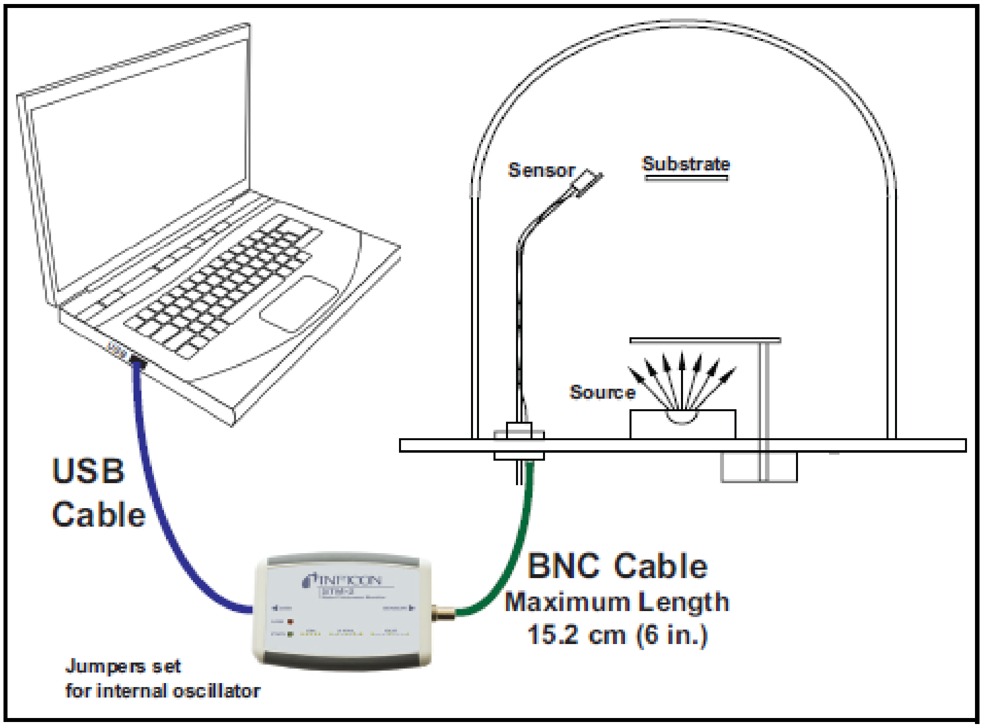
The length of the in-vacuum cable (front load and sputtering sensors) or the electrical conduit tube (cool drawer and bakeable sensors) must not exceed 78.1 cm (30.75 in.).

6.2 System Connections

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

6.2.1 Internal Oscillator

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



3 Install and run the STM-2 software or the STM-2 LabVIEW application.

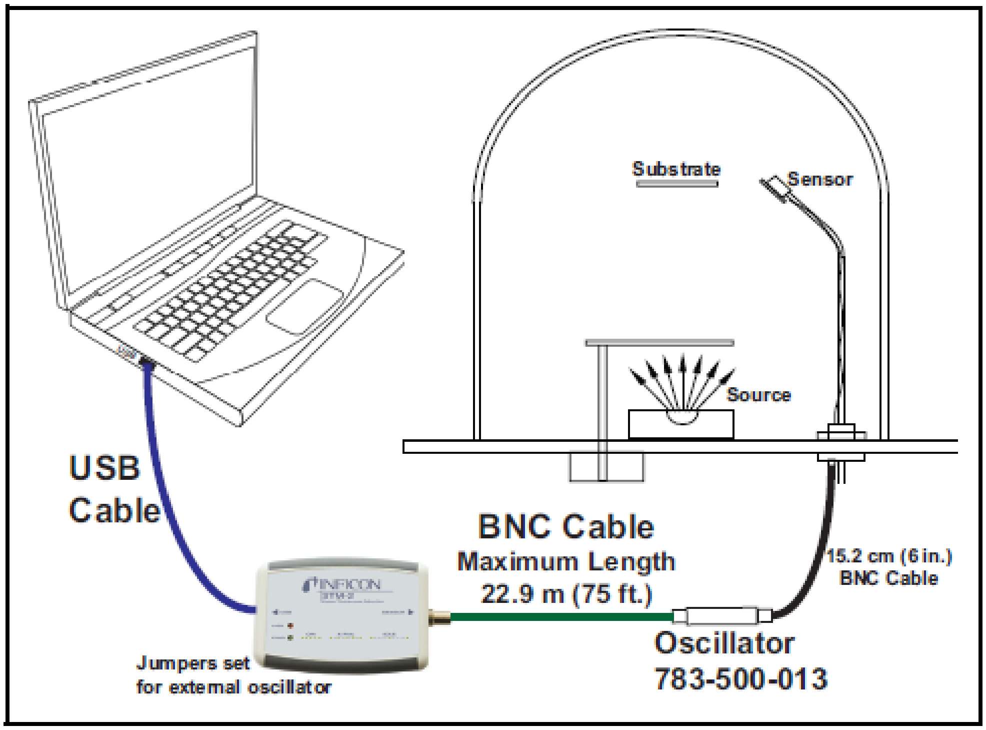
The STM-2 software and STM-2 LabVIEW can be installed and run on the same computer without interference, but not simultaneously. Only one application should be active at any one time.

4 The **PWR** indicator on STM-2 illuminates.

5 The **USB** indicator on STM-2 illuminates.

6.2.2 External Oscillator

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



6.3 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.

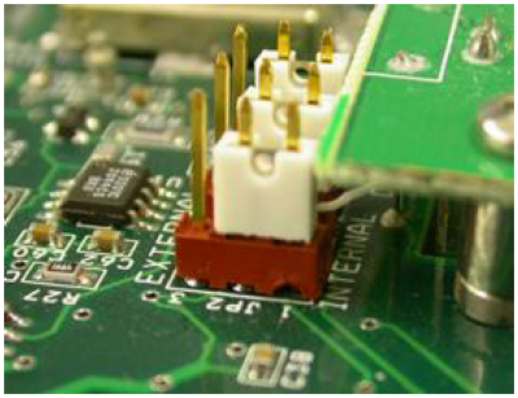
⚠ CAUTION

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

Remove the two Philips screws that 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.
- to **External** for external oscillator operation.



6.4 STM-2 Indicators

6.4.1 Power

Illuminated	STM-2 is powered up and is connected to a functioning 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 functioning crystal.
Blinking slow (approximately once per second)	STM-2 is powered up and the crystal is functioning, but the computer application has not initialized STM-2. Once the computer initializes STM-2, the indicator will illuminate continuously.
Extinguished	STM-2 does not have power. Check the USB connection and make sure the computer is turned on.

6.4.2 USB

The USB indicator detects communications signal traffic.

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

STM-x_win32 LabVIEW application software and INFICON STM-2 software 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.

7 Software Operation

7.1 Introduction

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

7.2 Install INFICON STM-2 Software

7.2.1 Install the Protocol Server

✓ Insert the Thin Film Manuals CD into the CD drive on the computer that will be connected to STM-2

1. Click **Windows Explorer** or click **File Explorer >> Computer >> (CD Drive letter:) >> Common Software**.
2. Double-click **setup_smdp_svr_lv.exe**.
   ⇨ The **Zip Self-Extractor** window displays.
3. Click **Unzip**.
   ⇨ The **SMDP Serial Protocol Service** window displays.
4. In the **Destination Directory** window, click **Browse** to select the location where the software will be installed.
5. Click **Next**.
6. Read the license agreement.
7. Click **I accept License Agreement(s)**.
8. Click **Next**.
9. Review the summary of information.
10. Click **Next**.
    ⇨ **Installation Complete** is displayed.
11. Click **Next**.
    ⇨ The **Confirm Installation** window is displayed.
12. Click **Next**.
13. Read the license agreement.
14. Click **I Agree**.
15. Click **Next**.

⇨ **Installation Complete** is displayed.

16 Click **Close**.

17 Close the **Zip Self-Extractor**.

7.2.2 Install the INFICON STM-2 Software and Device Drivers

✓ Insert the Thin Film Manuals CD into the CD drive of the computer that is connected to STM-2.

1 Click **Windows Explorer** or **File Explorer >> Computer >> (CD drive letter:) >> STM-2**.

2 Double-click **STM-2 v1.0.0 Setup.exe**.

⇨ The **STM2 InstallShield Wizard** is displayed.

3 Click **Next**.

4 Review the summary of information.

5 Select **I accept the terms in the license agreement**.

6 Click **Next**.

7 Click **Change** to select the location of the software files to be installed.

8 Click **Next**.

9 Click **Install**.

10 Click **Finish**.

⇨ The **USB Installer - InstallShield Wizard** window is displayed.

11 Click **Next**.

12 Review the summary of information.

13 Select **I accept the terms in the license agreement**.

14 Click **Next**.

15 Click **Install**.

16 Click **Finish.**

⇨ The **CP210x USB to UART Bridge Driver Installer** window is displayed.

17 Click **Next**.

18 Review the summary of information.

19 Select **I accept this agreement**.

20 Click **Next**.

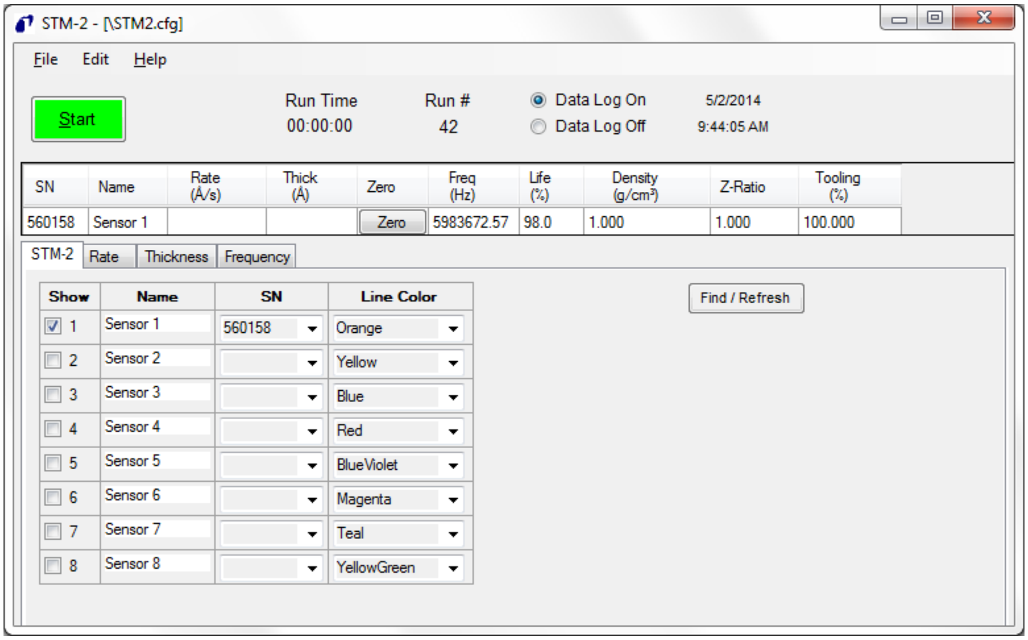
21 Click **Finish**.

7.3 Start the STM-2 Software

7.3.1 Start the Software in Windows XP or Windows 7

► Click **Start**, then select **All Programs**, **INFICON**, **STM-2**.

⇨ The **STM-2** windows displays.



7.3.2 Start the Software in Windows 11, Windows 10, or Windows 8

1. In the **Start** window, click the **STM-2** icon.
2. If the icon cannot be found:

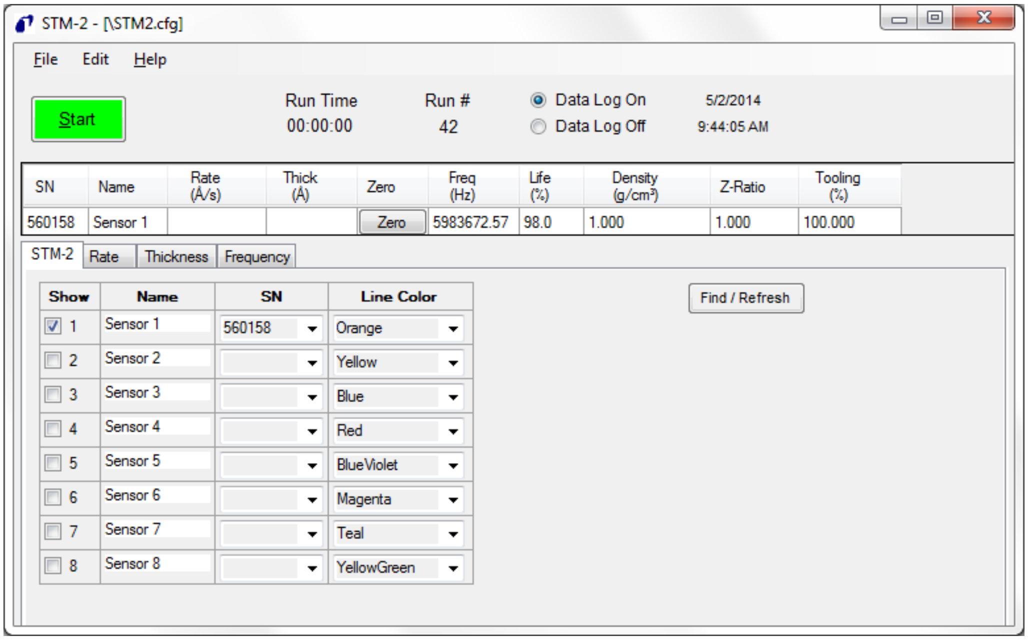
⇨ Click **Search**, then select **Apps**.

⇨ Type **STM** in the **Search** text box.

⇨ Click the **STM-2** icon.

7.3.3 STM-2 Window

The STM-2 window displays the serial number (**SN**), the sensor **Name**, the **Rate**, the thickness (**Thick**) of the film, the **Zero** thickness button, the frequency (**Freq**), the crystal **Life**, the **Density** of the film, the **Z-Ratio**, and the **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 logging (**Data Log**) 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.



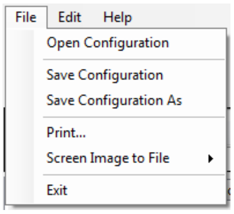
- **File** menu
- **Edit** menu
- **Help** menu
- **STM-2** tab
- **Rate** tab
- **Thickness** tab
- **Frequency** tab

Start/Stop	Click **Start** to start monitoring. The **Start** button changes to **Stop**. Click **Stop** to halt the process and the data log. Restart the process by clicking **Start**.
Pause/Resume	**Pause** is displayed while monitoring. Clicking **Pause** stops the monitoring at its current time. The **Pause** button changes to **Resume** when clicked. Clicking **Resume** continues the monitoring and increments the **Run Time**.
Run Time	**Run Time** shows the time that the current run number has been monitored. It resets when **Start** is clicked. It stops and continues when **Pause/Resume** is clicked.
Run #	The **Run #** is 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	**Date** displays the current date in month/day/year format.
Time	**Time** displays the current time in hh:mm:ss format.
SN	**SN** displays the serial number of the selected STM-2.
Name	**Name** displays the name of the selected STM-2.
Rate	**Rate** displays the rate in Å/s or the mass rate in $ng/cm^2/s$ of the selected STM-2.
Thick	**Thick** displays the thickness in Å or kÅ, or the mass in $\mu g/cm^2$, of the selected STM-2.
Zero	Click **Zero** to zero the thickness.
Freq	**Freq** displays the frequency of the crystal connected to the selected STM-2. **Freq** changes to **!XTAL FAIL!** if there is a crystal failure.
Life	**Life** displays the percentage of crystal life remaining, decremented from 100%. **Life** is based on a 6 MHz crystal.
Density	The density is between 0.5 to 99.99. **Density** displays the value in grams per cubic centimeter of the material being deposited. Click in the text box to edit the density value. For a list of common material densities, see Appendix A: Material Table [▸ 82].
Z-Ratio	The Z-Ratio is between 0.1 to 9.999. **Z-Ratio** displays the Z-Ratio of the 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: Material Table [▸ 82].

Tooling	The tooling is between 10 to 399. **Tooling** displays the tooling of the sensor connected to STM-2. Click in the text box to edit the tooling value. To determine tooling, see Determine Tooling [▸ 74].

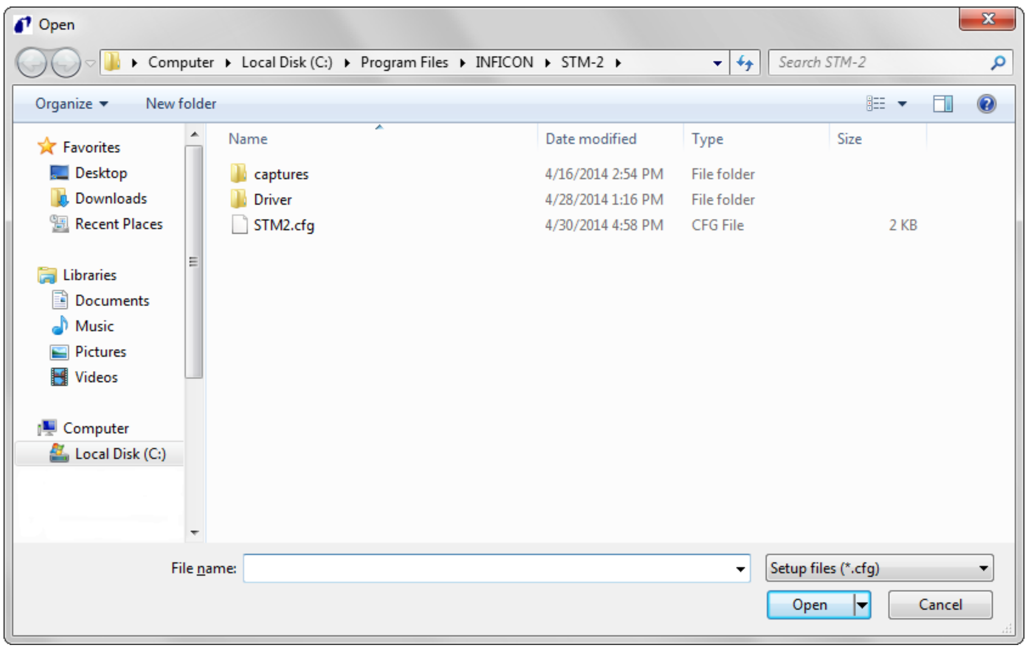
7.3.3.1 File Menu

Click **File** to open or save a configuration file, to print or capture screen images, or to exit the STM-2 software.



Open Configuration

Click **Open Configuration** to select a file location of a configuration file and load that configuration file into the STM-2 software.

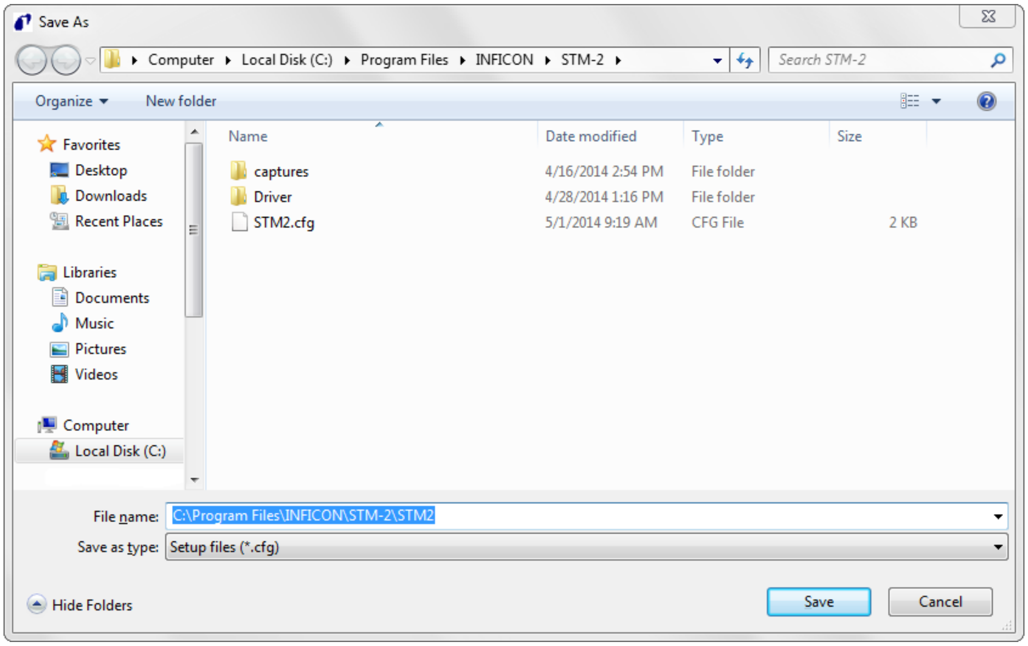


Save Configuration

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

Save Configuration As

Click **Save Configuration As** to select a name and location to save the configuration file.



Print

Click to print all of the current views of the STM-2 window 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.

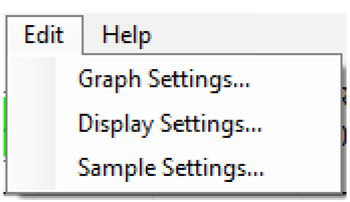
Screen Image to File

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

Current View to JPG	Places a JPG 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 JPG 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.

7.3.3.2 Edit Menu

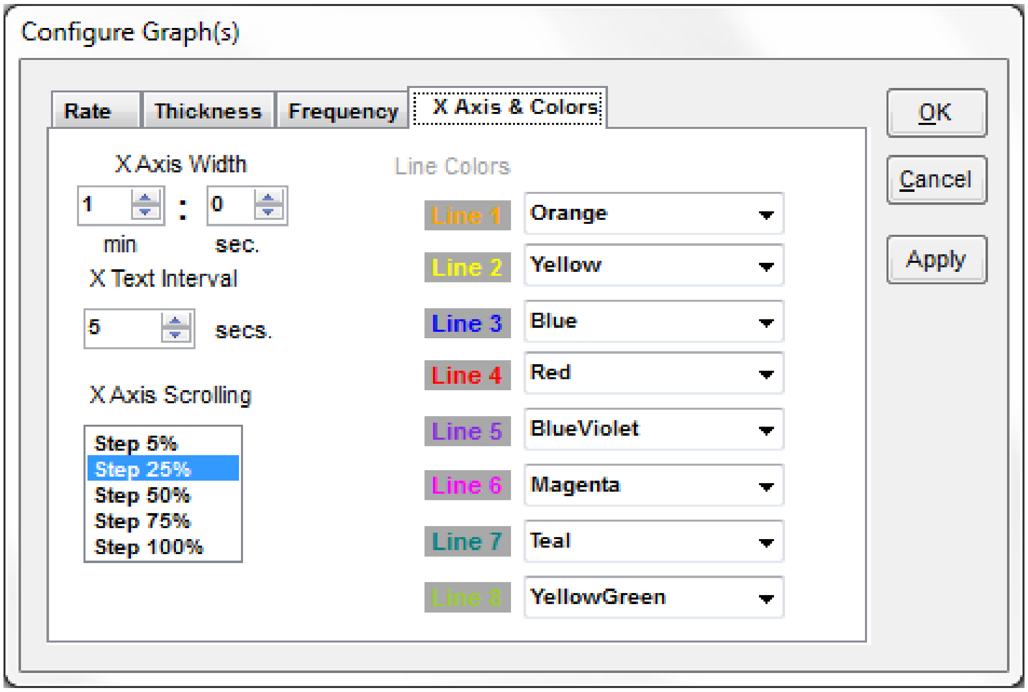
The **Edit** menu provides options to customize the graph, display, and sample settings.



Graph Settings

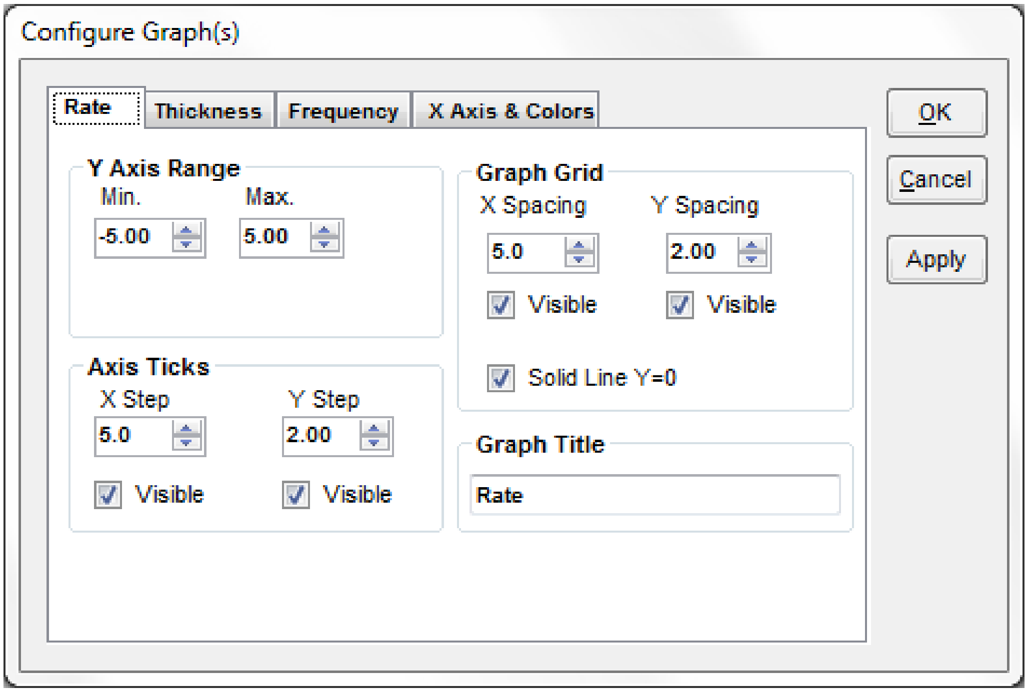
Click **Graph Settings** to display a window to configure the settings for the rate, thickness, and frequency graphs. Also provides customization of line colors, axis formatting, and scrolling.

Graph Settings is disabled while monitoring.



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 list to select a color to correspond with each STM-2 connected. This will also change the line color on the **STM-2** tab.

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.



Min.	-100.00 to 100.00 (Minimum y-axis value displayed on the rate graph. The 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. The maximum value must be greater than the value entered for the minimum.)

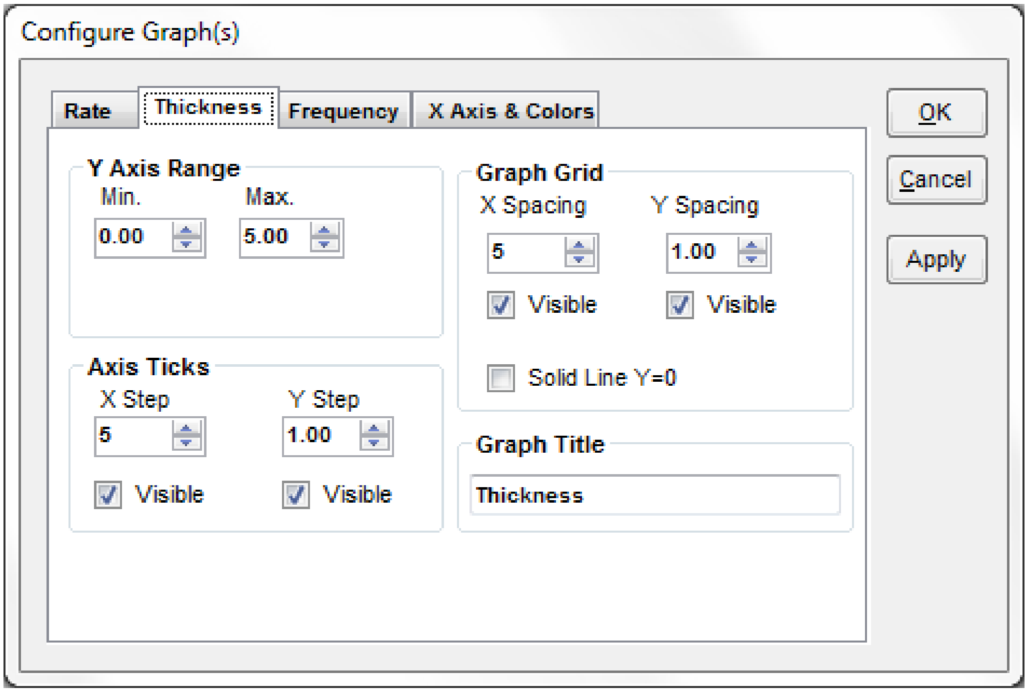
X Step	0 to 100.0 (Displays unlabeled x-axis ticks at the interval selected. Ticks are only visible if **Visible** has been selected. Clear to disable the ticks.)
Y Step	0 to 100.0 (Displays unlabeled y-axis ticks at the interval selected. Ticks are only visible if **Visible** has been selected. Clear to disable the ticks.)

X Spacing	0 to 100.0 (Displays x-axis grid at the interval selected. The grid is only visible at the selected interval when **Visible** has been selected. Clear to disable the grid lines.)
Y Spacing	to 100.0 (Displays y-axis grid at the interval selected. The grid is only visible at the selected interval when **Visible** has been selected. Clear to disable the 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.

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.



Min.	4.000000 to 6.100000 MHz (Minimum y-axis value displayed on the frequency graph. The 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. The maximum value must be greater than the value entered for the minimum.)

X Step	0 to 100 (Displays unlabeled x-axis ticks at the interval selected. The ticks are only visible if **Visible** has been selected. Clear to disable the ticks.)
Y Step	0.000000 to 100.000000 MHz (Displays unlabeled y-axis ticks at the interval selected. The ticks are only visible if **Visible** has been selected. Clear to disable the ticks.)

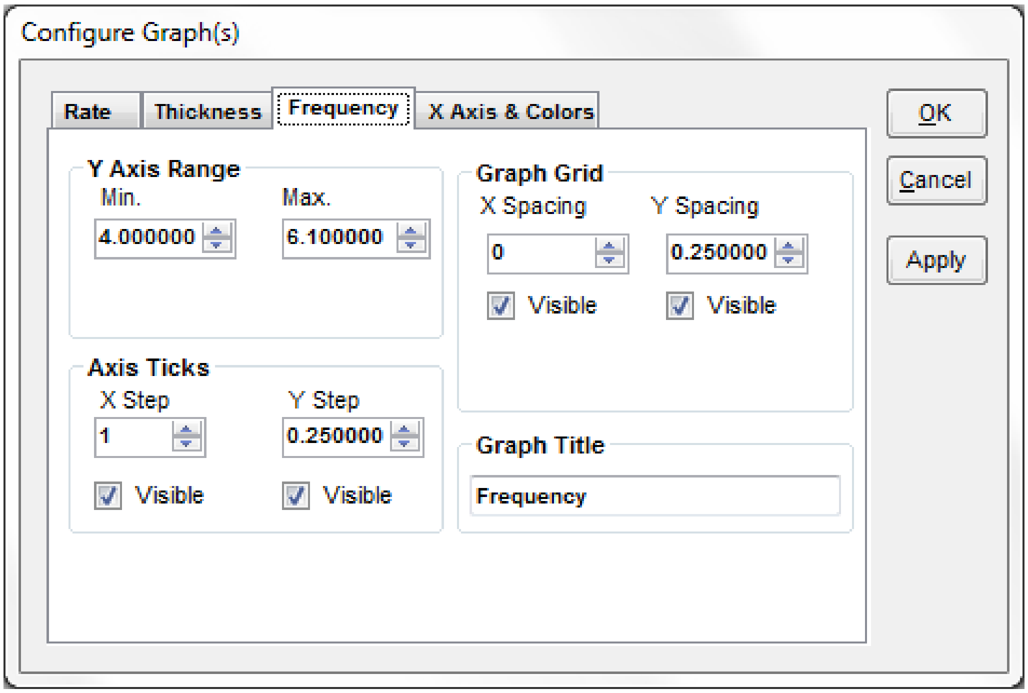
X Spacing	0 to 100.0 (Displays the x-axis grid at the interval selected. The grid is only visible at the selected interval when **Visible** has been selected. Clear to disable the grid lines.)

Y Spacing	0 to 100.0 (Displays the y-axis grid at the interval selected. The grid is only visible at the selected interval when **Visible** has been selected. Clear to disable the 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 frequency graph.

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.



Min.	4.000000 to 6.100000 MHz (The minimum y-axis value displayed on the frequency graph. The minimum value must be less than the value entered for the maximum.)
Max.	4.000000 to 6.100000 MHz (The maximum y-axis value displayed on the frequency graph. The maximum value must be greater than the value entered for the minimum.)

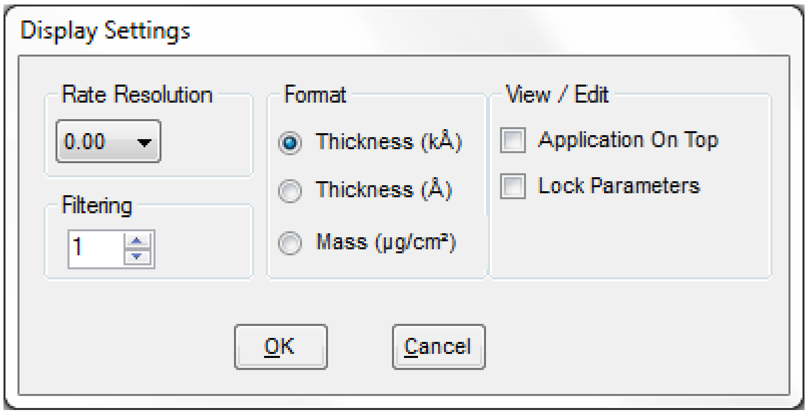
X Step	0 to 100 (Displays the x-axis grid at the interval selected. The grid is only visible at the selected interval when **Visible** has been selected. Clear to disable the grid lines.)
Y Step	0.000000 to 100.000000 (Displays the y-axis grid at the interval selected. The grid is only visible at the selected interval when **Visible** has been selected. Clear to disable the grid lines.)

Graph Title Pane

Edit text box to rename the frequency graph.

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.

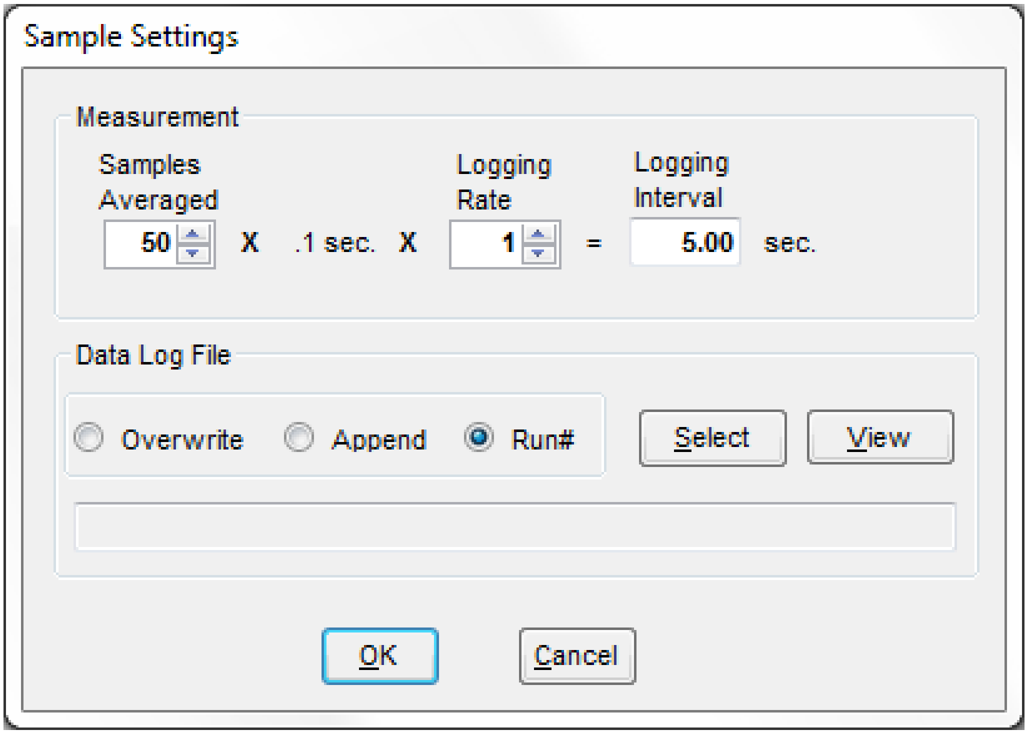
Click to display a window to configure the settings for **Rate Resolution**, **Filtering**, **Format**, and **View** of the STM-2 window.



Rate Resolution	Use the list 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. This value does not affect graphs or data logs. Use the **Samples Averaged** parameter for averaging to affect all displays and data logs.)
Format	Select **Thickness** in kÅ, **Thickness** in Å, or **Mass** in µg/cm^2 to be displayed on the STM-2 window and on the thickness graph. The mass in µg/cm^2 displays the rate as a mass rate in ng/cm^2/s.
View/Edit	Select **Application On Top** to display the STM-2 window in front of all the other open windows. Select **Lock Parameters** to disable editing of **Density, Z-Ratio,** and **Tooling** on the STM-2 window.

Click to display a window to configure the settings for data logging, display, and graphs.

Sample Settings is disabled while monitoring.



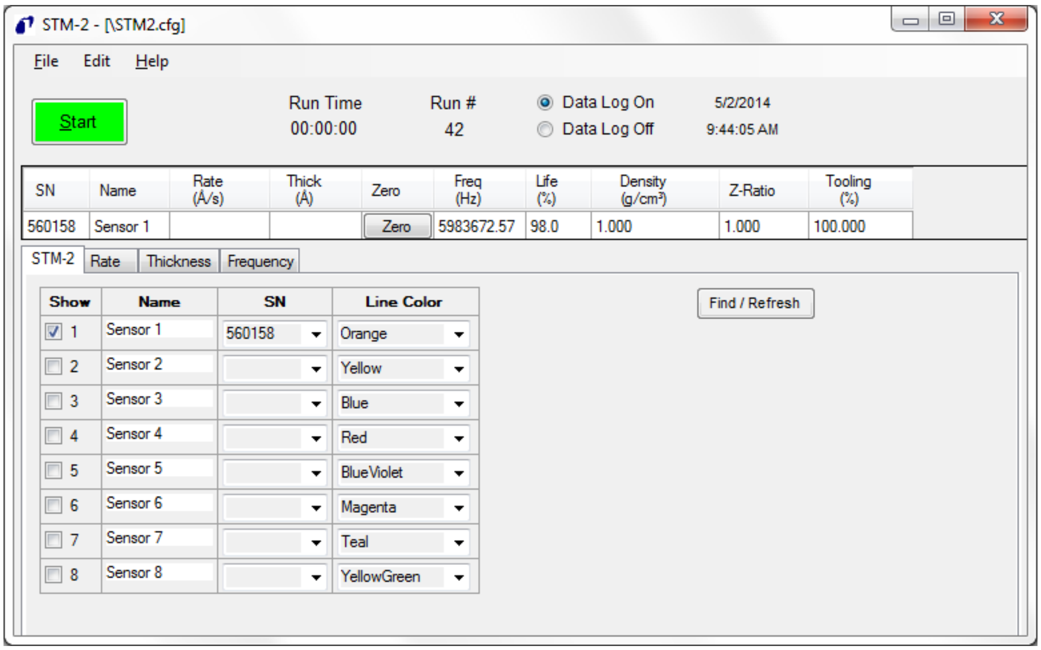
Samples averaged	1 to 50 (Use the spin box to enter the number of samples averaged for the display, graphs, and data logging.)
Logging Rate	1 to 120 (Use the spin box to select the logging rate. A **Logging Rate** of **1** will log every averaged measurement.)
Logging Interval	Displays the data logging 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.

7.3.3.3 Help Menu

About	Click **About** to view the **About** window.

The **About STM-2** window displays the version number of INFICON STM-2 software, copyright information, and the location of the software files.

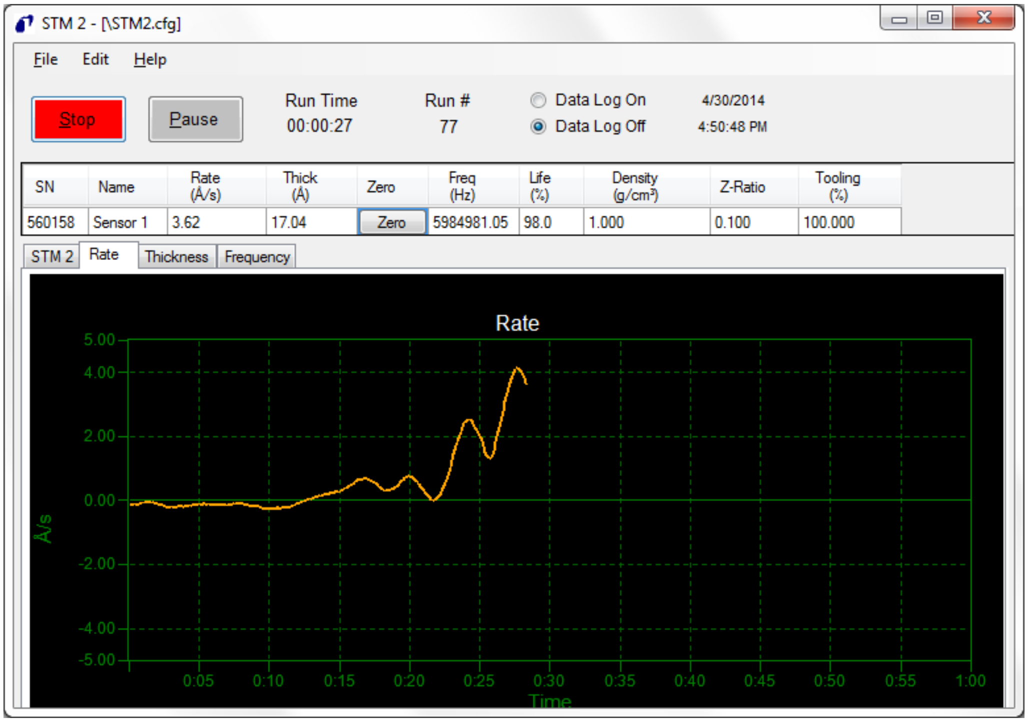
7.3.3.4 STM-2 Tab



Show	Select the sensors to be displayed in the **STM-2** window.
Name	Edit the name of the sensor. This name is 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 list to select the serial number of the connected STM-2 associated with the named sensor.
Line Color	Use the list to select a color to correspond with each STM-2 connected. This also changes the **Line Color** on the **X Axis & Colors** tab of the **Graph Settings** window.
Find/ Refresh	Click to find or refresh the list of connected STM-2(s).

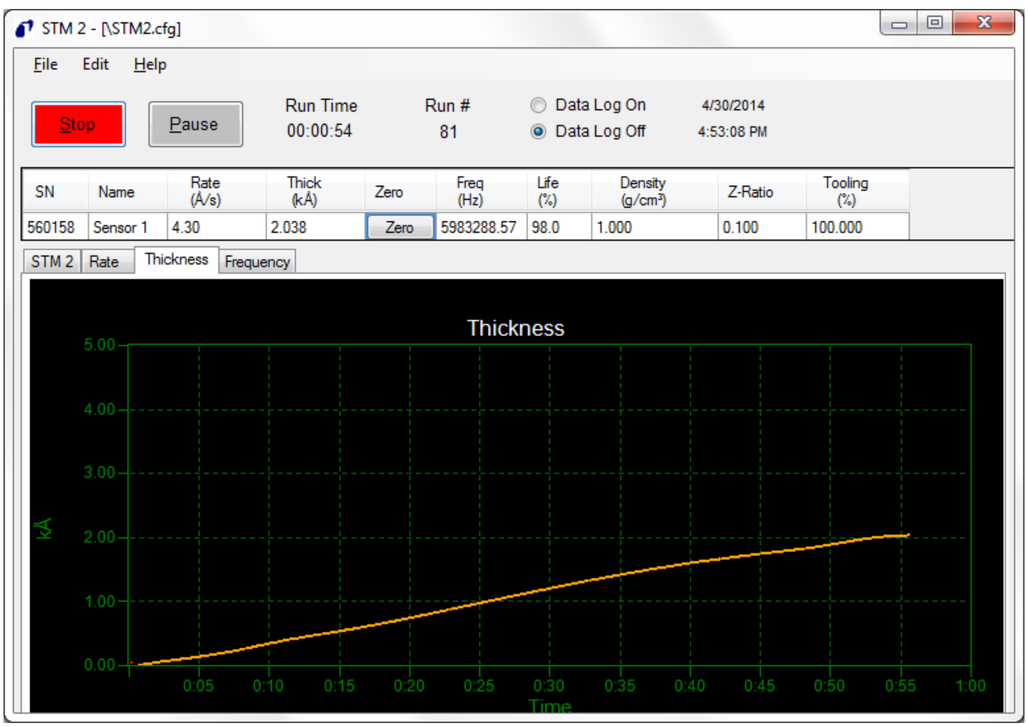
7.3.3.5 Rate Tab

The **Rate** tab displays a graph of rate and time for the selected STM-2(s).



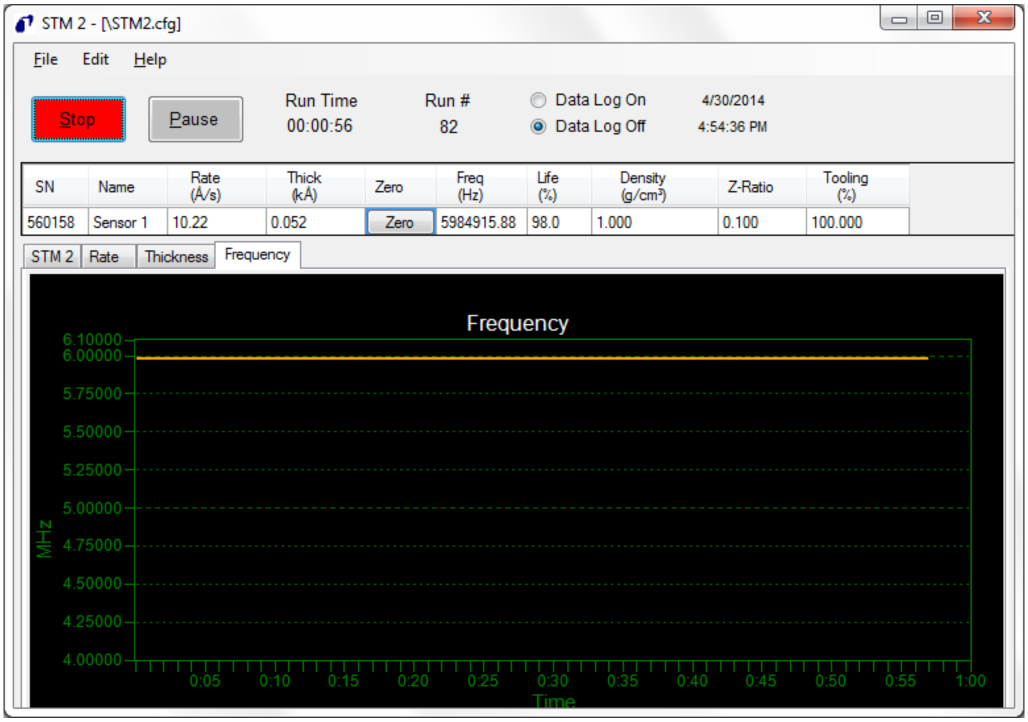
7.3.3.6 Thickness Tab

The **Thickness** tab displays a graph of thickness or mass and **Time** for the selected STM-2(s).



7.3.3.7 Frequency Tab

The **Frequency** tab displays a graph of thickness or mass and **Time** for the selected STM-2(s).



7.4 Laboratory Determination of Z-Ratio

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

$Z = (d_q\mu_q / d_f\mu_f)^{1/2}$ [3]

$Z = 9.378x10^5 (d_f\mu_f)^{-1/2}$ [4]

where:

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

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

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

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

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

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

1 Establish the correct density value as described in the section titled Determine Density.

2 Install a new crystal and record its starting frequency (F_{co}). It is necessary to read the frequency value at PID 231.

3 Make a deposition on a test substrate such that the percent crystal life reads approximately 50%, or near the end of crystal life for the particular material, whichever is smaller. Monitor the **Read Request Value** PID 234 to get the crystal life value.

4 Stop the deposition and record the ending crystal frequency (F_c) using the **Read Request Value** PID 231.

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.

$$T_f = (Z_q x10^4/2\pi zp)((1/F_{co}) \arctan(z \tan(\pi F_{co})/F_q)) - (1/F_c) \arctan(z \tan(\pi F_c)/F_q))) \quad [5]$$

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 (MKS units)

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

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

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

8 STM-2 LabVIEW Operation

8.1 Introduction

The STM-2 LabVIEW application is capable of displaying the rate, thickness, and crystal life for one STM-2 and the connected sensor. The STM-2 LabVIEW application has the option to use a multi-layer mode to enable cumulative substrate thickness and independent density, Z-Ratio, tooling, and sample parameters for each film to allow multi-layer monitoring capabilities. The STM-2 LabVIEW application can also operate in **Simulate** mode without a connected STM-2.

8.2 Install the STM-2 LabVIEW Application

8.2.1 Install the Protocol Server

1. Download STM-2 LabVIEW Application Software from https://www.inficon.com/en/products/thin-film-technology/thickness-monitor-stm-2-usb-thin-film-rate on the computer that will be connected to STM-2.
2. Double click **setup_smdp_svr_lv.exe.** The **Zip Self-Extractor** window displays.
3. Click **Unzip**. The **SMDP Serial Protocol Server** window displays.
4. On the **Destination Directory** pane, click **Browse** to select the location where all software will be installed.
5. Click **Next.**
6. Read the license agreement.
7. Click **I accept License Agreement(s).**
8. Click **Next.**
9. Review the summary of information.
10. Click **Next. Installation Complete** displays.
11. Click **Next.** The **Setup Wizard** pane displays.
12. Click **Next.** The **Confirm Installation** pane displays.
13. Click **Next.**
14. Read the license agreement.
15. Click **I Agree.**
16. Click **Next. Installation Complete** displays.
17. Click **Close.**

18 Click **Close** on the **Zip Self-Extractor.**

8.2.2 Install the LabVIEW Application and Device Drivers

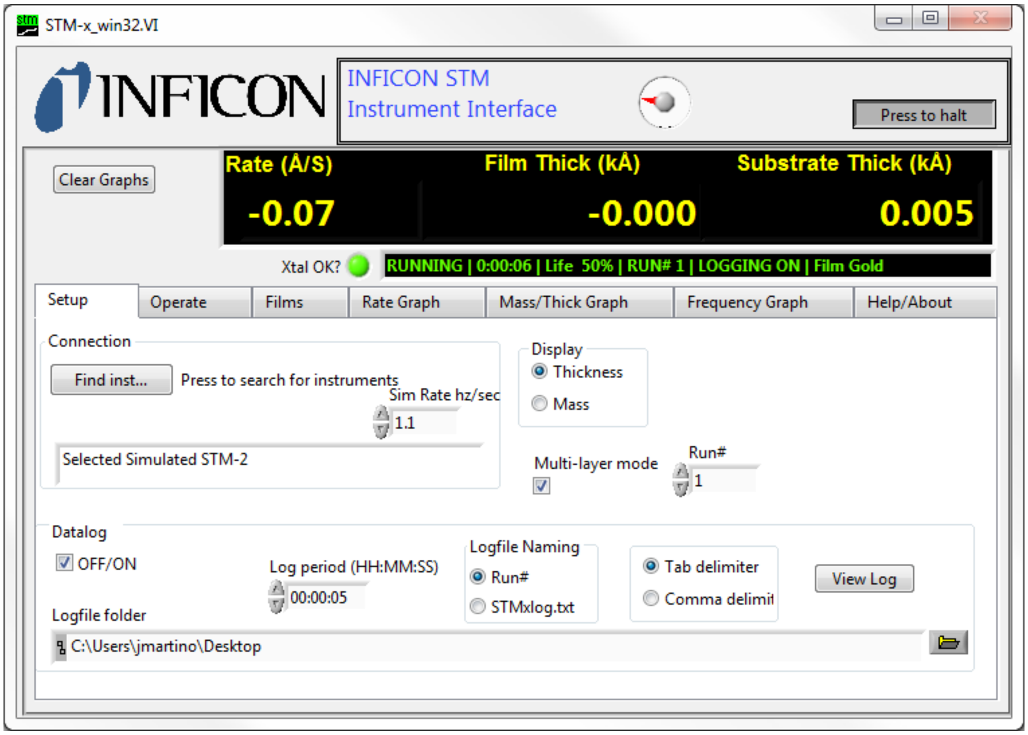
1. Insert the **Thin Film Manuals CD** into the CD drive on the computer that will be connected to STM-2.
2. Click **Windows Explorer or File Explorer >> Computer >> (CD drive letter:) >> STM-2 >> TOOLS >> main app.**
3. Double click **setup_stm-x_win32.exe.** The **Zip Self-Extractor** window displays.
4. Click **Unzip.** The **Sycon STM-x_win32** window displays.
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** displays.
9. Click **Next.** The **Silicon Laboratories CP210x VCP Drivers for Windows 2000/XP/2003 Server/Vista window** displays.
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 displays.
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 displays.
21. Click **OK.**
22. Click **Close** on the **Zip Self-Extractor.**

8.2.3 Starting the STM-2 LabVIEW Application

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 displays.



Starting the Software in Windows 8

1 In the **Start** window, click the **STM-x_win32** icon.

2 If the icon cannot be found:

⇨ Click **Search >> Apps.**

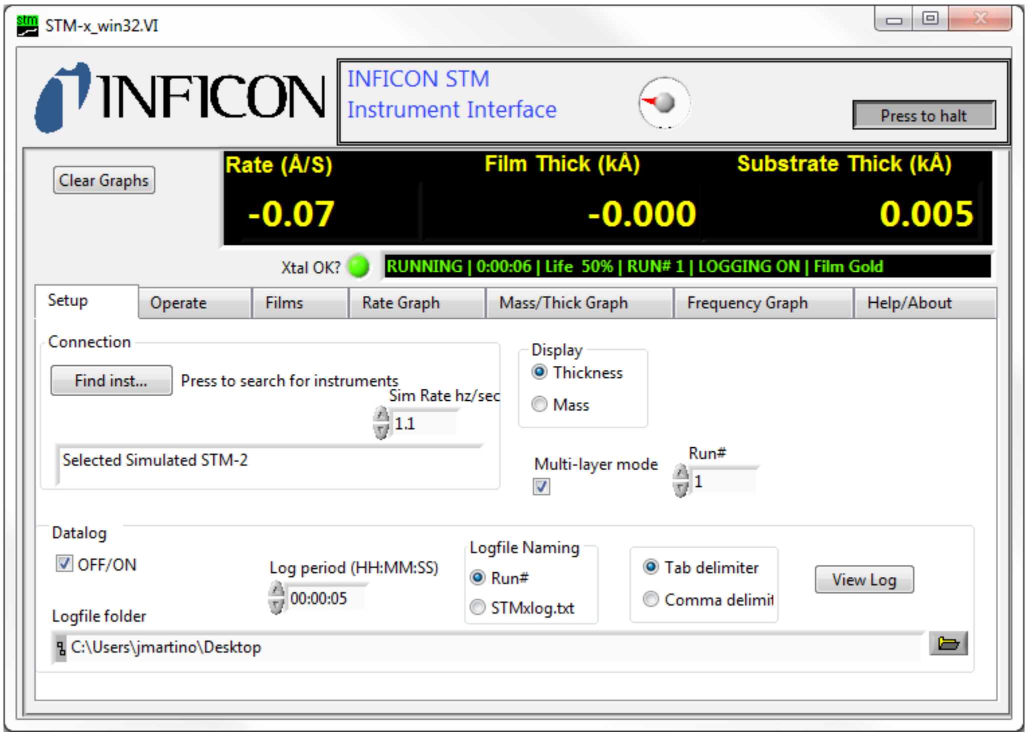
⇨ Type **STM** in the **Search** text box.

⇨ Click the **STM-x_win32** icon.

8.3 STM-x_win32.VI Window

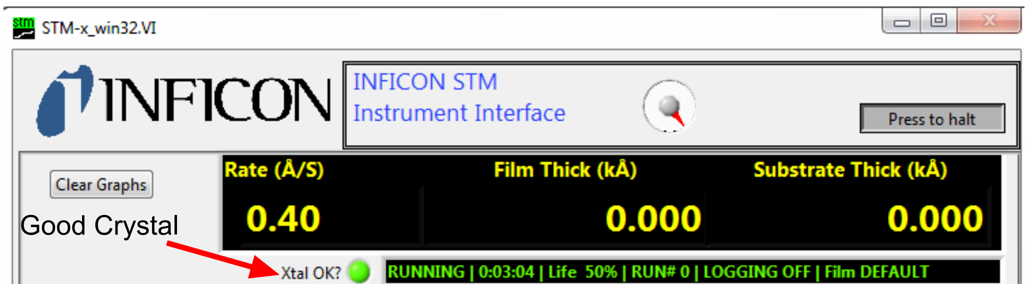
The **STM-x_win32.VI** window displays **Rate**, **Film Thick**(ness), and **Substrate Thick**(ness) for the connected sensor. This window also provides an indicator for a crystal fail (**Xtal OK?**), running time, life percentage, run number, logging status, and film name as well as customizable display parameters, graphical information, and access to the **Setup**, **Operate**, **Films**, **Rate Graph**, **Mass/Thick Graph**, **Frequency Graph**, and **Help/About** tabs.

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



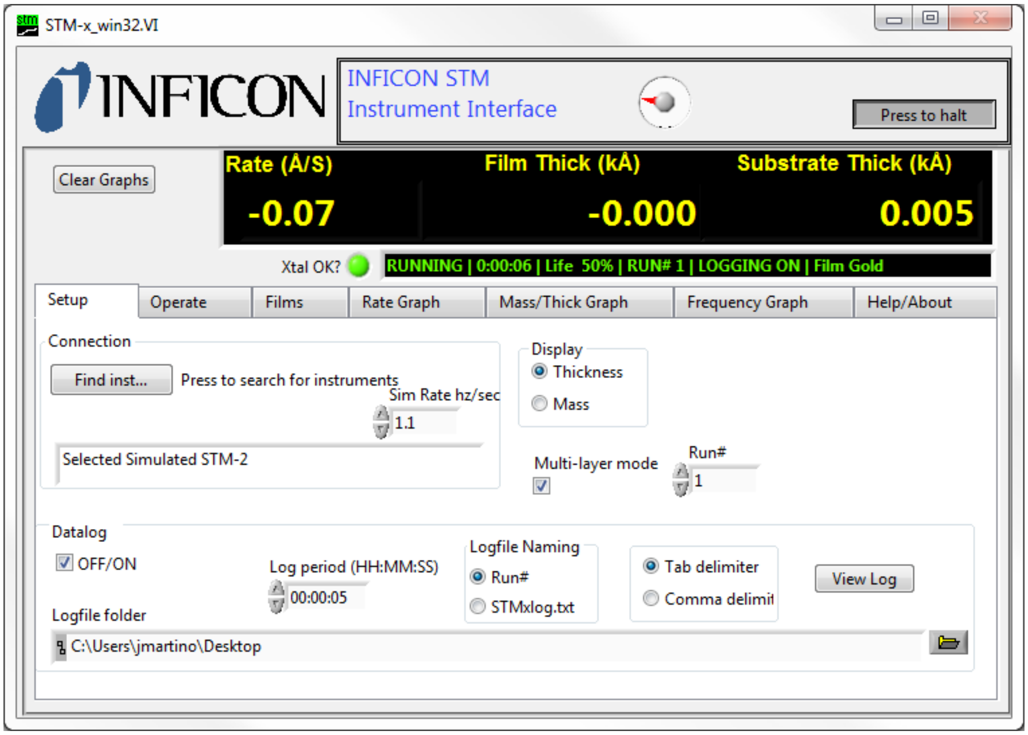
- **Setup** tab
- **Operate** tab
- **Films** tab
- **Rate Graph** tab
- **Mass/Thick Graph** tab
- **Frequency Graph** tab
- **Help/About** tab

Press to Halt	Click to exit the 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	The deposition rate based on the frequency of the crystal.
Film Thick/ Film Mass	The thickness or mass of the film being monitored.
Substrate Thick/ Substrate Mass.	The accumulated thickness or mass of all layers.
Clear Graphs	Clears the **Rate**, **Mass/Thick**, and **Frequency** graphs.
Xtal OK?	There is an illuminated light green when a good crystal is connected; a dark green when a crystal fail has occurred.

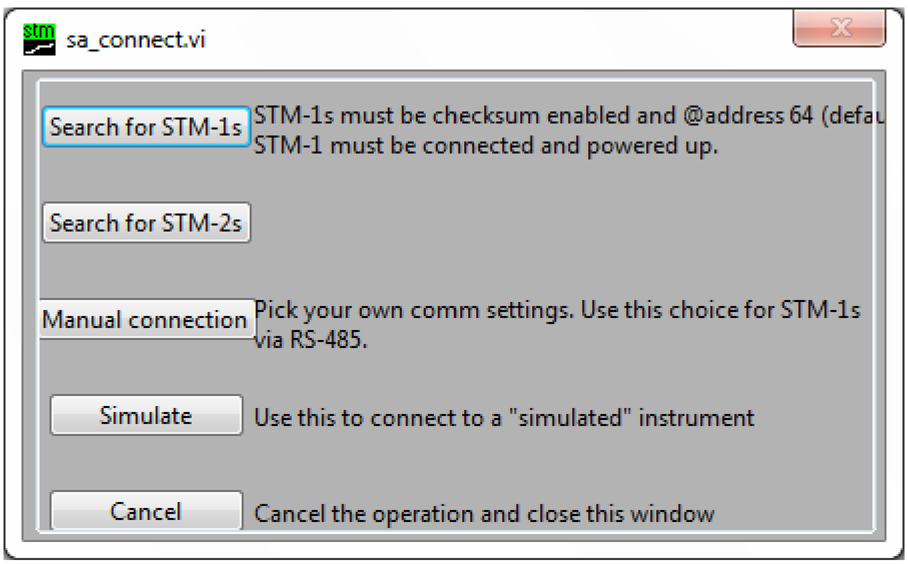


RUNNING/ PAUSED	**Running** changes to **Paused** if the process is paused in the **Operate** tab.
h:mm:ss	The time that the current run number has been running; resets with each new run.
Life/XTAL FAIL	The percentage of crystal life remaining, decremented from 100%; changes to **XTAL FAIL** upon a crystal failure.
RUN #	Incremented when **New run** is clicked in the **Operate** tab.
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.
Film	The name of film being monitored is displayed.

8.3.1 Setup



Find Instrument	Click to search for instruments.



Search for STM-1s	Automatically detects connected STM-1s.
Search for STM-2s	Automatically detects connected STM-2s.
Manual Connection	See below.
Simulate	See below.
Cancel	Closes the **Find Instrument** window.
Text Box	Displays the connection information for the connected STM-2.

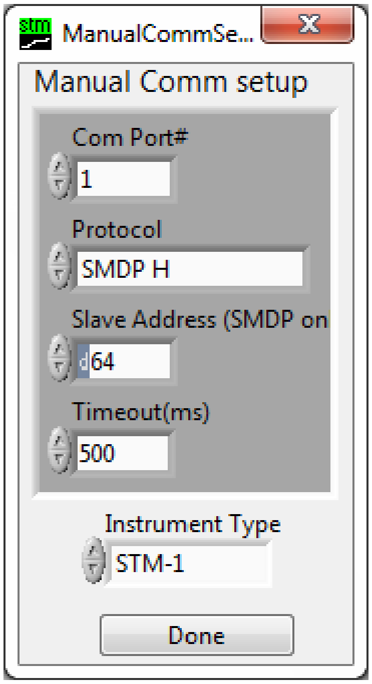
Thickness	Displays **Rate** in units of Å/s, **Film Thick** in units of kÅ, and **Substrate Thick** in units of kÅ on the **STM-x_win32.VI** window.
Mass	Displays **Rate** in units of µg*s/cm^2, **Film Mass** in units of µg/cm^2, and **Substrate Mass** in units of µg/cm^2 on the **STM-x_win32.VI** window.
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.

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.

Manual Connection

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 is displayed. Select the correct **Com Port#, Protocol, Slave Address, Timeout(ms)**, and **Instrument Type**. Click **Done.**

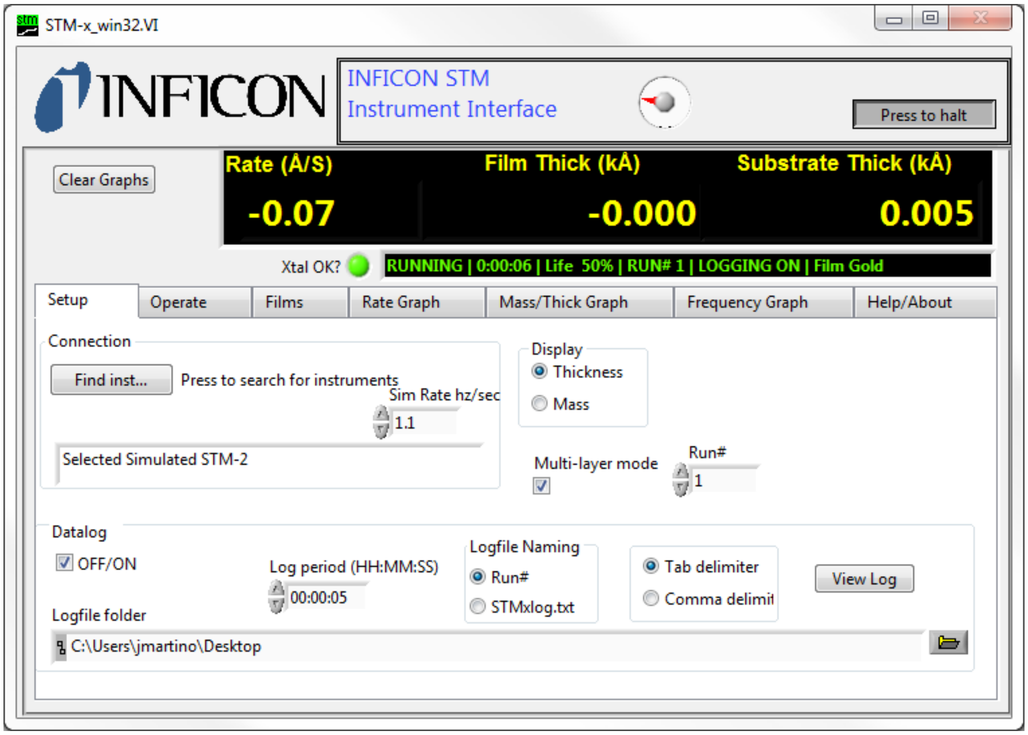
Do not close the **Manual Comm Setup** window by selecting **X**.



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.

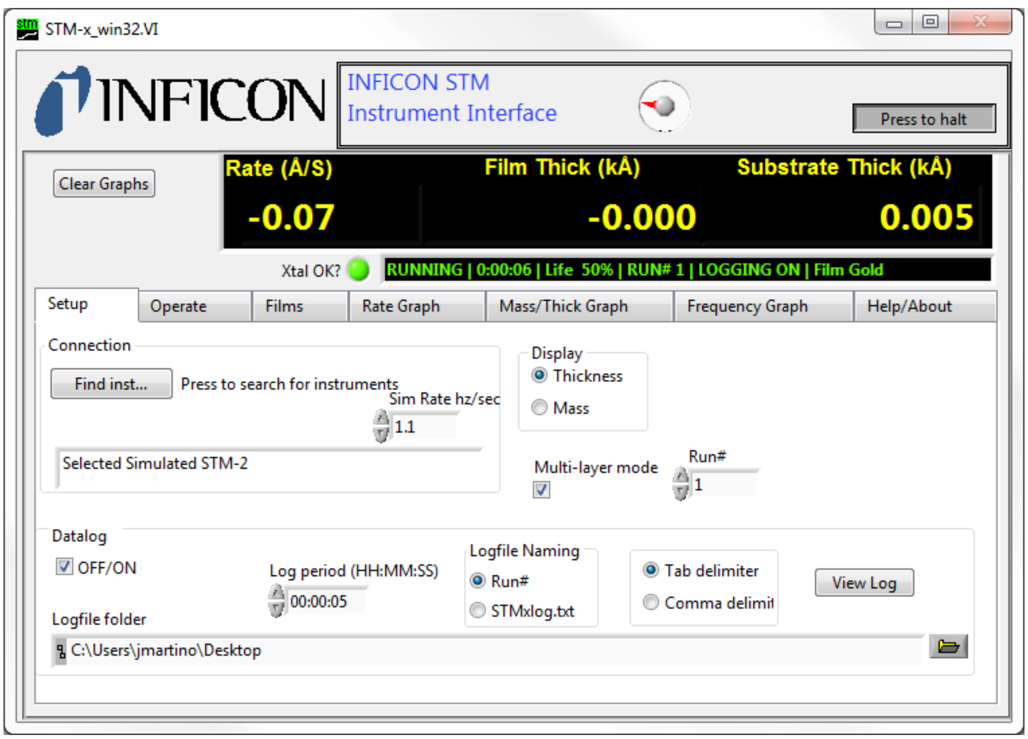
Simulate Mode

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 is displayed on the **Setup** tab. Enter the rate simulation in hertz per second.

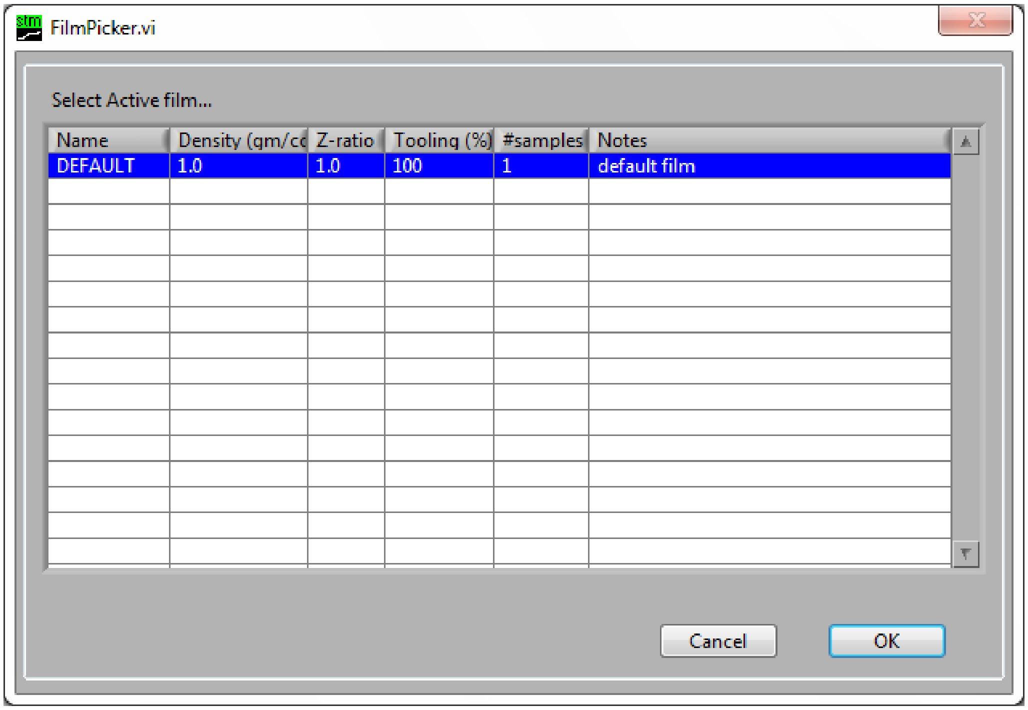


With a rate of hertz per second defined, the software converts the change in frequency to a rate in angstroms per second or microgram second per centimeter squared based on the selection of **Thickness** or **Mass** on the **Display** pane.

8.3.2 Operate



Change Film	This option changes the active film. Clicking this opens the **FilmPicker.vi** window that displays the films to run. The existing thickness is not zeroed and the thickness is recalculated with the new Z-ratio and tooling.

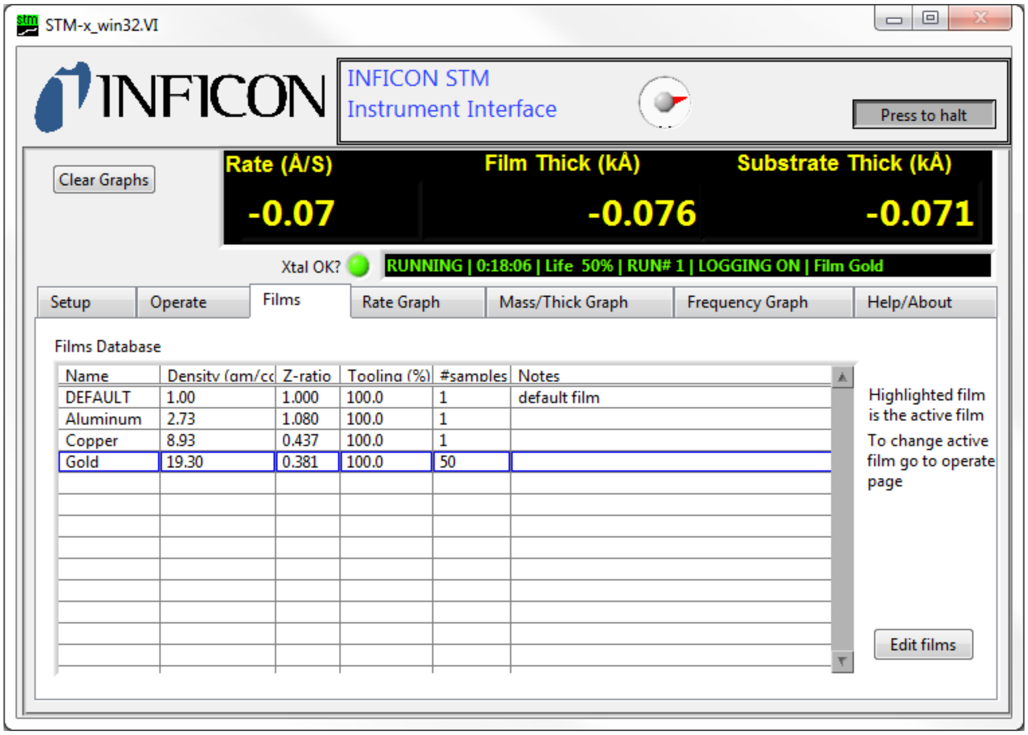


If a film is not displayed in this window, the film needs to be added by clicking **Edit Films** on the **Films** tab.

New Layer	This option opens the **FilmPicker.vi** window and adds the selection as a new layer to the **Layer Stackup**.
New Run	This option 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	This option changes the **Pause** button to **Resume** and changes the background of the Sycon STM instrument interface pane to red. It pauses data logging and graphing until **Resume** is clicked.
Zero Timer	This option resets the timer on the Sycon STM instrument interface pane.
Zero Film Thk	This option resets the **Film Thickness** or **Film Mass**.
Layer Stackup	This option lists the **Film Name** and the current **Thickness** or **Mass** for each layer in the process.

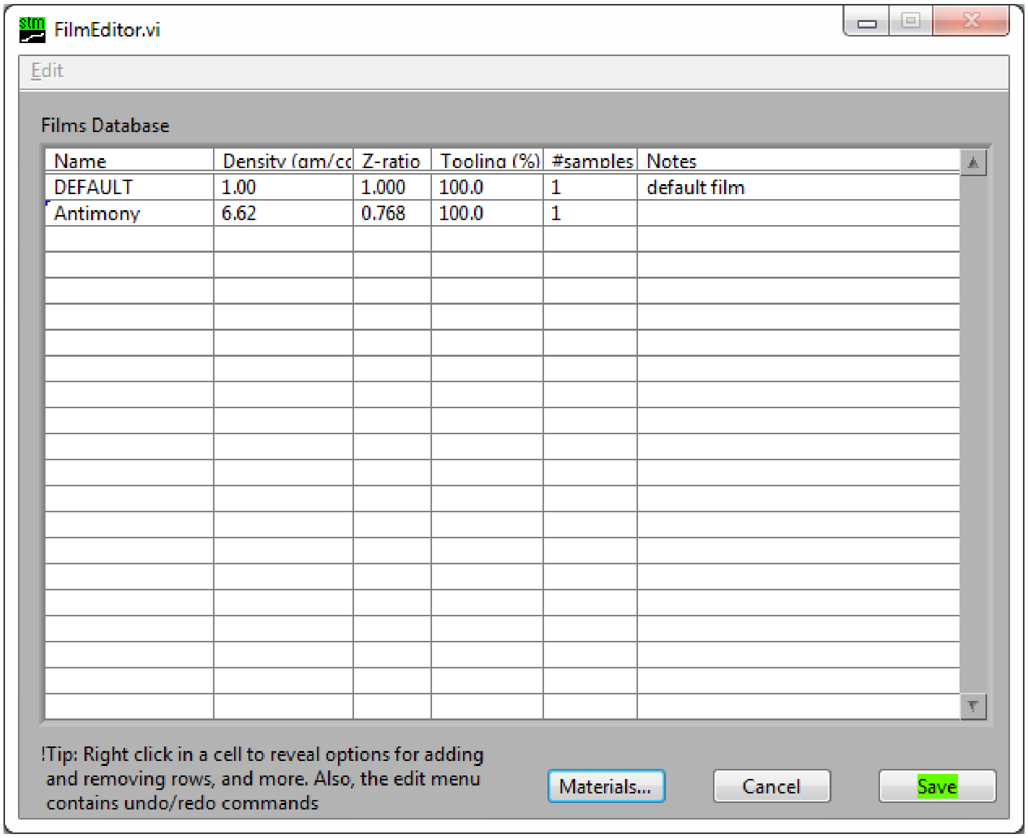
8.3.3 Films

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



Edit Films	This button displays the **FilmEditor.vi** window, allowing the user to add or remove films in the **Films Database**. Each of the following parameters can be manually edited or input using the **Materials** button: **Name, Density, Z-Ratio, Tooling, # samples, Notes**.

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



Materials	This button shows a list of materials to be added to the **Films Database** on the **FilmEditor.vi** window.
Cancel	This button exits the **FilmEditor.vi** window without saving changes.
Save	This button saves the changes to the **Films Database** on **Films** tab.

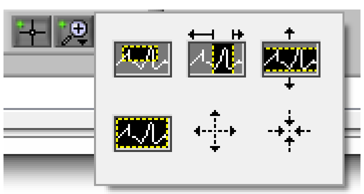
Right-click on the **FilmEditor.vi** window to **Cut**, **Copy**, **Insert**, or **Delete** rows.

8.3.4 Rate Graph

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.

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



- 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.

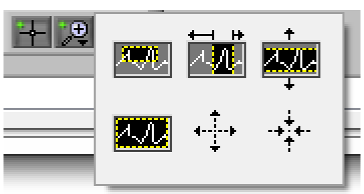
Click the hand icon and then press and drag in the graph pane to move the graph.

8.3.5 Mass/Thick Graph

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.

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



- 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.

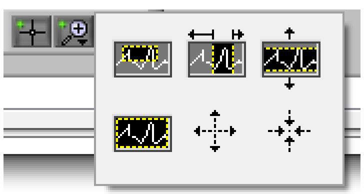
Click the hand icon and then press and drag in the graph pane to move the graph.

8.3.6 Frequency Graph

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.

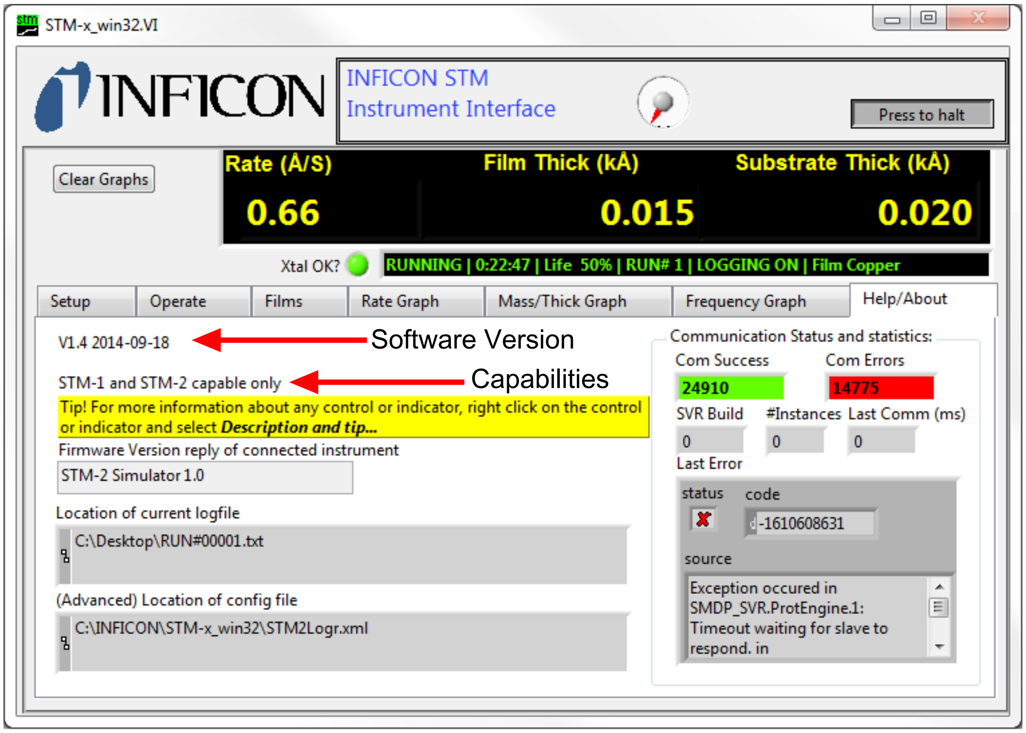
Zoom in and out are not available if **Auto Scale X** or **Auto Scale Y** are selected.



- 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.

8.3.7 Help/About



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.

Com Success	This is a counter that displays the number of successful communication attempts to STM-2.
Com Error	This is as counter that 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	(check) indicates successful communication (X) indicates failed communication
Code	Displays the **Error Code** for the failed communication.
Source	Describes the **Error Code**.

9 Communication

9.1 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.

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.

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.

9.2 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 causes STM-2 to reboot, as though power was cycled. This sets STM-2 into a known state. Another common command queries the product type or ID. This command (0x30) returns an ASCII integer code that identifies the product type. 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.

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.

9.2.1 Command Format

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 is 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, but the RSP2 through RSP0 field will be non-zero (indicating actual unit response status). 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.

D7	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
CMD3	CMD2	CMD1	CMD2	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.

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).

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) are ignored by slaves (and masters). No response is sent by the slave.

Command Packet Format

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

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.

Response Packet Format

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 the <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

9.2.2 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 Sycon Multi-Drop Protocol (SMDP) [▸ 55], 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. 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 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 allows the responses to be received by the proper line of communication.

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.

Optional Serial Command Format

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).

9.3 Communications Commands

Some processes may require the development of specialized software. The STM-2 command set is listed in the table below.

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 Command Format [▸ 56].

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 Sycon Multi-Drop Protocol (SMDP) [▸ 55]) 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 Command Format [▸ 56]. 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.

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 the correct sensor.
@B	None	@B	1	Instrument build type

STM-2 command	Parameter	Send	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

STM-2 command	Parameter	Send	Description
B	None	B	Zeroes timer and thickness
D	None	D	Zeroes thickness
C	None	C	Zeroes timer

Film commands

= nnn to update parameter

? to query parameter

STM-2 command	Parameter	Send	Returned	Description
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		Sets 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

STM-2 command	Parameter	Send	Returned	Description
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/ cm²
T	None	T	12.46	Return rate, 12.46 Å/s
t	None	t	1.307	Return mass accumulation rate in µg/ (*s/cm²), 1.307 µg/ (*s/cm²)

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.

10 Troubleshooting and Maintenance

10.1 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.

10.1.1 Indicator

If there is a problem with STM-2, the indicator displays a signal as to the likely cause.

SYMPTOM	CAUSE	REMEDY
The power indicator is flashing.	STM-2 and/or the sensor are not connected.	Verify that the STM-2/sensor connections are correct.
	The crystal has failed or there is no crystal.	Replace the crystal with a new INFICON crystal.
	Two crystals are placed into the crystal holder.	Remove one of the crystals.
	The computer did not initialize STM-2.	Click **Find Instruments** >> **Search for STM-2s** on the LabVIEW application.
	STM-2 does not have power.	Verify that the computer is turned on and the USB cable is plugged in.
	The device drivers are not properly installed.	Uninstall and reinstall the device drivers.
The power indicator is extinguished.	There is communication traffic.	Program the software to query STM-2 every 100 ms for the indicator to be illuminated.
The USB indicator is flashing.	The software is not running.	Open STM-x_win32 application.
The USB indicator is extinguished	The software not installed.	Install STM-x_win32 application.

10.1.2 General STM-2 Troubleshooting

SYMPTOM	CAUSE	REMEDY
Rate, Thickness, and Frequency readings are unstable or incorrect.	The 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.
	The humidity level on the crystal is changing. Moisture is being absorbed or exuded from the crystal surface.	Avoid condensation by turning off the cooling water to the 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.
	There is a defective in-vacuum cable or coax cable.	Use an ohmmeter to check electrical continuity and isolation.
	The crystal seating on the crystal holder surface is scratched or contaminated.	Clean or replace the crystal holder. Refer to the sensor operating manual.
	Excessive cable length between oscillator and crystal causes a self-oscillation condition.	Use an in-vacuum cable no longer than 78.1 cm (30.75 in.) Use only the 15.2 cm (6 in.) cable between the STM-2 or oscillator and feedthrough.

SYMPTOM	CAUSE	REMEDY
The crystal has failed.	There is a failed or defective crystal, or there is no crystal in the sensor.	Install a new crystal.
	Two crystals were installed or the crystal is upside down.	Remove the extra crystal. Reverse the crystal orientation. Inspect the crystal for scratches; if it is scratched, replace it with a new crystal.
	There is a build-up of material at the crystal holder aperture that is touching the crystal.	Clean or replace the crystal holder. Refer to the sensor operating manual.
	The crystal frequency is not within the **Min** and **Max** frequency settings.	Install a new crystal. Use a 6 MHz crystal.
	There is excessive cable length between the oscillator and the crystal.	Use an in-vacuum cable no longer than 78.1 cm (30.75 in.) Use only the 15.2 cm (6 in.) cable between STM-2 or the oscillator and feedthrough.
	The sensor is not connected, or there is a bad electrical connection in the sensor head or feedthrough, or there are bad cables.	Check the sensor connections. Refer to the sensor operating manual. Use an ohmmeter to check for 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 6 MHz test crystal or a known good sensor for the suspect sensor.

SYMPTOM	CAUSE	REMEDY
	There is a bad coax cable between feedthrough and STM-2 or oscillator, or a bad coax cable between oscillator and STM-2.	Use an ohmmeter to check for electrical continuity/ isolation. Substitute a known functioning coax cable.
	STM-2 or the oscillator is malfunctioning.	Substitute a known functioning STM-2 (or other QCM). Substitute a known functioning oscillator.
There is a crystal fail during deposition before “normal” life of the crystal is exceeded.	The 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.
	There is a damaged crystal or deposited material that is causing stress to the crystal.	Replace the crystal. Use an alloy crystal if it is appropriate for the deposited material.
	Material buildup on the crystal holder is partially masking the crystal surface.	Clean or replace the crystal holder. Refer to the sensor operating manual.
	The shutter is partially obstructing the deposition flux or the sensor is poorly positioned, causing uneven distribution of material on the crystal.	Visually check the crystal for an uneven coating, and if present, correct the shutter or sensor positioning problem.
There is a crystal fail when the vacuum chamber is opened to air.	The crystal is near the end of its life. Opening to air causes film oxidation, which increases film stress.	Replace the crystal.
	There is excessive moisture accumulation on the crystal.	Avoid condensation by turning off the cooling water to the sensor before opening the vacuum chamber to air, and then

SYMPTOM	CAUSE	REMEDY
		flow heated water above the dew point of the room through the sensor when the chamber is open.
Rate, Thickness, and Frequency readings are noisy.	There is excessive cable length between the oscillator and the crystal.	Use a 78.1 cm (30.75 in.) in-vacuum cable (or shorter). Use a 15.2 cm (6 in.) cable between oscillator and feedthrough.
	Electrical noise is being picked up by STM-2.	Place the STM-2 and the cables at least 30.5 cm (1 ft.) away from high voltage/ high power cables and other sources of electrical noise. This will significantly help to reduce noise pickup.
	There is 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.
The thickness reading has large excursions during deposition.	There is mode hopping due to a damaged or heavily dampened crystal.	Replace the crystal.
	The crystal is near the end of its life.	Replace the crystal.
	There are 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.
	There is uneven coating onto the crystal.	A straight line from the center of the source to the center of the crystal should be perpendicular to the face of the crystal.

SYMPTOM	CAUSE	REMEDY
	There are particles on the crystal.	Replace the crystal. Remove the source of the particles.
	There are 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.
	There is inadequate cooling of the crystal.	Check the water flow rate and temperature for sensor cooling. Refer to the sensor operating manual.
The thickness reading has large excursions during source warm-up or when the source shutter is opened. This usually causes the thickness reading to decrease. The thickness reading has large excursions after the termination of deposition. This usually causes the thickness reading to increase.	The crystal is not properly seated or there is a dirty crystal holder.	Check the crystal installation. Clean the crystal seating surface inside the crystal holder or replace the crystal holder. Refer to the sensor operating manual.
	There is excessive heat input to the crystal.	If the heat is due to radiation from the evaporation source, move the sensor farther away (at least 25.4 cm (10 in.)) from the source. Use SPC-1157-G10 crystals designed to minimize frequency shifts due to thermal shock.
	There is inadequate cooling of the crystal.	Check the water flow rate and the temperature for sensor cooling. Refer to the sensor operating manual.
	The crystal is being heated by electron flux.	Use a sputtering sensor for non-magnetron sputtering.

SYMPTOM	CAUSE	REMEDY
	The 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.
	There is intermittent connection occurring in the 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.
The thickness reproducibility is poor.	There are erratic evaporation flux characteristics.	Move the sensor to a different location. Check the evaporation source for proper operating conditions. Ensure a relatively constant pool height and avoid tunneling into the melt.
	The 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.

10.1.3 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.

11 Calibration Procedures

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 Determine Density.

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 Determine Tooling [▸ 74].

If the Z-Ratio is not known, it could be estimated from the procedures outlined in Laboratory Determination of Z-Ratio [▸ 75].

11.1 Determine Density

NOTICE

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

To determine the **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:

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

where:

D_1 = Initial Density setting

T_x = Thickness reading on SQM-160

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.

NOTICE

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.

NOTICE

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

11.2 Determine Tooling

1. Place a test substrate in the system substrate holder.
2. Make a short deposition and determine the actual thickness.
3. Calculate tooling from the relationship shown in equation [2].
4. Round off percent tooling to the nearest 0.1%.
5. When entering the new value for tooling into the program, T_m equals T_x if calculations are done properly.

Tooling (%) = $TF_i (T_m/T_x)$ [2]

where T_m = Actual thickness at substrate holder T_x = Thickness reading in TF_i = Initial tooling factor

It is recommended that a minimum of three separate evaporations be made when calibrating tooling. Variations in source distribution and other system factors will contribute to slight thickness variations. An average value tooling factor should be used for final calibrations.

11.3 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 formula:

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

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

where:

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

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

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

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

NOTICE

The densities and shear modulus 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 Determine Density [▸ 73]
2. Install a new crystal and record its starting Frequency, F_{co}.

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.

$$T_f = \frac{Z_q \times 10^4}{2\pi z p}\left\{\left(\frac{1}{F_{co}}\right)ATan\left(zTan\left(\frac{\pi F_{co}}{F_q}\right)\right) - \left(\frac{1}{F_c}\right)ATan\left(zTan\left(\frac{\pi F_c}{F_q}\right)\right)\right\}$$

where:

T_f = Thickness of deposited film (kÅ)

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

F_c = Final frequency of the sensor crystal (Hz)

F_q = Nominal blank frequency = 6045000 (Hz)

z = Z-Ratio of deposited film material

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

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

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

⇨ If the thickness of layer 1 is large compared to layer 2, use 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.

12 Measurement Theory

12.1 Basics

A quartz crystal deposition monitor, or QCM, uses the converse piezoelectric properties of a quartz crystal to detect added mass. The QCM uses this mass sensitivity to measure the deposition rate and final thickness of a vacuum deposition. When a voltage is applied across the faces of a properly shaped piezoelectric crystal, the crystal is distorted and changes shape in proportion to the applied voltage. At certain discrete frequencies of applied voltage a condition of very sharp electro-mechanical resonance is encountered. When mass is added to the face of a resonating quartz crystal, the frequency of these resonances is reduced. This change in frequency is very repeatable and is precisely understood for specific oscillating modes of quartz. This easy to understand phenomenon is the basis of an indispensable measurement and process control tool that can easily detect the addition of less than an atomic layer of an adhered foreign material.

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

$M_f / M_q = \Delta F / F_q$ [1]

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

$T_f = K (\Delta F) / d_f$ [2]

where the film thickness, T_f, is proportional (through K) to the frequency change, ΔF, and inversely proportional to the density of the film, d_f. The constant, $K = N_{at} d_q / F_q^{\,2}$, where d_q (= 2.649 g/cm^3) is the density of single crystal quartz and N_{at} (=166100 Hz cm) is the frequency constant of AT-cut quartz. A crystal with a starting frequency of 6.0 MHz will display a reduction of its frequency by 2.27 Hz when 1 Å of aluminum (density of 2.77 g/cm^3) is added to its surface. In this manner the thickness of a rigid adlayer is inferred from the precise measurement of the crystal’s frequency shift. The quantitative knowledge of this effect provides a means of determining how much material is being deposited on a substrate in a vacuum system, a measurement that was not convenient or practical prior to this understanding.

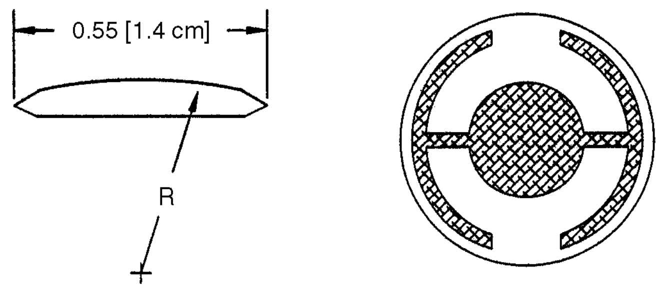
1.G. Z. Sauerbrey, Phys. Verhand .8, 193 (1957)

2.G. Z. Sauerbrey, Z. Phys. 155,206 (1959)

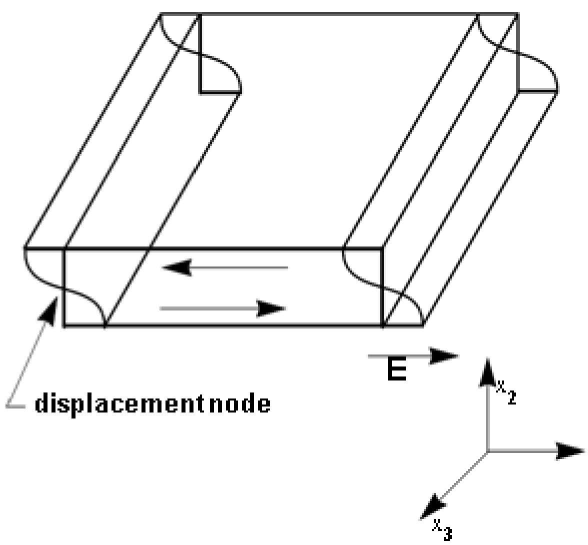
3. P. Lostis, Rev. Opt. 38,1 (1959)

12.2 Monitor Crystals

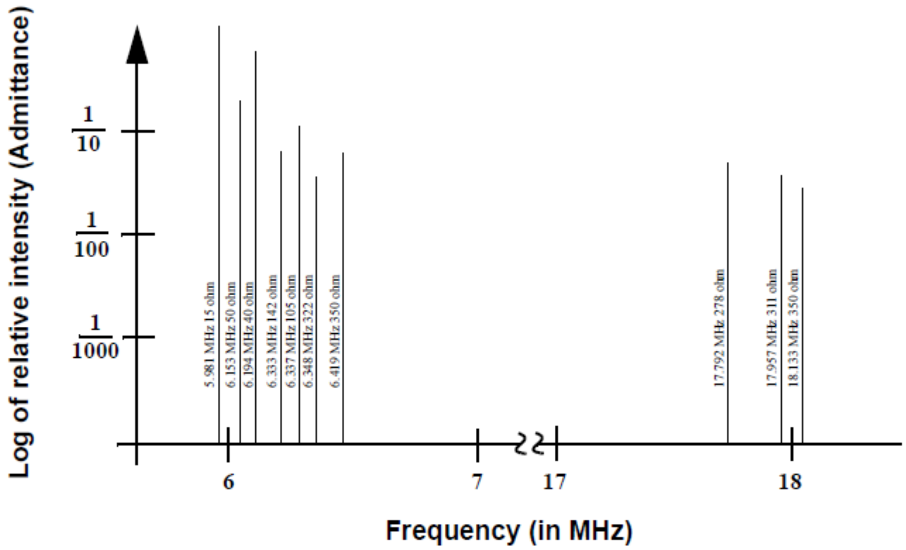
No matter how sophisticated the electronics surrounding it, the essential device of the deposition monitor is the quartz crystal.



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.



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 above is the result of several significant improvements from the square crystals with fully electroded plane parallel faces that were first used. The first improvement was to use circular crystals. This increased symmetry greatly reduced the number of allowed vibrational modes. The second set of improvements was to contour one face of the crystal and to reduce the size of the exciting electrode. These improvements have the effect of trapping the acoustic energy. Reducing the electrode diameter limits the excitation to the central area. Contouring dissipates the energy of the traveling acoustic wave before it reaches the edge of the crystal. Energy is not reflected back to the center where it can interfere with other newly launched waves, essentially making a small crystal appear to behave as though it is infinite in extent. With the crystal's vibrations restricted to the center, it is practical to clamp the outer edges of the crystal to a holder and not produce any undesirable effects. Contouring also reduces the intensity of response of the generally unwanted anharmonic modes; hence, the potential for an oscillator to sustain an unwanted oscillation is substantially reduced.



The use of an adhesion layer has improved the electrode-to-quartz bonding, reducing "rate spikes" caused by micro-tears between the electrode and the quartz as film stress rises. These micro-tears leave portions of the deposited film unattached and therefore unable to participate in the oscillation. These free portions are no longer detected and the wrong thickness is consequently inferred. The "AT" resonator is usually chosen for deposition monitoring because at room temperature it can be made to exhibit a very small frequency change due to temperature changes. Since there is presently no way to separate the frequency change caused by added mass (which is negative) from 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.

12.3 Period Measurement Technique

Although instruments using equation [2] were very useful, it was soon noted they had a very limited range of accuracy, typically holding accuracy for ΔF less than 0.02 F_q.

In 1961, it was recognized by Behrndt[4] that:

$M_f / M_q = (T_c - T_q) / T_q = \Delta F / F_q$ [3]

where T_c and T_q are the periods of oscillation of the crystal with film (composite) and the bare crystal, respectively. The period measurement technique was the outgrowth of two factors; first, the digital implementation of time measurement, and second, the recognition of the mathematically rigorous formulation of the proportionality between the crystal's thickness, I_q, and the period of oscillation, $T_q = 1/F_q$. Electronically, the period measurement technique uses a second crystal oscillator, or reference oscillator, not affected by the deposition and usually much higher in frequency than the monitor crystal. This reference oscillator is used to generate small precision time intervals which are used to determine the oscillation period of the monitor crystal. This is done by using two pulse accumulators. The first is used to accumulate a fixed number of cycles, m, of the monitor crystal. The second is turned on at the same time and accumulates cycles from the reference oscillator until m counts are accumulated in the first. 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 oscillator's frequency. The monitor crystal period is $(n/F_r)/m$, where n is the number of counts in the second accumulator. The precision of the measurement is determined by the speed of the reference clock and the length of the gate time (which is set by the size of m). Increasing one or both of these parameters 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 of a monitor crystal's frequency between measurements is small, that is, on the same order of size as the measurement precision, it is not possible to establish quality rate measurement. The uncertainty of the measurement injects more noise into the control loop, which can be counteracted only by longer control loop 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.

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

12.4 Z-Match Technique

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

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

where $Z=(d_q \mu_q / d_f \mu_f)^{1/2}$ is the acoustic impedance ratio and μ_q and μ_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 it 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 approximately $0.05F_q$.

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)

13 Appendix A: Material Table

The following represents the density and Z-Ratio for various materials. The list is alphabetical, by chemical formula. The Z-Ratio values shown are normalized for AT-cut quartz crystals

⚠ WARNING

Some of these materials are hazardous. 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. Z-Ratio values listed here is for AT-cut quartz crystals only. When using BT-cut, IT-cut, or SC-cut please select the correct encoding to indicate to STM-2 the type of crystal. Failure to do this will result in incorrect thickness translation of the resonance frequency shift by STM-2.

Formula	Density	Z-Ratio	Material Name
Ag	10.500	0.529	silver
AgBr	6.470	1.180	silver bromide
AgCl	5.560	1.320	silver chloride
Al	2.700	1.080	aluminum
Al_2O_3	3.970	0.336	aluminum oxide
Al_4C_3	2.360	*1.000	aluminum carbide
AlF_3	3.070	*1.000	aluminum fluoride
AlN	3.260	*1.000	aluminum nitride
AlSb	4.360	0.743	aluminum antimonide
As	5.730	0.966	arsenic
As_2Se_3	4.750	*1.000	arsenic selenide
Au	19.300	0.381	gold
B	2.370	0.389	boron
B_2O_3	1.820	*1.000	boron oxide
B_4C	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
BaN_2O_6	3.244	1.261	barium nitrate
BaO	5.720	*1.000	barium oxide
$BaTiO_3$	5.999	0.464	barium titanate (tetragonal)

Formula	Density	Z-Ratio	Material Name
$BaTiO_3$	6.035	0.412	barium titanate (cubic)
Be	1.820	0.543	beryllium
BeF_2	1.990	*1.000	beryllium fluoride
BeO	3.010	*1.000	beryllium oxide
Bi	9.800	0.790	bismuth
Bi_2O_3	8.900	*1.000	bismuth oxide
Bi_2S_3	7.390	*1.000	bismuth trisulfide
Bi_2Se_3	6.820	*1.000	bismuth selenide
Bi_2Te_3	7.700	*1.000	bismuth telluride
BiF_3	5.320	*1.000	bismuth fluoride
C	2.250	3.260	carbon (graphite)
C	3.520	0.220	carbon (diamond)
C_8H_8	1.100	*1.000	parlyene (union carbide)
Ca	1.550	2.620	calcium
CaF_2	3.180	0.775	calcium fluoride
CaO	3.350	*1.000	calcium oxide
$CaO\text{-}SiO_2$	2.900	*1.000	calcium silicate (3)
$CaSO_4$	2.962	0.955	calcium sulfate
$CaTiO_3$	4.100	*1.000	calcium titanate
$CaWO_4$	6.060	*1.000	calcium tungstate
Cd	8.640	0.682	cadmium
CdF_2	6.640	*1.000	cadmium fluoride
CdO	8.150	*1.000	cadmium oxide
CdS	4.830	1.020	cadmium sulfide
CdSe	5.810	*1.000	cadmium selenide
CdTe	6.200	0.980	cadmium telluride
Ce	6.780	*1.000	cerium
CeF_3	6.160	*1.000	cerium (III) fluoride
CeO_2	7.130	*1.000	cerium (IV) dioxide
Co	8.900	0.343	cobalt
CoO	6.440	0.412	cobalt oxide
Cr	7.200	0.305	chromium
Cr_2O_3	5.210	*1.000	chromium (III) oxide
Cr_3C_2	6.680	*1.000	chromium carbide
CrB	6.170	*1.000	chromium boride

Formula	Density	Z-Ratio	Material Name
Cs	1.870	*1.000	cesium
Cs_2SO_4	4.243	1.212	cesium sulfate
CsBr	4.456	1.410	cesium bromide
CsCl	3.988	1.399	cesium chloride
CsI	4.516	1.542	cesium iodide
Cu	8.930	0.437	copper
Cu_2O	6.000	*1.000	copper oxide
Cu_2S	5.600	0.690	copper (I) sulfide (alpha)
Cu_2S	5.800	0.670	copper (I) sulfide (beta)
CuS	4.600	0.820	copper (II) sulfide
Dy	8.550	0.600	dysprosium
Dy_2O_3	7.810	*1.000	dysprosium oxide
Er	9.050	0.740	erbium
Er_2O_3	8.640	*1.000	erbium oxide
Eu	5.260	*1.000	europium
EuF_2	6.500	*1.000	europium fluoride
Fe	7.860	0.349	iron
Fe_2O_3	5.240	*1.000	iron oxide
FeO	5.700	*1.000	iron oxide
FeS	4.840	*1.000	iron sulfide
Ga	5.930	0.593	gallium
Ga_2O_3	5.880	*1.000	gallium oxide (beta)
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_2O_3	7.410	*1.000	gadolinium oxide
Ge	5.350	0.516	germanium
Ge_3N_2	5.200	*1.000	germanium nitride
GeO_2	6.240	*1.000	germanium oxide
GeTe	6.200	*1.000	germanium telluride
Hf	13.090	0.360	hafnium
HfB_2	10.500	*1.000	hafnium boride
HfC	12.200	*1.000	hafnium carbide

Formula	Density	Z-Ratio	Material Name
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_2O_3	8.410	*1.000	holmium oxide
In	7.300	0.841	indium
In_2O_3	7.180	*1.000	indium sesquioxide
In_2Se_3	5.700	*1.000	indium selenide
In_2Te_3	5.800	*1.000	indium telluride
InAs	5.700	*1.000	indium arsenide
InP	4.800	*1.000	indium phosphide
InSb	5.760	0.769	indium antimonide
Ir	22.400	0.129	iridium
K	0.860	10.189	potassium
KBr	2.750	1.893	potassium bromide
KCl	1.980	2.050	potassium chloride
KF	2.480	*1.000	potassium fluoride
KI	3.128	2.077	potassium iodide
La	6.170	0.920	lanthanum
La_2O_3	6.510	*1.000	lanthanum oxide
LaB_6	2.610	*1.000	lanthanum boride
LaF_3	5.940	*1.000	lanthanum fluoride
Li	0.530	5.900	lithium
LiBr	3.470	1.230	lithium bromide
LiF	2.638	0.778	lithium fluoride
$LiNbO_3$	4.700	0.463	lithium niobate
Lu	9.840	*1.000	lutetium
Mg	1.740	1.610	magnesium
$MgAl_2O_4$	3.600	*1.000	magnesium aluminate
$MgAl_2O_6$	8.000	*1.000	spinel
MgF_2	3.180	0.637	magnesium fluoride
MgO	3.580	0.411	magnesium oxide
Mn	7.200	0.377	manganese
MnO	5.390	0.467	manganese oxide

Formula	Density	Z-Ratio	Material Name
MnS	3.990	0.940	manganese (II) sulfide
Mo	10.200	0.257	molybdenum
Mo_2C	9.180	*1.000	molybdenum carbide
MoB_2	7.120	*1.000	molybdenum boride
MoO_3	4.700	*1.000	molybdenum trioxide
MoS_2	4.800	*1.000	molybdenum disulfide
Na	0.970	4.800	sodium
Na_3AlF_6	2.900	*1.000	cryolite
$Na_5Al_3F_{14}$	2.900	*1.000	chiolite
NaBr	32.00	*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
Nb_2O_3	7.500	*1.000	niobium trioxide
Nb_2O_5	4.470	*1.000	niobium (V) oxide
NbB_2	6.970	*1.000	niobium boride
NbC	7.820	*1.000	niobium carbide
NbN	8.400	*1.000	niobium nitride
Nd	7.000	*1.000	neodymium
Nd_2O_3	7.240	*1.000	neodymium oxide
NdF_3	6.506	*1.000	neodymium fluoride
Ni	8.910	0.331	nickel
NiCr	8.500	*1.000	nichrome
NiCrFe	8.500	*1.000	Inconel
NiFe	8.700	*1.000	permalloy
NiFeMo	8.900	*1.000	supermalloy
NiO	7.450	*1.000	nickel oxide
P_3N_5	2.510	*1.000	phosphorus nitride
Pb	11.300	1.130	lead
$PbCl_2$	5.850	*1.000	lead chloride
PbF_2	8.240	0.661	lead fluoride
PbO	9.530	*1.000	lead oxide
PbS	7.500	0.566	lead sulfide

Formula	Density	Z-Ratio	Material Name
PbSe	8.100	*1.000	lead selenide
$PbSnO_3$	8.100	*1.000	lead stannate
PbTe	8.160	0.651	lead telluride
Pd	12.038	0.357	palladium
PdO	8.310	*1.000	palladium oxide
Po	9.400	*1.000	polonium
Pr	6.780	*1.000	praseodymium
Pr_2O_3	6.880	*1.000	praseodymium oxide
Pt	21.400	0.245	platinum
PtO_2	10.200	*1.000	platinum oxide
Ra	5.000	*1.000	radium
Rb	1.530	2.540	rubidium
RbI	3.550	*1.000	rubidium iodide
Re	21.040	0.150	rhenium
Rh	12.410	0.210	rhodium
Ru	12.362	0.182	ruthenium
S_8	2.070	2.290	sulfur
Sb	6.620	0.768	antimony
Sb_2O_3	5.200	*1.000	antimony trioxide
Sb_2S_3	4.640	*1.000	antimony trisulfide
Sc	3.000	0.910	scandium
Sc_2O_3	3.860	*1.000	scandium oxide
Se	4.810	0.864	selenium
Si	2.320	0.712	silicon
Si_3N_4	3.440	*1.000	silicon nitride
SiC	3.220	*1.000	silicon carbide
SiO	2.130	0.870	silicon (II) oxide
SiO_2	2.648	1.000	silicon dioxide
Sm	7.540	0.890	samarium
Sm_2O_3	7.430	*1.000	samarium oxide
Sn	7.300	0.724	tin
SnO_2	6.950	*1.000	tin oxide
SnS	5.080	*1.000	tin sulfide
SnSe	6.180	*1.000	tin selenide
SnTe	6.440	*1.000	tin telluride

Formula	Density	Z-Ratio	Material Name
Sr	2.600	*1.000	strontium
SrF_2	4.277	0.727	strontium fluoride
SrO	4.990	0.517	strontium oxide
Ta	16.600	0.262	tantalum
Ta_2O_5	8.200	0.300	tantalum (V) oxide
TaB_2	11.150	*1.000	tantalum boride
TaC	13.900	*1.000	tantalum carbide
TaN	16.300	*1.000	tantalum nitride
Tb	8.270	0.660	terbium
Tc	11.500	*1.000	technetium
Te	6.250	0.900	tellurium
TeO_2	5.990	0.862	tellurium oxide
Th	11.694	0.484	thorium
ThF_4	6.320	*1.000	thorium (IV) fluoride
ThO_2	9.860	0.284	thorium dioxide
$ThOF_2$	9.100	*1.000	thorium oxyfluoride
Ti	4.500	0.628	titanium
Ti_2O_3	4.600	*1.000	titanium sesquioxide
TiB_2	4.500	*1.000	titanium boride
TiC	4.930	*1.000	titanium carbide
TiN	5.430	*1.000	titanium nitride
TiO	4.900	*1.000	titanium oxide
TiO_2	4.260	0.400	titanium (IV) oxide
Tl	11.850	1.550	thallium
TlBr	7.560	*1.000	thallium bromide
TlCl	7.000	*1.000	thallium chloride
TlI	7.090	*1.000	thallium iodide (beta)
U	19.050	0.238	uranium
U_3O_8	8.300	*1.000	tri uranium octoxide
U_4O_9	10.969	0.348	uranium oxide
UO_2	10.970	0.286	uranium dioxide
V	5.960	0.530	vanadium
V_2O_5	3.360	*1.000	vanadium pentoxide
VB_2	5.100	*1.000	vanadium boride
VC	5.770	*1.000	vanadium carbide

Formula	Density	Z-Ratio	Material Name
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_2O_3	5.010	*1.000	yttrium oxide
Yb	6.980	1.130	ytterbium
Yb_2O_3	9.170	*1.000	ytterbium oxide
Zn	7.040	0.514	zinc
Zn_3Sb_2	6.300	*1.000	zinc antimonide
ZnF_2	4.950	*1.000	zinc fluoride
ZnO	5.610	0.556	zinc oxide
ZnS	4.090	0.775	zinc sulfide
ZnSe	5.260	0.722	zinc selenide
ZnTe	6.340	0.770	zinc telluride
Zr	6.490	0.600	zirconium
ZrB_2	6.080	*1.000	zirconium boride
ZrC	6.730	0.264	zirconium carbide
ZrN	7.090	*1.000	zirconium nitride
ZrO_2	5.600	*1.000	zirconium oxide

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