STM-2
Rate and Thickness Monitor
PN 074-613-P1D
Trademarks
The trademarks of the products mentioned in this manual are held by the companies that produce them.

Windows® and Microsoft® are registered trademarks of Microsoft Corporation.

Inconel® is a registered trademark of Inco Alloys International, Huntington, WV.

LabVIEW™ is a trademark of National Instruments Corporation.

Sycon Instruments™ is a trademark of INFICON, Inc.

All other brand and product names are trademarks or registered trademarks of their respective companies.

Disclaimer
The information contained in this manual is believed to be accurate and reliable. However, INFICON assumes no responsibility for its use and shall not be liable for any special, incidental, or consequential damages related to the use of this product.

Due to our continuing program of product improvements, specifications are subject to change without notice.

Copyright
©2016 All rights reserved.
Reproduction or adaptation of any part of this document without permission is unlawful.
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.
WARRANTY AND LIABILITY - LIMITATION: Seller warrants the products manufactured by it, or by an affiliated company and sold by it, and described on the reverse hereof, 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.

This manual is intended for private use by INFICON® Inc. and its customers. Contact INFICON before reproducing its contents.

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

Trademarks
Disclaimer
Copyright
Declaration of Conformity
Warranty

## Chapter 1

### Introduction and Specifications

1.1 Introduction ................................................................. 1-1
1.1.1 Related Manuals ....................................................... 1-1
1.2 Instrument Safety ......................................................... 1-2
1.2.1 Definition of Notes, Cautions and Warnings .................... 1-2
1.2.2 General Safety Information ........................................ 1-3
1.3 How To Contact INFICON .................................................. 1-4
1.3.1 Returning STM-2 ...................................................... 1-4
1.4 Specifications ............................................................ 1-5
1.4.1 Power ................................................................. 1-5
1.4.2 Operating Environment .............................................. 1-5
1.4.3 Size and Weight ....................................................... 1-5
1.4.4 Computer Requirements ............................................ 1-5
1.5 Unpacking and Inspection .............................................. 1-6
1.6 Parts and Options Overview ........................................... 1-6
1.6.1 Base Configuration .................................................. 1-6
1.6.2 Accessories .......................................................... 1-6
1.6.2.1 Oscillator Kit ................................................... 1-6
1.6.2.2 Sensors .......................................................... 1-7

## Chapter 2

### Installation

2.1 Installation Requirements ............................................... 2-1
2.1.1 Parts Requirements .................................................. 2-1
2.2 System Connections ...................................................... 2-2
2.2.1 Internal Oscillator ................................................... 2-2
2.2.2 External Oscillator .................................................. 2-3
2.3 Switching Between Internal and External Oscillator ............... 2-4
2.4 STM-2 Indicators ........................................................ 2-5
2.4.1 Power ............................................................... 2-5
Chapter 3

STM-2 Software Operation

3.1 Introduction ................................................................. 3-1
3.2 Installing INFICON STM-2 Software ......................... 3-1
3.2.1 Installing the Protocol Server .............................. 3-1
3.2.2 Installing the INFICON STM-2 Software and Device Drivers ....... 3-2
3.2.3 Starting INFICON STM-2 Software ....................... 3-3
3.2.3.1 Starting the Software in Windows XP or Windows 7 .................. 3-3
3.2.3.2 Starting the Software in Windows 8 .................. 3-3
3.3 STM-2 Window ............................................................... 3-4
3.3.1 File Menu ................................................................. 3-6
3.3.1.1 Open Configuration .......................................... 3-7
3.3.1.2 Save Configuration ........................................... 3-7
3.3.1.3 Save Configuration As ....................................... 3-7
3.3.1.4 Print ................................................................. 3-8
3.3.1.5 Screen Image to File ........................................ 3-8
3.3.2 Edit Menu ............................................................... 3-8
3.3.2.1 Graph Settings .................................................. 3-8
3.3.2.1.1 X Axis & Colors .................................... 3-9
3.3.2.1.2 Rate Tab .................................................... 3-10
3.3.2.1.3 Thickness Tab .......................................... 3-12
3.3.2.1.4 Frequency Tab .......................................... 3-14
3.3.2.2 Display Settings ................................................. 3-16
3.3.2.3 Sample Settings ................................................. 3-17
3.3.3 Help Menu ............................................................... 3-18
3.3.3.1 About Window .................................................. 3-18
3.3.4 STM-2 Tab ............................................................... 3-19
3.3.5 Rate Tab ................................................................. 3-20
3.3.6 Thickness Tab .......................................................... 3-21
3.3.7 Frequency Tab ........................................................ 3-22

Chapter 4

STM-2 LabVIEW Operation

4.1 Introduction ............................................................... 4-1
4.2 Installing the STM-2 LabVIEW Application ................. 4-1
4.2.1 Installing the Protocol Server .............................. 4-1
4.2.2 Installing the LabVIEW Application and Device Drivers ....... 4-2
4.2.3 Starting the STM-2 LabVIEW Application ............... 4-3
4.2.3.1 Starting the Software in Windows XP or Windows 7 .......................... 4-3
4.2.3.2 Starting the Software in Windows 8 ............................................... 4-3
4.3 STM-x_win32.VI Window ................................................................. 4-4
4.3.1 Setup ....................................................................................... 4-6
4.3.1.1 Manual Connection ................................................................. 4-8
4.3.1.2 Simulate Mode ................................................................... 4-9
4.3.2 Operate .................................................................................... 4-10
4.3.3 Films ....................................................................................... 4-12
4.3.4 Rate Graph ............................................................................. 4-14
4.3.5 Mass/Thick Graph ................................................................. 4-15
4.3.6 Frequency Graph ................................................................. 4-16
4.3.7 Help/About ........................................................................... 4-18

Chapter 5

Communication

5.1 Communication Protocol ................................................................. 5-1
5.2 Sycon Multi-Drop Protocol (SMDP) ............................................... 5-1
5.2.1 Command Format ................................................................. 5-1
5.2.1.1 Checksum ...................................................................... 5-4
5.2.1.2 Command Packet Format .............................................. 5-5
5.2.1.3 Response Packet Format .............................................. 5-6
5.2.2 Optional Serial Command Mode ........................................... 5-6
5.2.2.1 Optional Serial Command Format ......................... 5-7
5.2.2.2 Additional Option to Serial Command ................ 5-7
5.3 Communications Commands ................................................... 5-8

Chapter 6

Troubleshooting and Maintenance

6.1 Troubleshooting Guide ................................................................. 6-1
6.1.1 Indicator .............................................................................. 6-1
6.1.2 General STM-2 Troubleshooting ......................................... 6-2
6.1.3 Troubleshooting Computer Communications ....................... 6-7

Chapter 7

Calibration Procedures

7.1 Importance of Density, Tooling and Z-Ratio .............................. 7-1
7.2 Determining Density ................................................................. 7-1
7.3 Determining Tooling ................................................................. 7-2
7.4 Laboratory Determination of Z-Ratio ....................................... 7-3
Chapter 8  Measurement and Theory
  8.1 Basics ................................................................. 8-1
  8.1.1 Monitor Crystals .............................................. 8-2
  8.1.2 Period Measurement Technique ...................... 8-4
  8.1.3 Z-match Technique .......................................... 8-6

Appendix A  Material Table
  A.1 Introduction ..................................................... A-1
Chapter 1
Introduction and Specifications

1.1 Introduction

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

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

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

Figure 1-1  STM-2

1.1.1 Related Manuals

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

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

1.2.1 Definition of Notes, Cautions and Warnings

When using this manual, please pay attention to the notes, cautions and warnings found throughout. For the purposes of this manual they are defined as follows:

**NOTE:** Pertinent information that is useful in achieving maximum STM-2 efficiency when followed.

---

**CAUTION**

Failure to heed these messages could result in damage to STM-2 or the loss of data.

---

**WARNING**

Failure to heed these messages could result in personal injury.

---

**WARNING - Risk Of Electric Shock**

Dangerous voltages are present, which could result in personal injury.
1.2.2 General Safety Information

CAUTION

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

Refer all maintenance to qualified personnel.

CAUTION

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

WARNING

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

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

- Sales and Customer Service
- Technical Support
- Repair Service

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

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

1.3.1 Returning STM-2

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

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

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

Compatible Sensor ................. Non-shuttered single QCM sensor
Sensor Inputs ...................... 1
Sensor Input ....................... Female BNC
Measurement Frequency Range ...... 6.0 to 5.0 MHz (fixed)
Frequency Resolution .............. ± 0.03 Hz @ 6 MHz
Measurement Interval .............. 0.10 s
Reference Frequency Stability ...... ± 2 ppm

Thickness and Rate
Resolution/Measurement .............. ± 0.037 Å @ tooling/density = 100/1
Fundamental frequency = 6 MHz

Thickness Display Resolution ....... 1 Å
Interface .......................... USB, 5 m (16.4 ft.) maximum length

1.4.1 Power

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

1.4.2 Operating Environment

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

1.4.3 Size and Weight

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

1.4.4 Computer Requirements

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

1. Remove STM-2 from its packaging.

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

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

3. Refer to the invoice and take inventory.

4. To install STM-2, see Chapter 2, Installation.

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

1.6 Parts and Options Overview

1.6.1 Base Configuration

STM-2 with software and cables . . . PN STM-2

(Included cables shown in section 1.6.2)

1.6.2 Accessories

5 m (16.4 ft.) USB cable . . . . . . . . PN 068-0506

15.2 cm (6 in.) BNC . . . . . . . . . PN 755-257-G6

1.6.2.1 Oscillator Kit

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

3 m (10 ft.) Oscillator Kit . . . . . . . PN 783-500-109-10

7.6 m (25 ft.) Oscillator Kit . . . . . . PN 783-500-109-25

15.2 m (50 ft.) Oscillator Kit . . . . . PN 783-500-109-50

22.9 m (75 ft.) Oscillator Kit . . . . . PN 783-500-109-75
Oscillator kits include:

Oscillator . . . . . . . . . . . . . . . . . . . PN 783-500-013
15.2 cm (6 in.) BNC cable . . . . . . PN 782-902-011

One of the following:

3 m (10 ft.) BNC Cable . . . . . PN 782-902-012-10
7.6 m (25 ft.) BNC Cable . . . PN 782-902-012-25
15.2 m (50 ft.) BNC Cable . . PN 782-902-012-50
22.9 m (75 ft.) BNC Cable . . PN 782-902-012-75

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

1.6.2.2 Sensors

Front Load Single Sensor . . . . . . . . . PN SL-XXXXX
Cool Drawer Single Sensor . . . . . . . PN CDS-XXFXX
Sputtering Sensor . . . . . . . . . . . . . . . PN 750-618-G1
UHV Bakeable Sensor . . . . . . . . . . . PN BK-A0F

**NOTE:** "X" in part number indicates customer-selectable option, see [www.inficon.com](http://www.inficon.com) for Sensor Datasheets.

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

2.1 Installation Requirements
2.1.1 Parts Requirements

- STM-2 Monitor
- One crystal sensor with feedthrough
- One oscillator kit for the crystal sensor
  
  **NOTE:** The oscillator kit is not required when using the internal oscillator.

- Quartz crystals appropriate for the application
- One Windows computer meeting minimum specifications (refer to section 1.4 on page 1-5).

**CAUTION**

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

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

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

2.2.1 Internal Oscillator

1. Connect the (provided) USB cable to a computer USB port and to STM-2.

2. Use the (provided) 15.2 cm (6 in.) BNC cable to connect STM-2 to the sensor feedthrough (see Figure 2-1).

   Figure 2-1  Internal oscillator

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

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

4. The PWR indicator on STM-2 illuminates (see section 2.4.1 on page 2-5).

5. The USB indicator on STM-2 illuminates (see section 2.4.2 on page 2-5).
2.2.2 External Oscillator

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

Figure 2-2  External oscillator
2.3 Switching Between Internal and External Oscillator

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

CAUTION

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

CAUTION - Static Sensitive Device

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

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

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

- To Internal for internal oscillator operation (see Figure 2-3).
- To External for external oscillator operation.

Figure 2-3 Jumpers set for internal oscillator operation
2.4 STM-2 Indicators

2.4.1 Power

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

In addition, the host computer has initialized STM-2 by sending a reset command when the software begins communication.

Flashing fast .......................... STM-2 is powered up but cannot detect a good crystal.

Blinking slow
(approximately once per second) .... STM-2 is powered up and the crystal is good, but the computer application has not initialized STM-2. Once the computer initializes STM-2 the indicator will illuminate continuously (see section 6.1.1 on page 6-1).

Extinguished .......................... STM-2 does not have power. Check the USB connection, and make sure the computer is turned on.

2.4.2 USB

The USB indicator detects communications signal traffic.

Illuminated .......................... STM-2 is connected and communicating to a host computer. Communications sent/received every 100 ms will cause the indicator to be steadily illuminated.

Flashing .............................. STM-2 is connected and communicating to a host computer. A flashing indicator will correspond to the time elapsed between sent and received communications. A query sent once per second will correspond to the indicator flashing approximately once per second.

Extinguished .......................... STM-2 is not communicating to the computer.

STM-x_win32 LabVIEW application software and INFICON STM-2 software will steadily illuminate the indicator due to communications queries sent every 100 ms. User-created software may not steadily illuminate the indicator due a longer time period elapsing between communications queries being sent.
Chapter 3
STM-2 Software Operation

3.1 Introduction

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

3.2 Installing INFICON STM-2 Software

3.2.1 Installing the Protocol Server

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

1. Insert the Thin Film Manuals CD into the CD drive of the computer that will be connected to STM-2.

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

3. Double click STM-2 v1.0.0 Setup.exe. The STM-2 - InstallShield Wizard will display.

4. Click Next.

5. Review the summary of information.

6. Select I accept the terms in the license agreement.

7. Click Next.

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

9. Click Next.

10. Click Install.

11. Click Finish. The USB Installer - InstallShield Wizard window will display.

12. Click Next.

13. Review the summary of information.

14. Select I accept the terms in the license agreement.

15. Click Next.

16. Enter User Name and Organization information.

17. Click Next.

18. Click Install.

19. Click Finish. The CP210x USB to UART Bridge Driver Installer window will display.

20. Click Next.


22. Select I accept this agreement.

23. Click Next.

24. Click Finish.
3.2.3 Starting INFICON STM-2 Software

3.2.3.1 Starting the Software in Windows XP or Windows 7

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

Figure 3-1 STM-2 window

3.2.3.2 Starting the Software in Windows 8

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

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

Figure 3-2  STM-2 window

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

Start/Stop ......................... Click to Start monitoring. Start changes to Stop. Stop will halt the process and data log until Start is clicked.

Pause/Resume ...................... Pause is displayed while monitoring to pause the monitoring. Pause stops the monitoring at its current time and changes to Resume when clicked. Resume will continue monitoring and increment the Run Time.

Run Time ......................... Time that the current run number has been monitored; resets when Start is clicked, stops and continues when Pause/Resume are clicked.

Run # .......................... Incremented when Start is clicked.

Data Log On/Data Log Off ...... Select Data Log On to enable data logging. Select Data Log Off to disable data logging.

Date .......................... Current date in month/day/year format.

Time .......................... Current time in hh:mm:ss format.

SN ............................. Serial Number of STM-2(s) selected to view (see section 3.3.4 on page 3-19).

Name ........................... Name of STM-2(s) selected to view (see section 3.3.4 on page 3-19).

Rate ............................ Rate, displayed in Å/s or Mass Rate displayed in ng/cm²/s, of STM-2(s) selected to view (see section 3.3.4 on page 3-19).

Thick ........................... Thickness displayed in Å or kÅ, or Mass in µg/cm², of STM-2(s) selected to view (see section 3.3.2.2 on page 3-16).

Zero ............................. Click to zero thickness.

Freq ............................. Frequency of the crystal connected to STM-2(s) selected to view (see section 3.3.4 on page 3-19). This changes to !XTAL FAIL! upon a crystal failure.

Life ............................. Percentage of crystal life remaining, decremented from 100%.

NOTE: This is based on a 6 MHz crystal.
Density  ......................... 0.5 to 99.99

Value in grams per cubic centimeter of material being deposited. Click in the text box to edit the density value. For a list of common material densities, see Appendix A.

Z-Ratio  ......................... 0.1 to 9.999

Z-Ratio of material being deposited. Click in the text box to edit the Z-Ratio value. For a list of Z-Ratios for common materials, see Appendix A.

Tooling  ......................... 10 to 399

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

3.3.1 File Menu

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

Figure 3-3  File menu
3.3.1.1 Open Configuration

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

Figure 3-4 Open Configuration window

3.3.1.2 Save Configuration

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

3.3.1.3 Save Configuration As

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

Figure 3-5 Save As window
3.3.1.4 Print

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

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

3.3.1.5 Screen Image to File

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

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

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

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

3.3.2 Edit Menu

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

*Figure 3-6 Edit menu*

3.3.2.1 Graph Settings

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

NOTE: Graph Settings is disabled while monitoring.
3.3.2.1.1 X Axis & Colors

Figure 3-7  X Axis & Colors tab

X Axis Width ........................ 1 minute to 120 minutes, 59 seconds
Use the spin box to enter the minutes and seconds displayed as a maximum x-axis value on all of the graphs.

X Text Interval ....................... 1 to 480 seconds
Displays the time on the x-axis of all graphs for the selected interval.

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

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

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

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

Figure 3-8 Rate tab

Y Axis Range pane
Min. .................................. -100.00 to 100.00
Minimum y-axis value displayed on the Rate graph.

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

Max. ................................. -100.00 to 100.00
Maximum y-axis value displayed on the Rate graph.

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

Axis Ticks pane
X Step ............................... 0 to 100.0
Displays unlabeled x-axis ticks at the interval selected.

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

Y Step ............................... 0 to 100.0
Displays unlabeled y-axis ticks at the interval selected.

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

X Spacing . . . . . . . . . . . . . . . . . . . . 0 to 100.0
Displays x-axis grid at the interval selected.

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

Y Spacing . . . . . . . . . . . . . . . . . . . . 0 to 100.0
Displays y-axis grid at the interval selected.

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

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

Graph Title pane

Edit text box to rename the Rate graph.

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

Figure 3-9 Thickness tab

Y Axis Range pane

Min. ........................................... -100.00 to 100.00

Minimum y-axis value displayed on the Thickness graph.

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

Max. ................................. -100.00 to 100.00

Maximum y-axis value displayed on the Thickness graph.

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

Axis Ticks pane

X Step ................................. 0 to 100.0

Displays unlabeled x-axis ticks at the interval selected.

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

Y Step ................................. 0 to 100.0

Displays unlabeled y-axis ticks at the interval selected.

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

**X Spacing** . . . . . . . . . . . . . . . . . . 0 to 100.0

Displays x-axis grid at the interval selected.

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

**Y Spacing** . . . . . . . . . . . . . . . . . . 0 to 100.0

Displays y-axis grid at the interval selected.

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

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

Graph Title pane

Edit text box to rename the Thickness graph.

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

**Figure 3-10 Frequency tab**

**Y Axis Range pane**

**Min.** .......................... 4.000000 to 6.100000 MHz

Minimum y-axis value displayed on the Frequency graph.

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

**Max.** .......................... 4.000000 to 6.100000 MHz

Maximum y-axis value displayed on the Frequency graph.

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

**Axis Ticks pane**

**X Step** .......................... 0 to 100

Displays unlabeled x-axis ticks at the interval selected.

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

**Y Step** .......................... 0.000000 to 100.000000 MHz

Displays unlabeled y-axis ticks at the interval selected.

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

X Spacing . . . . . . . . . . . . . . . . . . . 0 to 100

Displays x-axis grid at the interval selected.

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

Y Spacing . . . . . . . . . . . . . . . . . . . 0.000000 to 100.000000

Displays y-axis grid at the interval selected.

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

Graph Title pane

Edit text box to rename the Frequency graph.

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

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

**Figure 3-11 Display Settings window**

![Display Settings window]

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

**Filtering**
1 to 99
Use the spin box to enter the number of samples to be averaged together for the STM-2 window Rate display.

**Format**
Select Thickness in kÅ, Thickness in Å, or Mass in µg/cm² to be displayed on the STM-2 window and on the Thickness graph.

**NOTE:** Mass in µg/cm² will display Rate as a Mass Rate in ng/cm²/s.

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

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

**NOTE:** Sample Settings is disabled while monitoring.

*Figure 3-12 Sample Settings window*

**Samples averaged** .............. 1 to 50

Use the spin box to enter the number of samples averaged for the display, graphs, and data logging.

**Logging Rate** ................... 1 to 120

Use the spin box to select the logging rate. A Logging Rate of 1 will log every averaged measurement.

**Logging Interval** ................ Displays the data logging period in seconds.

**Overwrite** ..................... Select to overwrite the current data log with new data.

**Append** ......................... Select to add new data log information to current data log.

**Run#** ............................. Select to create a new data log named with the run number being logged.

**Select** .......................... Click to select the name and location of data log files.

**View** ............................. Click to view the current data log.
### 3.3.3 Help Menu

*Figure 3-13 Help menu*

![Help menu](image)

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

#### 3.3.3.1 About Window

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

*Figure 3-14 About window*

![About window](image)
3.3.4 STM-2 Tab

**Figure 3-15 STM-2 tab**

![STM-2 Tab Diagram]

**Show** .............................. Select the sensors to be displayed on the STM-2 window.

**Name** .............................. Edit the name of the sensor. This name will be displayed on the STM-2 window if selected. This ensures a fixed assignment between the sensor and the STM-2 module, as each module has a unique serial number.

**SN** ................................. Use the drop-down list box to select the serial number of the connected STM-2 associated with the named sensor.

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

**NOTE:** This will also change the Line Color on the **X Axis & Colors** tab of the **Graph Settings** window (refer to **Figure 3-7 on page 3-9**).

**Find/Refresh** ........................ Click to Find or Refresh connected STM-2(s).
3.3.5 Rate Tab

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

Figure 3-16 Rate tab
3.3.6 **Thickness Tab**

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

*Figure 3-17 Thickness tab*
3.3.7 Frequency Tab

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

Figure 3-18 Frequency tab
Chapter 4
STM-2 LabVIEW Operation

4.1 Introduction

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

4.2 Installing the STM-2 LabVIEW Application

4.2.1 Installing the Protocol Server

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

2. Click Windows Explorer or File Explorer >> Computer >> (CD drive letter:) >> Common Software.

3. Double click setup_smdp_svr_lv.exe. The Zip Self-Extractor window will display.

4. Click Unzip. The SMDP Serial Protocol Server window will display.

5. On the Destination Directory pane, click Browse to select the location where all software will be installed.

6. Click Next.

7. Read the license agreement.

8. Click I accept License Agreement(s).

9. Click Next.

10. Review the summary of information.

11. Click Next. Installation Complete will display.

12. Click Next. The Setup Wizard pane will display.

13. Click Next. The Confirm Installation pane will display.

14. Click Next.

15. Read the license agreement.

16. Click I Agree.

17. Click Next. Installation Complete will display.

18. Click Close.

4.2.2 Installing the LabVIEW Application and Device Drivers

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

4.2.3.1 Starting the Software in Windows XP or Windows 7

1. Click Start >> All Programs >> Inficon >> STM-xINF_win32 >> STM-xINFwin32.

2. The STM-x_win32.VI window will display (see Figure 4-1).

Figure 4-1 STM-x_win32.VI initial display

4.2.3.2 Starting the Software in Windows 8

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

2. If the icon cannot be found:

   2a. Click Search >> Apps.

   2b. Type STM in the Search text box.

   2c. Click the STM-x_win32 icon.
4.3 STM-x_win32.VI Window

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

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

Figure 4-2  STM-x_win32.VI live display

- Setup tab (see section 4.3.1 on page 4-6)
- Operate tab (see section 4.3.2 on page 4-10)
- Films tab (see section 4.3.3 on page 4-12)
- Rate Graph tab (see section 4.3.4 on page 4-14)
- Mass/Thick Graph tab (see section 4.3.5 on page 4-15)
- Frequency Graph tab (see section 4.3.6 on page 4-16)
- Help/About tab (see section 4.3.7 on page 4-18)
Inficon STM Instrument Interface pane

Press to Halt .................... Click to exit STM-x_win32.VI application. Notice the upper right X exit button is greyed out. Press to Halt is the only way to exit the program.

Rate .......................... Deposition rate based on the frequency of the crystal.

Film Thick/Film Mass ........... Thickness or Mass of Film being monitored.

Substrate Thick/Substrate Mass Accumulated Thickness or Mass of all layers.

Clear Graphs ...................... Clears Rate, Mass/Thick, and Frequency graphs.

Xtal OK? ....................... Illuminated light green when a good crystal is connected; dark green when a crystal fail has occurred (see Figure 4-3).

Figure 4-3  Xtal OK

RUNNING/PAUSED ................ Running changes to Paused if the process is paused on the Operate tab (see section 4.3.2 on page 4-10).

h:mm:ss ........................ Time that the current run number has been running; resets with each new run.

Life/XTAL FAIL .................. Percentage of crystal life remaining, decremented from 100%; changes to XTAL FAIL upon a crystal failure.

RUN # .............................. Incremented when New run is clicked on the Operate tab (see section 4.3.2 on page 4-10).

LOGGING OFF/LOGGING ON ...... Logging off changes to logging on when data logging is enabled by selecting OFF/ON in the Datalog pane of the Setup tab (see section 4.3.1).

Film .......................... Name of film being monitored is displayed.
4.3.1 Setup

Figure 4-4 Setup tab

Connection pane

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

Figure 4-5 Find instrument window

Search for STM-1s .......... Automatically detects connected STM-1s.
Search for STM-2s .......... Automatically detects connected STM-2s.
Manual Connection .......... See section 4.3.1.1 on page 4-8.
Simulate ...................... See section 4.3.1.2 on page 4-9.
Cancel ......................... Closes Find Instrument window.

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

**Thickness**
Displays Rate units of Å/s, Film Thick units of kÅ, and Substrate Thick units of kÅ on the STM-x_win32.VI window.

**Mass**
Displays Rate units of µg*s/cm², Film Mass units of µg/cm², and Substrate Mass units of µg/cm² on the STM-x_win32.VI window.

**Multi-layer mode**
When enabled, displays Substrate Thick/Substrate Mass on the STM-x_win32.VI window and displays the New Layer button and Layer Stackup pane on the Operate tab.

**Run#**
Manually increment/decrement the Run number on the INFICON STM Instrument Interface pane.

Datalog pane

**OFF/ON**
Enables data logging.

**Log Period**
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.
4.3.1.1 Manual Connection

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

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

Figure 4-6 Manual connection

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

Protocol . . . . . . . . . . . . . . . . . . . . . . . . Sycon, SMDP L, SMDP M, SMDP H
Enter the STM-2 communications protocol and baud rate. For STM-2 SMDP H is the only valid setting.
- Sycon: Sycon protocol (9.6 kbps)
- SMDP L: SMDP protocol (9.6 kbps)
- SMDP M: SMDP protocol (38.4 kbps)
- SMDP H: SMDP protocol (115.2 kbps)

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

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

Figure 4-7  Simulate mode

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

**Figure 4-8 Operate tab**

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

**Figure 4-9 FilmPicker.vi window**

**NOTE:** If a film is not displayed in this window, the film will need to be added by clicking Edit Films on the Films tab (see section 4.3.3).
**New Layer**  
Opens the **FilmPicker.vi** window and adds the selection as a new layer to the Layer Stackup.

**New run**  
Clears the Layer Stackup, opens the **FilmPicker.vi** window, adds the selection as a new layer to the Layer Stackup, and increments the Run number.

**Pause/Resume**  
Changes the Pause button to Resume and changes the background of the Sycon STM Instrument Interface pane to red. Pauses data logging and graphing until Resume is clicked.

**ZERO TIMER**  
Resets the timer on the Sycon STM Instrument Interface pane.

**ZERO FILM THK**  
Resets Film Thickness or Film Mass.

**Layer Stackup**  
Lists Film Name and current Thickness or Mass for each layer in the process.
4.3.3 Films

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

*Figure 4-10 Films tab*

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

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

**NOTE:** User defined films can be input by typing over existing values or by entering data into empty cells.
**Materials**  
List of materials to be added to the Films Database on the **FilmEditor.vi** window.

**Cancel**  
Exits the **FilmEditor.vi** window without saving changes.

**Save**  
Saves changes to Films Database on **Films** tab.

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

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

Figure 4-12 Rate Graph tab

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

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

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

Figure 4-13 Zoom in and out

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

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

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

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

NOTE: Zoom in and out are not available if Auto Scale X or Auto Scale Y are selected.
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 (\(\text{手}\)) and then press and drag in the graph pane to move the graph.

### 4.3.6 Frequency Graph

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

Figure 4-16 Frequency Graph tab

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

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

**NOTE:** Zoom in and out are not available if Auto Scale X or Auto Scale Y are selected.
Figure 4-17  Zoom in and out

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

Click the hand icon ( mano ) and then press and drag in the graph pane to move the graph.
4.3.7 Help/About

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

*Figure 4-18 Help/About tab*

**Software Version** . . . . . . . . Displays the software version.

**Capabilities** . . . . . . . . . . Displays the instruments compatible with STM-x_win32.VI Application software.

**Tip** . . . . . . . . . . Displays directions on how to access Descriptions and Tips throughout the STM-x_win32.VI Application.

**Firmware Version** . . . . . Queries STM-2 and displays the firmware version of the connected STM-2.

**Location of current logfile** . . . Displays the location of the log file that was set up on the Setup tab.

**(Advanced) Location of config file** Displays the location of the configuration file.
Communication Status and Statistics pane

Com Success  Counter which displays the number of successful communication attempts to STM-2.

Com Error  Counter which displays the number of failed communications (communication errors).

SVR Build  Build or version of the communication server.

#Instances  Displays the number of instruments using the communication server. It is possible to have multiple instances of STM-x_win32.VI running.

NOTE: It is possible to have other programs running that access the same instrument without conflict.

Last Comm (ms)  The last communication time in milliseconds.

Last Error  Report of errors in communication.

Status  indicates successful communication
  indicates failed communication.

Code  Displays the Error Code for the Failed Communication.

Source  Describes the Error Code.
Chapter 5
Communication

5.1 Communication Protocol

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

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

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

5.2 Sycon Multi-Drop Protocol (SMDP)

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

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

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

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

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

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

**ADDR** .......................... One byte address field

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

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

Address FF hexadecimal is reserved. It is used as an extension to indicate another byte of address information follows for products that have an address range higher than an address of FE hexadecimal.

**CMD_RSP** ........................ Command/Response field

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

When a command is received from a slave to a master, CMD bits are the same as in the message that was sent (see section 5.2.1.2), but the RSP2 through RSP0 field will be non-zero (indicating actual unit response status) (see section 5.2.1.3). The slave will set or clear the RSPF flag bit in the reply CMD_RSP frame to indicate an unacknowledged slave reset. This bit only has meaning when a command is going from slave to master. If this bit is 1, the slave has
been reset since the last AckPF, acknowledge power fail flag command was received (see Table 5-1).

Table 5-1 Command/Response

<table>
<thead>
<tr>
<th>CMD3</th>
<th>CMD2</th>
<th>CMD1</th>
<th>CMD0</th>
<th>RSPF</th>
<th>RSP2</th>
<th>RSP1</th>
<th>RSP0</th>
</tr>
</thead>
</table>

DATA .......................... Optional data

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

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

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

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

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

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

CKSUM1,2 .......................... Checksum characters for the message

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

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

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

---

**CAUTION**

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

---

5.2.1.2 Command Packet Format

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

Where `<CMD>` is:

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

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

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

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

Where <RSP> is:

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

5.2.2 Optional Serialization Command Mode

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

- A serial number byte must be placed before the checksum bytes. This must be a value greater than or equal to 0x10 (16), otherwise it could be mistaken as a framing or escape character byte (see section 5.2.2.1). This byte is summed as a part of the packet payload in computing the packet checksum value.

- The checksum character base must be hexadecimal 40 (@), instead of hexadecimal 30 (0) to inform the slave that it is receiving a packet with the extra SRLNO field postamble. This makes the last two characters of the command (the checksums) range from @ (0x40) through the letter, O (0x4f).

- For a response, the slave places the corresponding SRLNO byte into its response packet just before the two reply packet checksum characters, also 0x40 based.

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

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

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

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

- **ACKSM1, 2** ................ Alternate 0x40 based checksum characters
  
  This has a range of values from @ (0x40) through the letter, O (0x4f).

**NOTE:** Refer to section 5.2.1 on page 5-2 for additional information identifying the bytes in this command string.
5.3 Communications Commands

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

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

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

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

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

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

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

Table 5-2 STM-2 command set

<table>
<thead>
<tr>
<th>STM-2 command</th>
<th>Parameter</th>
<th>Send</th>
<th>Returned</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>@</td>
<td>None</td>
<td>@</td>
<td>STM-2 A0.3</td>
<td>Instrument model and firmware version. User references this when reporting product behavior issues.</td>
</tr>
<tr>
<td>@A</td>
<td>None</td>
<td>@A</td>
<td>600022</td>
<td>Instrument serial number (600022 is an example, each unit is unique). This reply allows multiple units connected to a computer to be identified to associate with correct sensor.</td>
</tr>
<tr>
<td>@B</td>
<td>None</td>
<td>@B</td>
<td>1</td>
<td>Instrument build type</td>
</tr>
</tbody>
</table>
Table 5-2  STM-2 command set (continued)

<table>
<thead>
<tr>
<th>STM-2 command</th>
<th>Parameter</th>
<th>Send</th>
<th>Returned</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>None</td>
<td>L</td>
<td>L</td>
<td>Acknowledge &quot;a&quot; response, reset flags so response to 'a' poll is &quot;@&quot; next time.</td>
</tr>
<tr>
<td>b</td>
<td>None</td>
<td>b</td>
<td></td>
<td>Set parameters to default values. Clears memory, reboots module, sets power loss and memloss flags so response to 'a' command is 'E'.</td>
</tr>
<tr>
<td>d</td>
<td>None</td>
<td>d</td>
<td></td>
<td>Cause reset</td>
</tr>
<tr>
<td>p</td>
<td>None</td>
<td>p</td>
<td></td>
<td>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.</td>
</tr>
</tbody>
</table>

Zeroing commands

| B | None | B | Zeroes timer and thickness |
| C | None | C | Zeroes thickness |
| D | None | D | Zeroes timer |

Film commands

- nnn to update parameter
- ? to query parameter

| q | =[8 char string],[?] | q=COPPER | Sets the current film name to COPPER. This allows the customer to name each module for simple reference. Additionally, the unique serial number reply to the query @A will allow a unique module specific identification. |
| E | =[0.40 - 99.99],[?]  | E=1.23 | Set current film density to 1.23 |
| F | =[0.100 - 9.999],[?] | F? 1.230 | Returns current film Z-ratio |
| J | =[10.0 - 999.9],[?]  | J = 80.1 | Set current film tooling to 80.1%. Spaces before or after = sign are legal. Can be used for readability. |
| r | =[1 – 50],[?]        | r=10 | Sets number of samples to 10 for temporal averaging |

Runtime data commands

| M | None | M | ! | Return crystal fail status @ crystal good ! crystal failed |
| S | None | S | -1.595 | Return thickness value -1.595 Å |
| s | None | s | 1.234 | Return film mass 1.234 µg/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) |
Table 5-2  STM-2 command set (continued)

<table>
<thead>
<tr>
<th>STM-2 command</th>
<th>Parameter</th>
<th>Send</th>
<th>Returned</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>None</td>
<td>U</td>
<td>5319234.34</td>
<td>Return sensor frequency 5,319,234.34Hz</td>
</tr>
<tr>
<td>V</td>
<td>None</td>
<td>V</td>
<td>15</td>
<td>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.</td>
</tr>
<tr>
<td>W</td>
<td>None</td>
<td>W</td>
<td>0:12:45</td>
<td>Return timer in H:MM:SS format, 12 min 45 s</td>
</tr>
<tr>
<td>a</td>
<td>None</td>
<td>a</td>
<td>A</td>
<td>Return RESET Status</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>@ = OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A = lost power</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>D = lost NONV memory</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>E = lost power and NONV memory</td>
</tr>
</tbody>
</table>

**NOTE:** NONV refers to non-volatile memory, i.e. memory that is persistent even when power is lost. This status is indicating that there was a loss of data, either due to an internal database problem, or a database purge.
Chapter 6
Troubleshooting and Maintenance

6.1 Troubleshooting Guide

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

### CAUTION

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

Refer all maintenance to qualified personnel.

6.1.1 Indicator

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

**Table 6-1 Indicator troubleshooting guide**

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

<table>
<thead>
<tr>
<th>SYMPTOM</th>
<th>CAUSE</th>
<th>REMEDY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate, Thickness, and Frequency readings are unstable or incorrect.</td>
<td>Temperature of the crystal is unstable (an AT-cut crystal may drift as much as 10 Hz/°C).</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Humidity level on the crystal is changing. Moisture being absorbed or exuded from the crystal surface.</td>
<td>Avoid condensation by turning off cooling water to sensor before opening the vacuum chamber to air. Flow water above the dew point of the room through the sensor when the chamber is open.</td>
</tr>
<tr>
<td></td>
<td>Defective in-vacuum cable or coax cables.</td>
<td>Use an ohmmeter to check electrical continuity and isolation.</td>
</tr>
<tr>
<td></td>
<td>Crystal seating on the crystal holder surface is scratched or contaminated.</td>
<td>Clean or replace crystal holder. Refer to the sensor operating manual.</td>
</tr>
<tr>
<td></td>
<td>Excessive cable length between oscillator and crystal causes a self-oscillation condition.</td>
<td>Use no longer than a 78.1 cm (30.75 in.) in-vacuum cable. Use only the 15.2 cm (6 in.) cable between STM-2 or oscillator and feedthrough.</td>
</tr>
<tr>
<td>SYMPTOM</td>
<td>CAUSE</td>
<td>REMEDY</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-----------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Crystal fail</td>
<td>Failed or defective crystal, or no crystal in sensor.</td>
<td>Install a new crystal.</td>
</tr>
<tr>
<td></td>
<td>Two crystals were installed or crystal is upside down.</td>
<td>Remove extra crystal. Reverse crystal orientation. Inspect crystal for scratches; if scratched, replace with new crystal.</td>
</tr>
<tr>
<td></td>
<td>Build-up of material at crystal holder aperture is touching the crystal.</td>
<td>Clean or replace the crystal holder. Refer to the sensor operating manual.</td>
</tr>
<tr>
<td></td>
<td>Crystal frequency is not within the Min and Max frequency settings.</td>
<td>Install a new crystal. Use a 6 MHz crystal.</td>
</tr>
<tr>
<td></td>
<td>Excessive cable length between oscillator and crystal.</td>
<td>Use no longer than a 78.1 cm (30.75 in.) in-vacuum cable. Use only the 15.2 cm (6 in.) cable between STM-2 or oscillator and feedthrough.</td>
</tr>
<tr>
<td></td>
<td>Sensor not connected, or bad electrical connection in sensor head or feedthrough, or bad cables.</td>
<td>Check sensor connections. Refer to the sensor operating manual. Use an ohmmeter to check electrical continuity/isolation of sensor head, feedthrough, in-vacuum cable, SMA/BNC adapter cable, and BNC cables. Refer to the sensor operating manual. Substitute a 5.5 MHz test crystal or a known good sensor for the suspect sensor.</td>
</tr>
<tr>
<td>Crystal fail</td>
<td>Bad coax cable between feedthrough and STM-2 or oscillator, or bad coax cable between oscillator and STM-2.</td>
<td>Use an ohmmeter to check electrical continuity/isolation. Substitute a known good coax cable.</td>
</tr>
<tr>
<td></td>
<td>STM-2 or oscillator is malfunctioning.</td>
<td>Substitute a known good STM-2 (or other QCM). Substitute a known good oscillator.</td>
</tr>
<tr>
<td>SYMPTOM</td>
<td>CAUSE</td>
<td>REMEDY</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Crystal fail during deposition before “normal” life of crystal is exceeded.</td>
<td>Crystal is being hit by small droplets of molten material from the evaporation source (spatter or spitting).</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Damaged crystal or deposited material is causing stress to crystal.</td>
<td>Replace the crystal. Use an Alloy crystal if appropriate for deposited material.</td>
</tr>
<tr>
<td></td>
<td>Material buildup on crystal holder is partially masking the crystal surface.</td>
<td>Clean or replace the crystal holder. Refer to the sensor operating manual.</td>
</tr>
<tr>
<td></td>
<td>Shutter is partially obstructing deposition flux or sensor is poorly positioned, causing uneven distribution of material on crystal.</td>
<td>Visually check crystal for an uneven coating, and if present, correct shutter or sensor positioning problem.</td>
</tr>
<tr>
<td>Crystal fail when vacuum chamber is opened to air.</td>
<td>Crystal was near the end of its life; opening to air causes film oxidation, which increases film stress.</td>
<td>Replace the crystal.</td>
</tr>
<tr>
<td></td>
<td>Excessive moisture accumulation on the crystal.</td>
<td>Avoid condensation by turning off cooling water to sensor before opening the vacuum chamber to air, and then flow heated water above the dew point of the room through the sensor when the chamber is open.</td>
</tr>
</tbody>
</table>
### Table 6-2 General troubleshooting (continued)

<table>
<thead>
<tr>
<th>SYMPTOM</th>
<th>CAUSE</th>
<th>REMEDY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate, Thickness, and Frequency readings are noisy.</td>
<td>Excessive cable length between oscillator and crystal.</td>
<td>Use 78.1 cm (30.75 in.) in-vacuum cable (or shorter). Use 15.2 cm (6 in.) cable between oscillator and feedthrough.</td>
</tr>
<tr>
<td></td>
<td>Electrical noise is being picked up by STM-2.</td>
<td>Locating STM-2 and cables at least 30.5 cm (1 ft.) away from high voltage / high power cables and other sources of electrical noise significantly reduces noise pickup.</td>
</tr>
<tr>
<td></td>
<td>Inadequate system grounding.</td>
<td>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.</td>
</tr>
<tr>
<td>SYMPTOM</td>
<td>CAUSE</td>
<td>REMEDY</td>
</tr>
<tr>
<td>-----------------------------------------------------------</td>
<td>-----------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Thickness reading has large excursions during deposition.</td>
<td>Mode hopping due to damaged or heavily dampened crystal.</td>
<td>Replace the crystal.</td>
</tr>
<tr>
<td></td>
<td>Crystal is near the end of its life.</td>
<td>Replace the crystal.</td>
</tr>
<tr>
<td></td>
<td>Scratches or foreign particles on the crystal holder seating surface.</td>
<td>Clean the crystal seating surface inside the crystal holder or replace crystal holder. Refer to the sensor operating manual.</td>
</tr>
<tr>
<td></td>
<td>Uneven coating onto crystal.</td>
<td>A straight line from center of source to center of crystal should be perpendicular to face of crystal.</td>
</tr>
<tr>
<td></td>
<td>Particles on crystal.</td>
<td>Replace crystal. Remove source of particles.</td>
</tr>
<tr>
<td></td>
<td>Intermittent cables or connections.</td>
<td>Use an ohmmeter to check electrical continuity / isolation of sensor head, feedthrough, in-vacuum cable, and BNC cables. Refer to the sensor operating manual.</td>
</tr>
<tr>
<td></td>
<td>Inadequate cooling of crystal.</td>
<td>Check water flow rate and temperature for sensor cooling. Refer to the sensor operating manual.</td>
</tr>
</tbody>
</table>
### Table 6-2  General troubleshooting (continued)

<table>
<thead>
<tr>
<th>SYMPTOM</th>
<th>CAUSE</th>
<th>REMEDY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness reading has large excursions during source warm-up or when source shutter is opened (usually causes Thickness reading to decrease) and after the termination of deposition (usually causes Thickness reading to increase).</td>
<td>Crystal not properly seated or dirty crystal holder.</td>
<td>Check crystal installation. Clean the crystal seating surface inside the crystal holder or replace crystal holder. Refer to the sensor operating manual.</td>
</tr>
<tr>
<td>Excessive heat input to the crystal.</td>
<td>If heat is due to radiation from the evaporation source, move sensor farther away (at least 25.4 cm (10 in.)) from source. Use SPC-1157-G10 crystals designed to minimize frequency shifts due to thermal shock.</td>
<td></td>
</tr>
<tr>
<td>Inadequate cooling of crystal.</td>
<td>Check water flow rate and temperature for sensor cooling. Refer to the sensor operating manual.</td>
<td></td>
</tr>
<tr>
<td>Crystal is being heated by electron flux.</td>
<td>Use a sputtering sensor for non-magnetron sputtering.</td>
<td></td>
</tr>
<tr>
<td>Crystal is being hit by small droplets of molten material from the evaporation source (spatter or spitting).</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>Intermittent connection occurring in sensor or feedthrough with thermal variation.</td>
<td>Use an ohmmeter to check electrical continuity/isolation of sensor head, feedthrough, and in-vacuum cable. Refer to the sensor operating manual.</td>
<td></td>
</tr>
</tbody>
</table>
6.1.3 Troubleshooting Computer Communications

Table 6-3 Troubleshooting computer communications

<table>
<thead>
<tr>
<th>SYMPTOM</th>
<th>CAUSE</th>
<th>REMEDY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communications cannot be established between the host computer and STM-2.</td>
<td>Improper cable connection.</td>
<td>Verify for cable connections are seated properly.</td>
</tr>
<tr>
<td></td>
<td>Driver not installed properly.</td>
<td>Reinstall drivers.</td>
</tr>
<tr>
<td>Computer did not initialize STM-2.</td>
<td></td>
<td>Click Find Instruments &gt;&gt; Search for STM-2s on LabVIEW Application.</td>
</tr>
</tbody>
</table>
Chapter 7  
Calibration Procedures

7.1 Importance of Density, Tooling and Z-Ratio

The quartz crystal microbalance is capable of precisely measuring the mass added to the face of the oscillating quartz crystal sensor. STM-2 recognizes the density of this added material to allow conversion of the mass information into thickness. In some instances where highest accuracy is required, it is necessary to make a density calibration, as outlined in section 7.2.

Because the flow of material from a deposition is not uniform, it is necessary to account for the different amount of material flow onto the sensor, compared to the substrates; this is accounted for by the Tooling parameter. Tooling can be experimentally established by following the guidelines in section 7.3 on page 7-2.

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

7.2 Determining Density

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

To determine density value:

1. Place a substrate (with proper masking for film thickness measurement) adjacent to the sensor, to ensure the same thickness will be accumulated on the crystal and substrate.
2. Set Density to the bulk value of the Film material or to an approximate value.
3. Set Z-Ratio to 1.000 and Tooling to 100%.
4. Place a new crystal in the sensor and make a short deposition (1000 to 5000 Å).
5. After deposition, remove the test substrate and measure the Film thickness with either a multiple beam interferometer or a stylus-type profilometer.
Determine the new Density value with equation [1]:

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

where:
- \(D_1\) = Initial Density setting
- \(T_x\) = Thickness reading on STM-2
- \(T_m\) = Measured thickness

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

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

**NOTE:** Slight adjustment of Density may be necessary, in order to achieve \(T_x = T_m\).

### 7.3 Determining Tooling

1. Place a test substrate in the substrate holder of the system.
2. Make a short deposition and determine actual thickness.
3. Calculate Tooling from the relationship shown in equation [2]:

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

where
- \(T_m\) = Actual thickness at substrate holder
- \(T_x\) = Thickness reading in STM-2 software
- \(TF_i\) = Initial tooling factor

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

**NOTE:** To account for variations in source distribution and other system factors, obtain an average value for Tooling, using a minimum of three separate evaporations.
7.4 Laboratory Determination of Z-Ratio

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

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

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

where:

- \(d_f\) = Density (g/cm\(^3\)) of deposited film
- \(\mu_f\) = Shear modulus (dynes/cm\(^2\)) of deposited film
- \(d_q\) = Density of quartz (crystal) (2.649 g/cm\(^3\))
- \(\mu_q\) = Shear modulus of quartz (crystal) (3.32 \times 10^{11} \text{ dynes/cm}^2)

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

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

1. Establish the correct density value as described in section 7.2 on page 7-1.

2. Install a new crystal and record its starting Frequency, \(F_{co}\). The starting Frequency will be displayed on the Frequency Graph tab.

3. Make a deposition on a test substrate such that the percent Crystal Life display will read approximately 50%, or near the end of crystal life for the particular material, whichever is smaller.

4. Stop the deposition and record the ending crystal Frequency \(F_c\).

5. Remove the test substrate and measure the film thickness with either a multiple beam interferometer or a stylus-type profilometer.
Using the Density value from step 1 and the recorded values for $F_{co}$ and $F_c$, adjust the Z-Ratio value in thickness equation [5] to bring the calculated thickness value into agreement with the actual thickness.

- If the calculated value of thickness is greater than the actual thickness, increase the Z-Ratio value.
- If the calculated value of thickness is less than the actual thickness, decrease the Z-Ratio value.

\[
T_f = \frac{Z_q \times 10^4}{2\pi zp} \left\{ \left( \frac{1}{F_{co}} - \frac{1}{F_c} \right) \right\}
\]

where:
- $T_f$ = Thickness of deposited film (Å)
- $F_{co}$ = 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/(m²s))
- $p$ = Density of deposited film (g/cm³)

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

- If the thickness of layer 1 is large compared to layer 2, use material 1 Z-Ratio for both layers.
- If the thickness of layer 1 is thin compared to layer 2, use material 2 Z-Ratio for both layers.
- If the thickness of both layers is similar, use a value for Z-Ratio which is the weighted average of the two Z-Ratio values for deposition of layer 2 and subsequent layers.
Chapter 8
Measurement and Theory

8.1 Basics

The Quartz Crystal deposition Monitor (QCM) utilizes the piezoelectric sensitivity of a quartz monitor crystal to added mass. The QCM uses this mass sensitivity to control the deposition rate and final thickness of a vacuum deposition.

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

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

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

\[
\frac{M_f}{M_q} = \frac{\Delta F}{F_q}
\]

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

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

where the film thickness, \(T_f\), is proportional (through \(K\)) to the frequency change, \(DF\), and inversely proportional to the density of the film, \(d_f\). The constant, \(K = N_{at}d_q/F_q^2\); where \(d_q\) (= 2.649 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 angstrom of Aluminum (density of 2.77 g/cm³) is added to its surface. In this manner, the thickness of a rigid adlayer is inferred from the precise measurement of the frequency shift of the crystal.

The quantitative knowledge of this effect provides a means of determining how much material is being deposited on a substrate in a vacuum system, a measurement that was not convenient or practical prior to this understanding.

### 8.1.1 Monitor Crystals

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

*Figure 8-1 Quartz resonator*

The lowest frequency response is primarily a “thickness shear” mode that is called the **fundamental**. The characteristic movement of the thickness shear mode is for displacement to take place parallel to the major monitor crystal faces. In other words, the faces are displacement antinodes as shown in Figure 8-3 on page 8-4.

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

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

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

The second set of improvements was to contour one face of the crystal and to reduce the size of the exciting electrode. These improvements have the effect of trapping the acoustic energy.
Reducing the electrode diameter limits the excitation to the central area. Contouring dissipates the energy of the traveling acoustic wave before it reaches the edge of the crystal. Energy is not reflected back to the center where it can interfere with other newly launched waves, essentially making a small crystal appear to behave as though it is infinite in extent.

With the vibrations of the crystal restricted to the center, it is practical to clamp the outer edges of the crystal to a holder, and not produce any undesirable effects. Contouring also reduces the intensity of response of the generally unwanted anharmonic modes; hence, the potential for an oscillator to sustain an unwanted oscillation is substantially reduced.

Figure 8-2 Frequency response spectrum

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

The “AT” resonator is usually chosen for deposition monitoring, because at room temperature it can be made to exhibit a very small frequency change, due to temperature changes.

Since there is currently no way to separate the frequency change caused by added mass (which is negative), or even the frequency changes caused by temperature gradients across the crystal or film induced stresses, it is essential to minimize these temperature-induced changes. It is only in this way that small changes in mass can be measured accurately.
8.1.2 Period Measurement Technique

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

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

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

The period measurement technique was the outgrowth of two factors:

- the digital implementation of time measurement, and
- the recognition of the mathematically rigorous formulation of the proportionality between the thickness of the crystal, \( I_q \), 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, which is usually much higher in frequency than the monitor crystal. This reference oscillator is used to generate small precision time intervals, which are used to determine the oscillation period of the monitor crystal. This is done by using two pulse accumulators:

- The first is used to accumulate a fixed number of cycles, m, of the monitor crystal.
- The second is turned on at the same time and accumulates cycles from the reference oscillator until m counts are accumulated in the first.

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

The period of the monitor crystal is (n/F_r)/m, where n is the number of counts in the second accumulator. The precision of the measurement is determined by the speed of the reference clock and the length of the gate time (set by the size of m). Increasing one or both of these leads to improved measurement precision.

Having a high frequency reference oscillator is important for rapid measurements (which require short gating times), low deposition rates, and low density materials. All of these require high time precision to resolve the small, mass-induced frequency shifts between measurements.

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

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

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

After learning of fundamental work by Miller and Bolef\textsuperscript{5}, which rigorously treated the resonating quartz and deposited film system as a one-dimensional, continuous acoustic resonator, Lu and Lewis\textsuperscript{6} developed the simplifying Z-match™ equation in 1972. Advances in electronics taking place at the same time, namely the micro-processor, made it practical to solve the Z-match equation in "real-time".

Most deposition process controllers/monitors sold today use this sophisticated equation that takes into account the acoustic properties of the resonating quartz and film system as shown in equation [4].

\[
T_f = \left( \frac{N_at_{q}}{\pi d_{f} F_c Z} \right) \arctan \left( Z \tan \left( \frac{\pi (F_q - F_c)}{F_q} \right) \right)
\]

[4]

where \(Z=(d_{q}u_{q}/d_{f}u_{f})^{1/2}\) is the acoustic impedance ratio and \(u_{q}\) and \(u_{f}\) are the shear moduli of the quartz and film, respectively.

Finally, there was a fundamental understanding of the frequency-to-thickness conversion that could yield theoretically correct results in a time frame that was practical for process control.

To achieve this new level of accuracy requires only that the user enter an additional material parameter, \(Z\), for the film being deposited. This equation has been tested for a number of materials, and has been found to be valid for frequency shifts equivalent to \(F_f = 0.4F_q\).

Keep in mind that equation [2] was valid to only 0.02\(F_q\) and equation [3] was valid only to \(\sim 0.05F_q\).

\textsuperscript{5}J. G. Miller and D. I. Bolef, J. Appl. Phys. \textbf{39}, 5815, 4589 (1968)
\textsuperscript{6}C. Lu and O. Lewis, J Appl. Phys. \textbf{43}, 4385 (1972)
Appendix A
Material Table

A.1 Introduction

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

CAUTION

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

An * is used to indicate that a Z-Ratio has not been established for a certain material. A value of 1.000 is defaulted in these situations.

<table>
<thead>
<tr>
<th>Formula</th>
<th>Density</th>
<th>Z-Ratio</th>
<th>Material Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag</td>
<td>10.500</td>
<td>0.529</td>
<td>silver</td>
</tr>
<tr>
<td>AgBr</td>
<td>6.470</td>
<td>1.180</td>
<td>silver bromide</td>
</tr>
<tr>
<td>AgCl</td>
<td>5.560</td>
<td>1.320</td>
<td>silver chloride</td>
</tr>
<tr>
<td>Al</td>
<td>2.700</td>
<td>1.080</td>
<td>aluminum</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>3.970</td>
<td>0.336</td>
<td>aluminum oxide</td>
</tr>
<tr>
<td>Al₄C₃</td>
<td>2.360</td>
<td>*1.000</td>
<td>aluminum carbide</td>
</tr>
<tr>
<td>AlF₃</td>
<td>3.070</td>
<td>*1.000</td>
<td>aluminum fluoride</td>
</tr>
<tr>
<td>AlN</td>
<td>3.260</td>
<td>*1.000</td>
<td>aluminum nitride</td>
</tr>
<tr>
<td>AlSb</td>
<td>4.360</td>
<td>0.743</td>
<td>aluminum antimonide</td>
</tr>
<tr>
<td>As</td>
<td>5.730</td>
<td>0.966</td>
<td>arsenic</td>
</tr>
<tr>
<td>As₂Se₃</td>
<td>4.750</td>
<td>*1.000</td>
<td>arsenic selenide</td>
</tr>
<tr>
<td>Au</td>
<td>19.300</td>
<td>0.381</td>
<td>gold</td>
</tr>
<tr>
<td>B</td>
<td>2.370</td>
<td>0.389</td>
<td>boron</td>
</tr>
<tr>
<td>B₂O₃</td>
<td>1.820</td>
<td>*1.000</td>
<td>boron oxide</td>
</tr>
<tr>
<td>B₄C</td>
<td>2.370</td>
<td>*1.000</td>
<td>boron carbide</td>
</tr>
<tr>
<td>BN</td>
<td>1.860</td>
<td>*1.000</td>
<td>boron nitride</td>
</tr>
<tr>
<td>Ba</td>
<td>3.500</td>
<td>2.100</td>
<td>barium</td>
</tr>
<tr>
<td>BaF₂</td>
<td>4.886</td>
<td>0.793</td>
<td>barium fluoride</td>
</tr>
<tr>
<td>Formula</td>
<td>Density</td>
<td>Z-Ratio</td>
<td>Material Name</td>
</tr>
<tr>
<td>-------------</td>
<td>---------</td>
<td>---------</td>
<td>----------------------</td>
</tr>
<tr>
<td>BaN₂O₆</td>
<td>3.244</td>
<td>1.261</td>
<td>barium nitrate</td>
</tr>
<tr>
<td>BaO</td>
<td>5.720</td>
<td>*1.000</td>
<td>barium oxide</td>
</tr>
<tr>
<td>BaTiO₃</td>
<td>5.999</td>
<td>0.464</td>
<td>barium titanate (tet)</td>
</tr>
<tr>
<td>BaTiO₃</td>
<td>6.035</td>
<td>0.412</td>
<td>barium titanate (cubic)</td>
</tr>
<tr>
<td>Be</td>
<td>1.850</td>
<td>0.543</td>
<td>beryllium</td>
</tr>
<tr>
<td>BeF₂</td>
<td>1.990</td>
<td>*1.000</td>
<td>beryllium fluoride</td>
</tr>
<tr>
<td>BeO</td>
<td>3.010</td>
<td>*1.000</td>
<td>beryllium oxide</td>
</tr>
<tr>
<td>Bi</td>
<td>9.800</td>
<td>0.790</td>
<td>bismuth</td>
</tr>
<tr>
<td>Bi₂O₃</td>
<td>8.900</td>
<td>*1.000</td>
<td>bismuth oxide</td>
</tr>
<tr>
<td>Bi₂S₃</td>
<td>7.390</td>
<td>*1.000</td>
<td>bismuth trisulfide</td>
</tr>
<tr>
<td>Bi₂Se₃</td>
<td>6.820</td>
<td>*1.000</td>
<td>bismuth selenide</td>
</tr>
<tr>
<td>Bi₂Te₃</td>
<td>7.700</td>
<td>*1.000</td>
<td>bismuth telluride</td>
</tr>
<tr>
<td>BiF₃</td>
<td>5.320</td>
<td>*1.000</td>
<td>bismuth fluoride</td>
</tr>
<tr>
<td>C</td>
<td>2.250</td>
<td>3.260</td>
<td>carbon (graphite)</td>
</tr>
<tr>
<td>C</td>
<td>3.520</td>
<td>0.220</td>
<td>carbon (diamond)</td>
</tr>
<tr>
<td>C₈H₈</td>
<td>1.100</td>
<td>*1.000</td>
<td>parlyene (union carbide)</td>
</tr>
<tr>
<td>Ca</td>
<td>1.550</td>
<td>2.620</td>
<td>calcium</td>
</tr>
<tr>
<td>CaF₂</td>
<td>3.180</td>
<td>0.775</td>
<td>calcium fluoride</td>
</tr>
<tr>
<td>CaO</td>
<td>3.350</td>
<td>*1.000</td>
<td>calcium oxide</td>
</tr>
<tr>
<td>CaO-SiO₂</td>
<td>2.900</td>
<td>*1.000</td>
<td>calcium silicate (3)</td>
</tr>
<tr>
<td>CaSO₄</td>
<td>2.962</td>
<td>0.955</td>
<td>calcium sulfate</td>
</tr>
<tr>
<td>CaTiO₃</td>
<td>4.100</td>
<td>*1.000</td>
<td>calcium titanate</td>
</tr>
<tr>
<td>CaWO₄</td>
<td>6.060</td>
<td>*1.000</td>
<td>calcium tungstate</td>
</tr>
<tr>
<td>Cd</td>
<td>8.640</td>
<td>0.682</td>
<td>cadmium</td>
</tr>
<tr>
<td>CdF₂</td>
<td>6.640</td>
<td>*1.000</td>
<td>cadmium fluoride</td>
</tr>
<tr>
<td>CdO</td>
<td>8.150</td>
<td>*1.000</td>
<td>cadmium oxide</td>
</tr>
<tr>
<td>CdS</td>
<td>4.830</td>
<td>1.020</td>
<td>cadmium sulfide</td>
</tr>
<tr>
<td>CdSe</td>
<td>5.810</td>
<td>*1.000</td>
<td>cadmium selenide</td>
</tr>
<tr>
<td>CdTe</td>
<td>6.200</td>
<td>0.980</td>
<td>cadmium telluride</td>
</tr>
<tr>
<td>Ce</td>
<td>6.780</td>
<td>*1.000</td>
<td>cerium</td>
</tr>
<tr>
<td>CeF₃</td>
<td>6.160</td>
<td>*1.000</td>
<td>cerium (III) fluoride</td>
</tr>
<tr>
<td>CeO₂</td>
<td>7.130</td>
<td>*1.000</td>
<td>cerium (IV) dioxide</td>
</tr>
<tr>
<td>Co</td>
<td>8.900</td>
<td>0.343</td>
<td>cobalt</td>
</tr>
<tr>
<td>Formula</td>
<td>Density</td>
<td>Z-Ratio</td>
<td>Material Name</td>
</tr>
<tr>
<td>-----------</td>
<td>---------</td>
<td>---------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>CoO</td>
<td>6.440</td>
<td>0.412</td>
<td>cobalt oxide</td>
</tr>
<tr>
<td>Cr</td>
<td>7.200</td>
<td>0.305</td>
<td>chromium</td>
</tr>
<tr>
<td>Cr₂O₃</td>
<td>5.210</td>
<td>*1.000</td>
<td>chromium (III) oxide</td>
</tr>
<tr>
<td>Cr₃C₂</td>
<td>6.680</td>
<td>*1.000</td>
<td>chromium carbide</td>
</tr>
<tr>
<td>CrB</td>
<td>6.170</td>
<td>*1.000</td>
<td>chromium boride</td>
</tr>
<tr>
<td>Cs</td>
<td>1.870</td>
<td>*1.000</td>
<td>cesium</td>
</tr>
<tr>
<td>Cs₂SO₄</td>
<td>4.243</td>
<td>1.212</td>
<td>cesium sulfate</td>
</tr>
<tr>
<td>CsBr</td>
<td>4.456</td>
<td>1.410</td>
<td>cesium bromide</td>
</tr>
<tr>
<td>CsCl</td>
<td>3.988</td>
<td>1.399</td>
<td>cesium chloride</td>
</tr>
<tr>
<td>CsI</td>
<td>4.516</td>
<td>1.542</td>
<td>cesium iodide</td>
</tr>
<tr>
<td>Cu</td>
<td>8.930</td>
<td>0.437</td>
<td>copper</td>
</tr>
<tr>
<td>Cu₂O</td>
<td>6.000</td>
<td>*1.000</td>
<td>copper oxide</td>
</tr>
<tr>
<td>Cu₂S</td>
<td>5.600</td>
<td>0.690</td>
<td>copper (I) sulfide (alpha)</td>
</tr>
<tr>
<td>Cu₂S₅</td>
<td>5.800</td>
<td>0.670</td>
<td>copper (I) sulfide (beta)</td>
</tr>
<tr>
<td>CuS</td>
<td>4.600</td>
<td>0.820</td>
<td>copper (II) sulfide</td>
</tr>
<tr>
<td>Dy</td>
<td>8.550</td>
<td>0.600</td>
<td>dysprosium</td>
</tr>
<tr>
<td>Dy₂O₃</td>
<td>7.810</td>
<td>*1.000</td>
<td>dysprosium oxide</td>
</tr>
<tr>
<td>Er</td>
<td>9.050</td>
<td>0.740</td>
<td>erbium</td>
</tr>
<tr>
<td>Er₂O₃</td>
<td>8.640</td>
<td>*1.000</td>
<td>erbium oxide</td>
</tr>
<tr>
<td>Eu</td>
<td>5.260</td>
<td>*1.000</td>
<td>europium</td>
</tr>
<tr>
<td>EuF₂</td>
<td>6.500</td>
<td>*1.000</td>
<td>europium fluoride</td>
</tr>
<tr>
<td>Fe</td>
<td>7.860</td>
<td>0.349</td>
<td>iron</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>5.240</td>
<td>*1.000</td>
<td>iron oxide</td>
</tr>
<tr>
<td>FeO</td>
<td>5.700</td>
<td>*1.000</td>
<td>iron oxide</td>
</tr>
<tr>
<td>FeS</td>
<td>4.840</td>
<td>*1.000</td>
<td>iron sulfide</td>
</tr>
<tr>
<td>Ga</td>
<td>5.930</td>
<td>0.593</td>
<td>gallium</td>
</tr>
<tr>
<td>Ga₂O₃</td>
<td>5.880</td>
<td>*1.000</td>
<td>gallium oxide (B)</td>
</tr>
<tr>
<td>GaAs</td>
<td>5.310</td>
<td>1.590</td>
<td>gallium arsenide</td>
</tr>
<tr>
<td>GaN</td>
<td>6.100</td>
<td>*1.000</td>
<td>gallium nitride</td>
</tr>
<tr>
<td>GaP</td>
<td>4.100</td>
<td>*1.000</td>
<td>gallium phosphide</td>
</tr>
<tr>
<td>GaSb</td>
<td>5.600</td>
<td>*1.000</td>
<td>gallium antimonide</td>
</tr>
<tr>
<td>Gd</td>
<td>7.890</td>
<td>0.670</td>
<td>gadolinium</td>
</tr>
<tr>
<td>Gd₂O₃</td>
<td>7.410</td>
<td>*1.000</td>
<td>gadolinium oxide</td>
</tr>
<tr>
<td>Formula</td>
<td>Density</td>
<td>Z-Ratio</td>
<td>Material Name</td>
</tr>
<tr>
<td>-----------</td>
<td>---------</td>
<td>---------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Ge</td>
<td>5.350</td>
<td>0.516</td>
<td>germanium</td>
</tr>
<tr>
<td>Ge₃N₂</td>
<td>5.200</td>
<td>*1.000</td>
<td>germanium nitride</td>
</tr>
<tr>
<td>GeO₂</td>
<td>6.240</td>
<td>*1.000</td>
<td>germanium oxide</td>
</tr>
<tr>
<td>GeTe</td>
<td>6.200</td>
<td>*1.000</td>
<td>germanium telluride</td>
</tr>
<tr>
<td>Hf</td>
<td>13.090</td>
<td>0.360</td>
<td>hafnium</td>
</tr>
<tr>
<td>HfB₂</td>
<td>10.500</td>
<td>*1.000</td>
<td>hafnium boride</td>
</tr>
<tr>
<td>HfC</td>
<td>12.200</td>
<td>*1.000</td>
<td>hafnium carbide</td>
</tr>
<tr>
<td>HfN</td>
<td>13.800</td>
<td>*1.000</td>
<td>hafnium nitride</td>
</tr>
<tr>
<td>HfO₂</td>
<td>9.680</td>
<td>*1.000</td>
<td>hafnium oxide</td>
</tr>
<tr>
<td>HfSi₂</td>
<td>7.200</td>
<td>*1.000</td>
<td>hafnium silicide</td>
</tr>
<tr>
<td>Hg</td>
<td>13.460</td>
<td>0.740</td>
<td>mercury</td>
</tr>
<tr>
<td>Ho</td>
<td>8.800</td>
<td>0.580</td>
<td>holmium</td>
</tr>
<tr>
<td>Ho₂O₃</td>
<td>8.410</td>
<td>*1.000</td>
<td>holmium oxide</td>
</tr>
<tr>
<td>In</td>
<td>7.300</td>
<td>0.841</td>
<td>indium</td>
</tr>
<tr>
<td>In₂O₃</td>
<td>7.180</td>
<td>*1.000</td>
<td>indium sesquioxide</td>
</tr>
<tr>
<td>In₂Se₃</td>
<td>5.700</td>
<td>*1.000</td>
<td>indium selenide</td>
</tr>
<tr>
<td>In₂Te₃</td>
<td>5.800</td>
<td>*1.000</td>
<td>indium telluride</td>
</tr>
<tr>
<td>InAs</td>
<td>5.700</td>
<td>*1.000</td>
<td>indium arsenide</td>
</tr>
<tr>
<td>InP</td>
<td>4.800</td>
<td>*1.000</td>
<td>indium phosphide</td>
</tr>
<tr>
<td>InSb</td>
<td>5.760</td>
<td>0.769</td>
<td>indium antimonide</td>
</tr>
<tr>
<td>Ir</td>
<td>22.400</td>
<td>0.129</td>
<td>iridium</td>
</tr>
<tr>
<td>K</td>
<td>0.860</td>
<td>10.189</td>
<td>potassium</td>
</tr>
<tr>
<td>KBr</td>
<td>2.750</td>
<td>1.893</td>
<td>potassium bromide</td>
</tr>
<tr>
<td>KCl</td>
<td>1.980</td>
<td>2.050</td>
<td>potassium chloride</td>
</tr>
<tr>
<td>KF</td>
<td>2.480</td>
<td>*1.000</td>
<td>potassium fluoride</td>
</tr>
<tr>
<td>KI</td>
<td>3.128</td>
<td>2.077</td>
<td>potassium iodide</td>
</tr>
<tr>
<td>La</td>
<td>6.170</td>
<td>0.920</td>
<td>lanthanum</td>
</tr>
<tr>
<td>La₂O₃</td>
<td>6.510</td>
<td>*1.000</td>
<td>lanthanum oxide</td>
</tr>
<tr>
<td>LaB₆</td>
<td>2.610</td>
<td>*1.000</td>
<td>lanthanum boride</td>
</tr>
<tr>
<td>LaF₃</td>
<td>5.940</td>
<td>*1.000</td>
<td>lanthanum fluoride</td>
</tr>
<tr>
<td>Li</td>
<td>0.530</td>
<td>5.900</td>
<td>lithium</td>
</tr>
<tr>
<td>LiBr</td>
<td>3.470</td>
<td>1.230</td>
<td>lithium bromide</td>
</tr>
<tr>
<td>LiF</td>
<td>2.638</td>
<td>0.778</td>
<td>lithium fluoride</td>
</tr>
<tr>
<td>Formula</td>
<td>Density</td>
<td>Z-Ratio</td>
<td>Material Name</td>
</tr>
<tr>
<td>-----------</td>
<td>---------</td>
<td>---------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>LiNbO₃</td>
<td>4.700</td>
<td>0.463</td>
<td>lithium niobate</td>
</tr>
<tr>
<td>Lu</td>
<td>9.840</td>
<td>*1.000</td>
<td>lutetium</td>
</tr>
<tr>
<td>Mg</td>
<td>1.740</td>
<td>1.610</td>
<td>magnesium</td>
</tr>
<tr>
<td>MgAl₂O₄</td>
<td>3.600</td>
<td>*1.000</td>
<td>magnesium aluminate</td>
</tr>
<tr>
<td>MgAl₂O₆</td>
<td>8.000</td>
<td>*1.000</td>
<td>spinel</td>
</tr>
<tr>
<td>MgF₂</td>
<td>3.180</td>
<td>0.637</td>
<td>magnesium fluoride</td>
</tr>
<tr>
<td>MgO</td>
<td>3.580</td>
<td>0.411</td>
<td>magnesium oxide</td>
</tr>
<tr>
<td>Mn</td>
<td>7.200</td>
<td>0.377</td>
<td>manganese</td>
</tr>
<tr>
<td>MnO</td>
<td>5.390</td>
<td>0.467</td>
<td>manganese oxide</td>
</tr>
<tr>
<td>MnS</td>
<td>3.990</td>
<td>0.940</td>
<td>manganese (II) sulfide</td>
</tr>
<tr>
<td>Mo</td>
<td>10.200</td>
<td>0.257</td>
<td>molybdenum</td>
</tr>
<tr>
<td>Mo₂C</td>
<td>9.180</td>
<td>*1.000</td>
<td>molybdenum carbide</td>
</tr>
<tr>
<td>MoB₂</td>
<td>7.120</td>
<td>*1.000</td>
<td>molybdenum boride</td>
</tr>
<tr>
<td>MoO₃</td>
<td>4.700</td>
<td>*1.000</td>
<td>molybdenum trioxide</td>
</tr>
<tr>
<td>MoS₂</td>
<td>4.800</td>
<td>*1.000</td>
<td>molybdenum disulfide</td>
</tr>
<tr>
<td>Na</td>
<td>0.970</td>
<td>4.800</td>
<td>sodium</td>
</tr>
<tr>
<td>Na₃AlF₆</td>
<td>2.900</td>
<td>*1.000</td>
<td>cryolite</td>
</tr>
<tr>
<td>Na₅Al₃F₁₄</td>
<td>2.900</td>
<td>*1.000</td>
<td>chiolite</td>
</tr>
<tr>
<td>NaBr</td>
<td>3.200</td>
<td>*1.000</td>
<td>sodium bromide</td>
</tr>
<tr>
<td>NaCl</td>
<td>2.170</td>
<td>1.570</td>
<td>sodium chloride</td>
</tr>
<tr>
<td>NaClO₃</td>
<td>2.164</td>
<td>1.565</td>
<td>sodium chlorate</td>
</tr>
<tr>
<td>NaF</td>
<td>2.558</td>
<td>1.645</td>
<td>sodium fluoride</td>
</tr>
<tr>
<td>NaNO₃</td>
<td>2.270</td>
<td>1.194</td>
<td>sodium nitrate</td>
</tr>
<tr>
<td>Nb</td>
<td>8.578</td>
<td>0.492</td>
<td>niobium (columbium)</td>
</tr>
<tr>
<td>Nb₂O₃</td>
<td>7.500</td>
<td>*1.000</td>
<td>niobium trioxide</td>
</tr>
<tr>
<td>Nb₂O₅</td>
<td>4.470</td>
<td>*1.000</td>
<td>niobium (V) oxide</td>
</tr>
<tr>
<td>NbB₂</td>
<td>6.970</td>
<td>*1.000</td>
<td>niobium boride</td>
</tr>
<tr>
<td>NbC</td>
<td>7.820</td>
<td>*1.000</td>
<td>niobium carbide</td>
</tr>
<tr>
<td>NbN</td>
<td>8.400</td>
<td>*1.000</td>
<td>niobium nitride</td>
</tr>
<tr>
<td>Nd</td>
<td>7.000</td>
<td>*1.000</td>
<td>neodymium</td>
</tr>
<tr>
<td>Nd₂O₃</td>
<td>7.240</td>
<td>*1.000</td>
<td>neodymium oxide</td>
</tr>
<tr>
<td>NdF₃</td>
<td>6.506</td>
<td>*1.000</td>
<td>neodymium fluoride</td>
</tr>
<tr>
<td>Ni</td>
<td>8.910</td>
<td>0.331</td>
<td>nickel</td>
</tr>
<tr>
<td>Formula</td>
<td>Density</td>
<td>Z-Ratio</td>
<td>Material Name</td>
</tr>
<tr>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>------------------------</td>
</tr>
<tr>
<td>NiCr</td>
<td>8.500</td>
<td>*1.000</td>
<td>nichrome</td>
</tr>
<tr>
<td>NiCrFe</td>
<td>8.500</td>
<td>*1.000</td>
<td>Inconel</td>
</tr>
<tr>
<td>NiFe</td>
<td>8.700</td>
<td>*1.000</td>
<td>permalloy</td>
</tr>
<tr>
<td>NiFeMo</td>
<td>8.900</td>
<td>*1.000</td>
<td>supermalloy</td>
</tr>
<tr>
<td>NiO</td>
<td>7.450</td>
<td>*1.000</td>
<td>nickel oxide</td>
</tr>
<tr>
<td>P₃N₅</td>
<td>2.510</td>
<td>*1.000</td>
<td>phosphorus nitride</td>
</tr>
<tr>
<td>Pb</td>
<td>11.300</td>
<td>1.130</td>
<td>lead</td>
</tr>
<tr>
<td>PbCl₂</td>
<td>5.850</td>
<td>*1.000</td>
<td>lead chloride</td>
</tr>
<tr>
<td>PbF₂</td>
<td>8.240</td>
<td>0.661</td>
<td>lead fluoride</td>
</tr>
<tr>
<td>PbO</td>
<td>9.530</td>
<td>*1.000</td>
<td>lead oxide</td>
</tr>
<tr>
<td>PbS</td>
<td>7.500</td>
<td>0.566</td>
<td>lead sulfide</td>
</tr>
<tr>
<td>PbSe</td>
<td>8.100</td>
<td>*1.000</td>
<td>lead selenide</td>
</tr>
<tr>
<td>PbSnO₃</td>
<td>8.100</td>
<td>*1.000</td>
<td>lead stannate</td>
</tr>
<tr>
<td>PbTe</td>
<td>8.160</td>
<td>0.651</td>
<td>lead telluride</td>
</tr>
<tr>
<td>Pd</td>
<td>12.038</td>
<td>0.357</td>
<td>palladium</td>
</tr>
<tr>
<td>PdO</td>
<td>8.310</td>
<td>*1.000</td>
<td>palladium oxide</td>
</tr>
<tr>
<td>Po</td>
<td>9.400</td>
<td>*1.000</td>
<td>polonium</td>
</tr>
<tr>
<td>Pr</td>
<td>6.780</td>
<td>*1.000</td>
<td>praseodymium</td>
</tr>
<tr>
<td>Pr₂O₃</td>
<td>6.880</td>
<td>*1.000</td>
<td>praseodymium oxide</td>
</tr>
<tr>
<td>Pt</td>
<td>21.400</td>
<td>0.245</td>
<td>platinum</td>
</tr>
<tr>
<td>PtO₂</td>
<td>10.200</td>
<td>*1.000</td>
<td>platinum oxide</td>
</tr>
<tr>
<td>Ra</td>
<td>5.000</td>
<td>*1.000</td>
<td>radium</td>
</tr>
<tr>
<td>Rb</td>
<td>1.530</td>
<td>2.540</td>
<td>rubidium</td>
</tr>
<tr>
<td>Rbl</td>
<td>3.550</td>
<td>*1.000</td>
<td>rubidium iodide</td>
</tr>
<tr>
<td>Re</td>
<td>21.040</td>
<td>0.150</td>
<td>rhenium</td>
</tr>
<tr>
<td>Rh</td>
<td>12.410</td>
<td>0.210</td>
<td>rhodium</td>
</tr>
<tr>
<td>Ru</td>
<td>12.362</td>
<td>0.182</td>
<td>ruthenium</td>
</tr>
<tr>
<td>S₈</td>
<td>2.070</td>
<td>2.290</td>
<td>sulfur</td>
</tr>
<tr>
<td>Sb</td>
<td>6.620</td>
<td>0.768</td>
<td>antimony</td>
</tr>
<tr>
<td>Sb₂O₃</td>
<td>5.200</td>
<td>*1.000</td>
<td>antimony trioxide</td>
</tr>
<tr>
<td>Sb₂S₃</td>
<td>4.640</td>
<td>*1.000</td>
<td>antimony trisulfide</td>
</tr>
<tr>
<td>Sc</td>
<td>3.000</td>
<td>0.910</td>
<td>scandium</td>
</tr>
<tr>
<td>Sc₂O₃</td>
<td>3.860</td>
<td>*1.000</td>
<td>scandium oxide</td>
</tr>
<tr>
<td>Formula</td>
<td>Density</td>
<td>Z-Ratio</td>
<td>Material Name</td>
</tr>
<tr>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Se</td>
<td>4.810</td>
<td>0.864</td>
<td>selenium</td>
</tr>
<tr>
<td>Si</td>
<td>2.320</td>
<td>0.712</td>
<td>silicon</td>
</tr>
<tr>
<td>Si₃N₄</td>
<td>3.440</td>
<td>*1.000</td>
<td>silicon nitride</td>
</tr>
<tr>
<td>SiC</td>
<td>3.220</td>
<td>*1.000</td>
<td>silicon carbide</td>
</tr>
<tr>
<td>SiO</td>
<td>2.130</td>
<td>0.870</td>
<td>silicon (II) oxide</td>
</tr>
<tr>
<td>SiO₂</td>
<td>2.648</td>
<td>1.000</td>
<td>silicon dioxide</td>
</tr>
<tr>
<td>Sm</td>
<td>7.540</td>
<td>0.890</td>
<td>samarium</td>
</tr>
<tr>
<td>Sm₂O₃</td>
<td>7.430</td>
<td>*1.000</td>
<td>samarium oxide</td>
</tr>
<tr>
<td>Sn</td>
<td>7.300</td>
<td>0.724</td>
<td>tin</td>
</tr>
<tr>
<td>SnO₂</td>
<td>6.950</td>
<td>*1.000</td>
<td>tin oxide</td>
</tr>
<tr>
<td>SnS</td>
<td>5.080</td>
<td>*1.000</td>
<td>tin sulfide</td>
</tr>
<tr>
<td>SnSe</td>
<td>6.180</td>
<td>*1.000</td>
<td>tin selenide</td>
</tr>
<tr>
<td>SnTe</td>
<td>6.440</td>
<td>*1.000</td>
<td>tin telluride</td>
</tr>
<tr>
<td>Sr</td>
<td>2.600</td>
<td>*1.000</td>
<td>strontium</td>
</tr>
<tr>
<td>SrF₂</td>
<td>4.277</td>
<td>0.727</td>
<td>strontium fluoride</td>
</tr>
<tr>
<td>SrO</td>
<td>4.990</td>
<td>0.517</td>
<td>strontium oxide</td>
</tr>
<tr>
<td>Ta</td>
<td>16.600</td>
<td>0.262</td>
<td>tantalum</td>
</tr>
<tr>
<td>Ta₂O₅</td>
<td>8.200</td>
<td>0.300</td>
<td>tantalum (V) oxide</td>
</tr>
<tr>
<td>TaB₂</td>
<td>11.150</td>
<td>*1.000</td>
<td>tantalum boride</td>
</tr>
<tr>
<td>TaC</td>
<td>13.900</td>
<td>*1.000</td>
<td>tantalum carbide</td>
</tr>
<tr>
<td>TaN</td>
<td>16.300</td>
<td>*1.000</td>
<td>tantalum nitride</td>
</tr>
<tr>
<td>Tb</td>
<td>8.270</td>
<td>0.660</td>
<td>terbium</td>
</tr>
<tr>
<td>Tc</td>
<td>11.500</td>
<td>*1.000</td>
<td>technetium</td>
</tr>
<tr>
<td>Te</td>
<td>6.250</td>
<td>0.900</td>
<td>tellurium</td>
</tr>
<tr>
<td>TeO₂</td>
<td>5.990</td>
<td>0.862</td>
<td>tellurium oxide</td>
</tr>
<tr>
<td>Th</td>
<td>11.694</td>
<td>0.484</td>
<td>thorium</td>
</tr>
<tr>
<td>ThF₄</td>
<td>6.320</td>
<td>*1.000</td>
<td>thorium (IV) fluoride</td>
</tr>
<tr>
<td>ThO₂</td>
<td>9.860</td>
<td>0.284</td>
<td>thorium dioxide</td>
</tr>
<tr>
<td>ThOF₂</td>
<td>9.100</td>
<td>*1.000</td>
<td>thorium oxyfluoride</td>
</tr>
<tr>
<td>Ti</td>
<td>4.500</td>
<td>0.628</td>
<td>titanium</td>
</tr>
<tr>
<td>Ti₂O₃</td>
<td>4.600</td>
<td>*1.000</td>
<td>titanium sesquioxide</td>
</tr>
<tr>
<td>TiB₂</td>
<td>4.500</td>
<td>*1.000</td>
<td>titanium boride</td>
</tr>
<tr>
<td>TiC</td>
<td>4.930</td>
<td>*1.000</td>
<td>titanium carbide</td>
</tr>
<tr>
<td>Formula</td>
<td>Density</td>
<td>Z-Ratio</td>
<td>Material Name</td>
</tr>
<tr>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>TiN</td>
<td>5.430</td>
<td>*1.000</td>
<td>titanium nitride</td>
</tr>
<tr>
<td>TiO</td>
<td>4.900</td>
<td>*1.000</td>
<td>titanium oxide</td>
</tr>
<tr>
<td>TiO₂</td>
<td>4.260</td>
<td>0.400</td>
<td>titanium (IV) oxide</td>
</tr>
<tr>
<td>TI</td>
<td>11.850</td>
<td>1.550</td>
<td>thallium</td>
</tr>
<tr>
<td>TIBr</td>
<td>7.560</td>
<td>*1.000</td>
<td>thallium bromide</td>
</tr>
<tr>
<td>TICl</td>
<td>7.000</td>
<td>*1.000</td>
<td>thallium chloride</td>
</tr>
<tr>
<td>TII</td>
<td>7.090</td>
<td>*1.000</td>
<td>thallium iodide (B)</td>
</tr>
<tr>
<td>U</td>
<td>19.050</td>
<td>0.238</td>
<td>uranium</td>
</tr>
<tr>
<td>U₃O₈</td>
<td>8.300</td>
<td>*1.000</td>
<td>tri uranium octoxide</td>
</tr>
<tr>
<td>U₄O₉</td>
<td>10.969</td>
<td>0.348</td>
<td>uranium oxide</td>
</tr>
<tr>
<td>UO₂</td>
<td>10.970</td>
<td>0.286</td>
<td>uranium dioxide</td>
</tr>
<tr>
<td>V</td>
<td>5.960</td>
<td>0.530</td>
<td>vanadium</td>
</tr>
<tr>
<td>V₂O₅</td>
<td>3.360</td>
<td>*1.000</td>
<td>vanadium pentoxide</td>
</tr>
<tr>
<td>VB₂</td>
<td>5.100</td>
<td>*1.000</td>
<td>vanadium boride</td>
</tr>
<tr>
<td>VC</td>
<td>5.770</td>
<td>*1.000</td>
<td>vanadium carbide</td>
</tr>
<tr>
<td>VN</td>
<td>6.130</td>
<td>*1.000</td>
<td>vanadium nitride</td>
</tr>
<tr>
<td>VO₂</td>
<td>4.340</td>
<td>*1.000</td>
<td>vanadium dioxide</td>
</tr>
<tr>
<td>W</td>
<td>19.300</td>
<td>0.163</td>
<td>tungsten</td>
</tr>
<tr>
<td>WB₂</td>
<td>10.770</td>
<td>*1.000</td>
<td>tungsten boride</td>
</tr>
<tr>
<td>WC</td>
<td>15.600</td>
<td>0.151</td>
<td>tungsten carbide</td>
</tr>
<tr>
<td>WO₃</td>
<td>7.160</td>
<td>*1.000</td>
<td>tungsten trioxide</td>
</tr>
<tr>
<td>WS₂</td>
<td>7.500</td>
<td>*1.000</td>
<td>tungsten disulfide</td>
</tr>
<tr>
<td>WSi₂</td>
<td>9.400</td>
<td>*1.000</td>
<td>tungsten silicide</td>
</tr>
<tr>
<td>Y</td>
<td>4.340</td>
<td>0.835</td>
<td>yttrium</td>
</tr>
<tr>
<td>Y₂O₃</td>
<td>5.010</td>
<td>*1.000</td>
<td>yttrium oxide</td>
</tr>
<tr>
<td>Yb</td>
<td>6.980</td>
<td>1.130</td>
<td>ytterbium</td>
</tr>
<tr>
<td>Yb₂O₃</td>
<td>9.170</td>
<td>*1.000</td>
<td>ytterbium oxide</td>
</tr>
<tr>
<td>Zn</td>
<td>7.040</td>
<td>0.514</td>
<td>zinc</td>
</tr>
<tr>
<td>Zn₃Sb₂</td>
<td>6.300</td>
<td>*1.000</td>
<td>zinc antimonide</td>
</tr>
<tr>
<td>ZnF₂</td>
<td>4.950</td>
<td>*1.000</td>
<td>zinc fluoride</td>
</tr>
<tr>
<td>ZnO</td>
<td>5.610</td>
<td>0.556</td>
<td>zinc oxide</td>
</tr>
<tr>
<td>ZnS</td>
<td>4.090</td>
<td>0.775</td>
<td>zinc sulfide</td>
</tr>
<tr>
<td>ZnSe</td>
<td>5.260</td>
<td>0.722</td>
<td>zinc selenide</td>
</tr>
</tbody>
</table>

Table A-1 Material Table (continued)
<table>
<thead>
<tr>
<th>Formula</th>
<th>Density</th>
<th>Z-Ratio</th>
<th>Material Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZnTe</td>
<td>6.340</td>
<td>0.770</td>
<td>zinc telluride</td>
</tr>
<tr>
<td>Zr</td>
<td>6.490</td>
<td>0.600</td>
<td>zirconium</td>
</tr>
<tr>
<td>ZrB₂</td>
<td>6.080</td>
<td>*1.000</td>
<td>zirconium boride</td>
</tr>
<tr>
<td>ZrC</td>
<td>6.730</td>
<td>0.264</td>
<td>zirconium carbide</td>
</tr>
<tr>
<td>ZrN</td>
<td>7.090</td>
<td>*1.000</td>
<td>zirconium nitride</td>
</tr>
<tr>
<td>ZrO₂</td>
<td>5.600</td>
<td>*1.000</td>
<td>zirconium oxide</td>
</tr>
</tbody>
</table>